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Optimizing the High-Speed Drilling of Small-Diameter Holes by Core Flat Drills

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Abstract—A model is developed for optimization of the high-speed drilling of small-diameter holes by core flat drills. Thanks to the structure of the model, the problem reduces to optimization of the process under constraints associated with optimization of the bit's structure and geometry.

Keywords: high-speed drilling, core flat drills, optimization, drilling conditions, structural parameters, geometric parameters

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Optimization of cutting processes significantly improves their efficiency, as established in [1–6].

In general terms, we consider the optimization of cutting in high-speed drilling [7–9], with allowance for the structure of the core flat drills.

In high-speed drilling, we must determine the following:

(1) the optimal drilling conditions (cutting speed v and supply s);

(2) the optimal structural parameters of the hollow bits;

(3) the optimal geometric parameters of the drill cutting part.

Thus, we must optimize the drilling process in the light of the known operating conditions, the requirements on the system conditions, and the optimality criteria. Such optimization of high-speed drilling is a multiparametric and multicriterial problem. It may be regarded as a complex optimization problem.

Thus, in the optimization of high-speed drilling, we must address three subproblems, each of which has a corresponding mathematical model.

(1) The mathematical model for the optimization of the drilling conditions is formulated as follows. We need to find values of the cutting speed v and supply s consistent with optimal cutting conditions $C(v, s)$

$$C(v,s) \Rightarrow \text{extremum}, \quad (1)$$

under the constraints

$$\Pi(v,s) \geq [\Pi]; \quad (2)$$

$$T(v,s) \geq [T]; \quad (3)$$

$$\Delta d(v,s) \geq [\Delta d]; \quad (4)$$

$$\Delta Y(v,s) \geq [\Delta Y]; \quad (5)$$

$$Ra(v,s) \geq [Ra]; \quad (6)$$

$$v_{\min} \leq v \leq v_{\max}; \quad (7)$$

$$s_{\min} \leq s \leq s_{\max}. \quad (8)$$

The optimization problem in Eqs. (1)–(8) reduces to determining the optimal drilling conditions on the basis of Eq. (1), with the constraints on the productivity in Eq. (2), the bit life in Eq. (3), the precision of the hole diameter in Eq. (4), the divergence of the hole axes in Eq. (5), the permissible surface roughness of the hole in Eq. (6), and the permissible limits on the drilling conditions in Eq. (7) and (8).

(2) We now turn to the optimization of the drill structural parameters. The cross section of the tubular housing is characterized by three areas (Fig. 1a): the area F_{ch} of each of the chip-extraction channels; the cross-sectional area F_{cr} of the housing; and the internal-channel area F_{in}. Together, the areas F_{ch} and F_{in} and the channel area F_{in1} in the cutting section (Fig. 1c) determine the conditions of chip extraction and working-liquid outflow from the cutting zone. The cross-sectional area F_{cr} ensures the required strength, rigidity, and stability of the bit. The shape and size of these areas depend on the specified structural dimensions D, R_{ch}, δ_1, δ_2, ν, d_c (Fig. 1b). By adjusting these variables, we may obtain different relations between the areas and determine the optimal shape of the bit housing. We know that the search for optimal structural configuration and dimensions is an optimal-design problem [10–12].

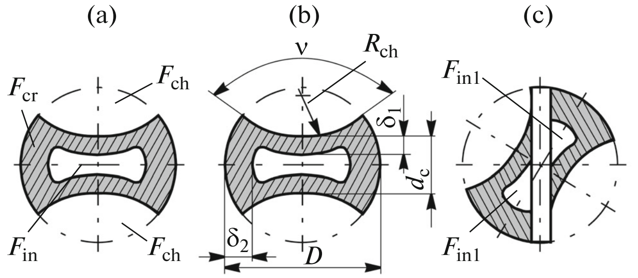

Fig. 1. Dimensions and shape of areas within the core flat drill.

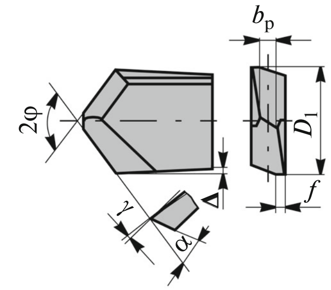

Fig. 2. Geometric parameters of the core flat drill cutting section (in plane sharpening).

In the light of the foregoing, the mathematical model for the optimization of the bit's structural parameters is formulated as follows.

We need to find values D, R_{ch}, δ_1, δ_2,ν, d_c, consistent with the optimality condition

$$C_1(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \Rightarrow \text{extremum} \quad (9)$$

under the constraints

$$M_{ch}(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [M_{to}(v, s)]; \quad (10)$$

$$P_{ch}(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [P_o(v, s)]; \quad (11)$$

$$Q(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [Q(v, s)]; \quad (12)$$

$$P_Q(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [P_Q(v, s)]; \quad (13)$$

$$D_{\min} \leq D \leq D_{\max}; \quad R_{ch_{\min}} \leq R_{ch} \leq R_{ch_{\max}}; \quad \delta_{1\min} \leq \delta_1 \leq \delta_{1\max}; \quad (14)$$

$$\delta_{2\min} \leq \delta_2 \leq \delta_{2\max}; \quad \nu_{1\min} \leq \nu_1 \leq \nu_{1\max}; \quad d_{c\min} \leq d_c \leq d_{c\max} \quad (15)$$

The optimization problem in Eqs. (9)–(15) reduces to determining the optimal structural parameters of the bit on the basis of Eq. (9), within the constraints on the permissible torque in Eq. (10), the bit's longitudinal stability in Eq. (11), the necessary quantity of working fluid in Eq. (12), the working-fluid pressure in Eq. (13), and the permissible limits on the structural parameters in Eq. (14) and (15).

The following assumptions are made in deriving the mathematical models for optimizing the drill parameters;

(a) the core flat drill is regarded as statically determinate rod with a doubly connected cross-sectional area;

(b) the chip-extraction channels are linear and symmetric with respect to the drill axis;

(c) the shape and size of the chip-extraction channels and other elements in the bit cross section are variable and depend on the permissible limits on the structural parameters;

(d) the variation in shape and size of the other elements in the bit cross section during manufacture is slight and may be disregarded at the design stage;

(e) the strength of the cutting plates is sufficient for machining with the maximum cutting forces.

(3) In optimizing the geometric parameters of the drill, the core flat drill cutting section is described by the parameters D_1, α, γ, 2φ, Δ, b_p, f (Fig. 2).

The mathematical model for the optimization of the bit geometry is formulated as follows. We need to find values of D, R_{ch}, U, δ_1, δ_2, ν, d_c consistent with optimal cutting conditions

$$C_1(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \Rightarrow \text{extremum} \quad (16)$$

under the constraints

$$T(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [T(v, s)]; \quad (17)$$

$$\Pi(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [\Pi(v, s)]; \quad (18)$$

$$D_{\min} \leq D \leq D_{\max}; \quad R_{ch_{\min}} \leq R_{ch} \leq R_{ch_{\max}}; \quad \delta_{1\min} \leq \delta_1 \leq \delta_{1\max}; \quad (19)$$

$$\delta_{2\min} \leq \delta_2 \leq \delta_{2\max}; \quad \nu_{1\min} \leq \nu_1 \leq \nu_{1\max}; \quad d_{c\min} \leq d_c \leq d_{c\max}. \quad (20)$$

The optimization problem in Eqs. (16)–(20) reduces to determining the optimal cutter geometry of the drill on the basis of Eq. (16), with the constraints on the permissible bit life in Eq. (17), the productivity of the process in Eq. (18), and the permissible limits on the geometric parameters in Eq. (19) and (20).

Summing up, the optimization of the high-speed drilling by core flat drills reduces to the following form.

We need to find the values of the cutting speed v and supply s such that

$$C(v, s) \Rightarrow \text{extremum} \quad (21)$$

under the constraints

$$\Pi(v, s) \geq [\Pi]; \quad (22)$$

$$T(v, s) \geq [T]; \quad (23)$$

$$\Delta d(v, s) \geq [\Delta d]; \quad (24)$$

$$\Delta Y(v, s) \geq [\Delta Y]; \quad (25)$$

$$Ra(v, s) \geq [Ra]; \quad (26)$$

$$v_{\min} \leq v \leq v_{\max}; \quad (27)$$

$$s_{\min} \leq s \leq s_{\max}. \quad (28)$$

Likewise, we need to find the values of D, R_{ch}, δ_1, δ_2, ν, d_c such that the structural parameters of the drill are optimal

$$C_1(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \Rightarrow \text{extremum} \tag{29}$$

under the constraints

$$M_{ch}(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq \lfloor M_{to}(v, s) \rfloor; \tag{30}$$

$$P_{ch}(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [P_o(v, s)]; \tag{31}$$

$$Q(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [Q(v, s)]; \tag{32}$$

$$P_Q(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [P_Q(v, s)]; \tag{33}$$

$$D_{\min} \leq D \leq D_{\max}; \quad R_{ch_{\min}} \leq R_{ch} \leq R_{ch_{\max}}; \quad \delta_{1\min} \leq \delta_1 \leq \delta_{1\max}; \tag{34}$$

$$\delta_{2\min} \leq \delta_2 \leq \delta_{2\max}; \quad \nu_{1\min} \leq \nu_1 \leq \nu_{1\max}; \quad d_{c\min} \leq d_c \leq d_{c\max}. \tag{35}$$

Finally, we need to find values of D, R_{ch}, U, δ_1, δ_2, ν, d_c such that the geometric parameters of the core flat drill cutting part are optimal

$$C_1(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \Rightarrow \text{extremum} \tag{36}$$

under the constraints

$$T(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [T(v, s)]; \tag{37}$$

$$\Pi(D, R_{ch}, \delta_1, \delta_2, \nu, d_c) \geq [\Pi(v, s)]; \tag{38}$$

$$D_{\min} \leq D \leq D_{\max}; \quad R_{ch_{\min}} \leq R_{ch} \leq R_{ch_{\max}}; \quad \delta_{1\min} \leq \delta_1 \leq \delta_{1\max}; \tag{39}$$

$$\delta_{2\min} \leq \delta_2 \leq \delta_{2\max}; \quad \nu_{1\min} \leq \nu_1 \leq \nu_{1\max}; \quad d_{c\min} \leq d_c \leq d_{c\max}. \tag{40}$$

The complex optimization problem in Eqs. (21)–(40) for the high-speed drilling of small-diameter holes (up to 10 mm) by core flat drills is multifactorial and multicriterial. It takes the form of a mathematical programming problem, whose solution calls for theoretical and experimental research.

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