SEARCH FOR OPTIMAL DESIGN OF SECTIONAL DRILLS
WITH REPLACEABLE MANY–SIDED PLATES AT RAILWAY RAILS DRILLING

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The power analysis technique of sectional drills with replaceable many-sided plates at railway rails drilling has been offered. It allowed increasing tool working capacity. The technique is based on summation of specific cutting force component by the length of working areas of plates cutting rims. The increase of working capacity is achieved due to decreasing cutting force radial components of each of the plate.

The new standard SS R 51685-2000 «Railway rails» (general specifications) is put into operation on December 18th, 2000 instead of SS 24182-80 (ST SEV 4983-85) «Railway rails of broad gage of types P75, P65 and P50 of open-hearth steel» (specifications). In this connection metallurgical plants of Russian Federation started producing volume-hardened rails the web hardness of which reaches 388 HB. This results in using sectional drills with mechanical clamping of replaceable many-sided plates (RMSP) of hard alloy for drilling rails. General view and diagram of spacing such drill plates are given in Fig. 1, 2. However at rails field drilling which is fulfilled by rail drilling machines of the types CTP-1, CTP-2, 3023, 3028 the stated drills reveal low working capacity. In this connection the increase of these drills working capacity is the urgent task.
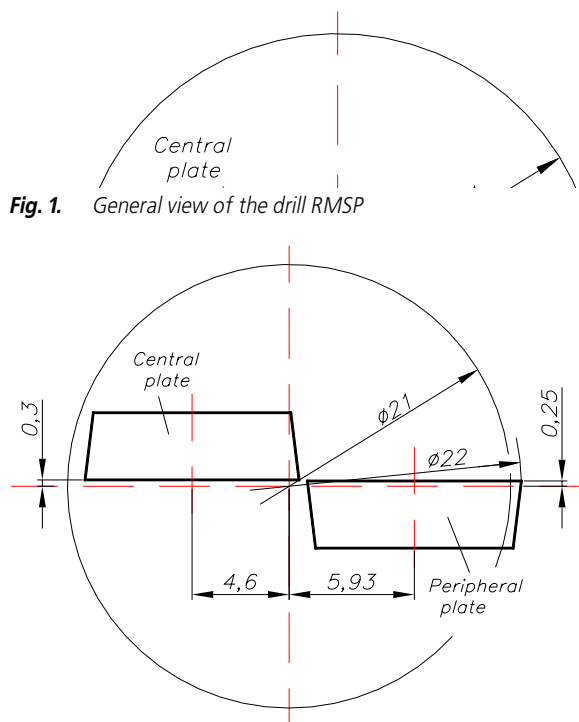

Fig. 1. *General view of the drill RMSP*

Fig. 2. *The diagram of RMSP placing on the drill*

To discover the reason of low working capacity of drills with RMSP the analysis of cutting plates geometric parameters was carried out. It was stated that the drills under study have unfavorable geometric parameters for drilling process: static hook γ_c, back α_c angle and slope angle of cutting rim λ_c [1–3].

Then the analysis of forces effecting in drilling process was carried out for estimating the reasons of low working capacity of drills with RMSP. For calculating cutting force components the technique based on summation of specific forces effecting on the length unity of drill cutting rims was used [3, 4]. The data on specific forces are taken from the experiments in turning proper materials by the tool with the geometry found at geometrical analysis of drill cutting plates. According to this technique plate cutting rims are divided into areas of equal length (Fig. 3) and for each area the magnitude and action direction of cutting force component are determined subject to static geometrical parameters.
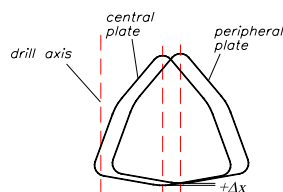

Fig. 3. *Partition scheme of plate cutting rim for defining cutting force simples*

Sum components of cutting force over the whole length of cutting rim were determined by the formula:

$$P_z = \sum_{i=1}^{n} P_{yi} \cdot \cos \varphi_{Hi} \cdot \sin \gamma_{yi} - P_{zi} \cdot \cos \gamma_{yi} ;$$

$$P_y = \sum_{i=1}^{n} P_{yi} \cdot \cos \varphi_{Hi} \cdot \cos \gamma_{yi} + P_{zi} \cdot \sin \gamma_{yi} ,$$

where P_{yi}, P_{zi} are the radial and tangential cutting force components respectively in toolroom coordinates falling on length unit of cutting rim; φ_{Hi} is the cutting edge angle in toolroom coordinate system; γ_{yi} is the frontal angle of RMSP orientation.

As geometrical parameters and cutting speed are different in each point of cutting rim it is necessary to know the values of cutting force components subject to their parameters and cutting speed i. e. to have the dependence P_{yi} and P_{zi} for defining $P_{yi}=f(\alpha_c, \gamma_c, \lambda_c, V)$ and $P_{zi}=f(\alpha_c, \gamma_c, \lambda_c, V)$. To determine these dependences the number of experiments in turning hardened steel 40X with hardness 368 HB by the tool with geometrical parameters corresponding to sectional drill parameters was carried out.

Using the results of these experiments it was stated by calculation that at drilling with the drills of the construction under consideration a significant unbalanced radial force occurs (diagrams of distribution P_y and action direction are presented in Fig. 4) which causes drill vibrations and high wear of its cutting plates in the conditions of low hardness of technological system in rail drilling machine. By the results of experimental investigation the cutting force components influencing the drill were obtained: P_z=196 N, P_y=869 N, P^Σ=890 N. It is obvious that it is necessary to trend to the fact that unbalanced radial force equals to zero for increasing drills working capacity.
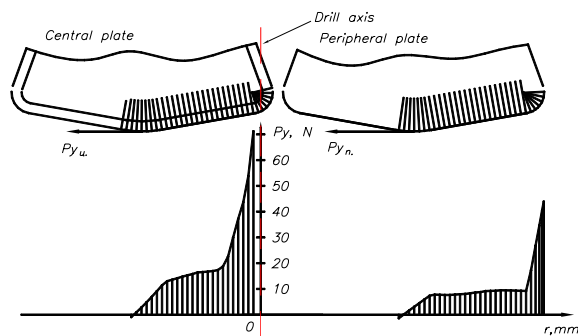

Fig. 4. *Diagrams of distribution of cutting force component P_y by the length of working areas of plates cutting rims*

The analysis showed that radial force may be minimized by the following ways:

- reciprocal plates moving-out along drill axis;
- reciprocal plates turn in drill body by the angle ψ;
- change of plate cutting rims shape and drill body construction.

Reciprocal plates moving-out along drill axis. For compensation cutting force tangential component P_z influencing the drill it is necessary to measure the width of the layer cut by each plate. At constant geometrical parameters and drill construction it may be achieved by reciprocal moving-out of plates Δx along axis X (Fig. 5).
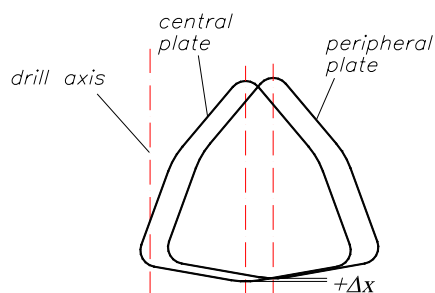

Fig. 5. *Reciprocal moving-out of plates along axis X*

As a result of the analysis it was stated that at Δx=0,12 mm cutting force tangential component $P_z \approx 0$. In this case radial force decreases not less than by 10 %.

Reciprocal plate turn in drill body by the angle ψ. For minimization of sum cutting force influencing the drill it is necessary to turn the plates reciprocally by the angle ψ (Fig. 6). To determine the value of angle ψ at which $P^\Sigma \to$min, it is necessary that $\dfrac{dP^\Sigma}{d\psi} = 0$ [5].
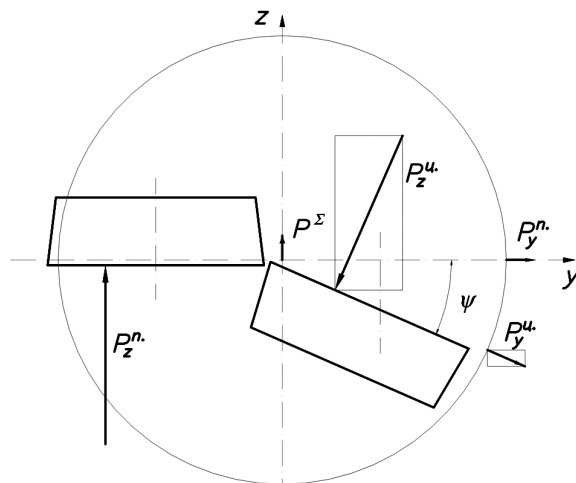

Fig. 6. *Reciprocal plates turn for minimization of sum cutting force on the drill*

It follows from Fig. 6:
$$(P^\Sigma)^2 = (P_y^\Sigma)^2 + (P_z^\Sigma)^2,$$

where

$$\begin{cases} P_y^\Sigma = P_y^\Pi - P_z^\text{Ц} \cdot \sin\psi + P_y^\text{Ц} \cdot \cos\psi \\ P_z^\Sigma = P_z^\Pi - P_z^\text{Ц} \cdot \cos\psi - P_y^\text{Ц} \cdot \sin\psi \end{cases},$$

here P_y^Π, $P_y^\text{Ц}$ и P_z^Π, $P_z^\text{Ц}$ are the radial and tangential components of cutting force on peripheral and central plates [6].

For base drill construction at plates turn by the angle ψ=23°12' radial force decreases from P^Σ=890 N to P^Σ=90 N.

Change of cutting rim form of the plates and drill body construction. Low hardness of technological system also negatively affects the plates working capacity in the process of cutting. As it is seen from Fig. 7 in the process of cutting-in the drill is influenced by resulting cutting force P^Σ changing by module and direction which results in drill vibrations and deflection from cylindrical shape of the obtained lead-in hole.
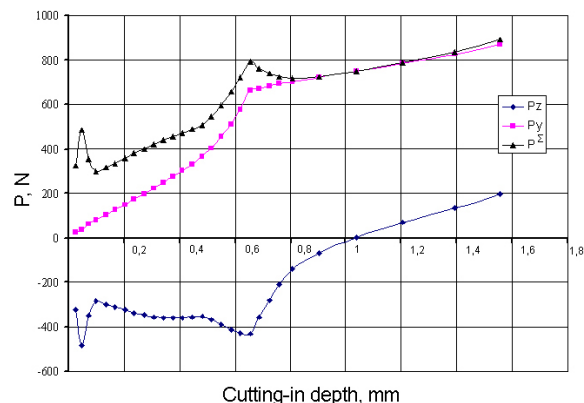

Fig. 7. *Dependence of cutting force components of both plates of standard drill on cutting-in depth*

To decrease vibrations of resulting cutting force it is necessary that condition $P_i^\Sigma \to$min is fulfilled at each elementary working area of cutting rim. For this purpo-

se it is necessary to form angle l_{ni} (in cutting plate) at each elementary working area of cutting rim (area length is 0, 2 mm) to fulfill the condition (Fig. 8)

$$P_{yi} + P_{zi} \cdot \sin \lambda_{\Pi i} \cdot \cos \lambda_{\Pi i} = 0.$$

Hence $\quad \lambda_{\Pi i} = -\dfrac{1}{2} \cdot \arcsin \dfrac{2 \cdot P_{yi}}{P_{zi}}.$

It follows from this equation that radial cutting force may be equal to zero on condition that $P_{yi} \le 0{,}5 \cdot P_{zi}$. Then it is not difficult to find proper profile of plate face.
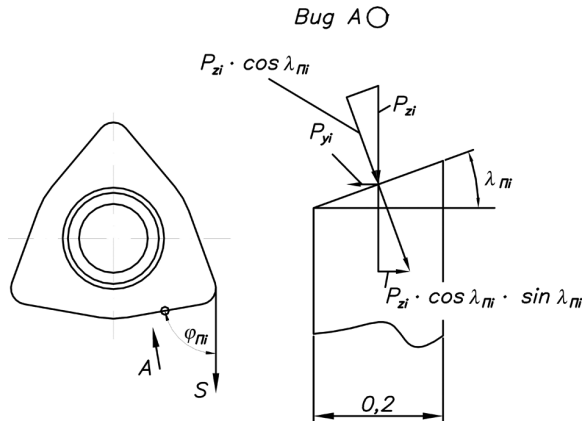

Fig. 8. *Diagram of force influence on elementary area of cutting rim inclined on-the-miter $\lambda_{\Pi i}$*

At drill cutting-in there are areas of cutting rims of RMSP which operate nonsimultaniously (radius area of peripheral plate and central area of central plate the most projected along axis X) and operating simultaneously (straight portions of both plates).

At the areas operating nonsimultaneously P^{Σ} should be minimized due to reciprocal plates turn by the angle ψ.

At the areas operating simultaneously at each elementary area of both plates (placing at the same level along axis X) angle λ_{ni} should be formed in such a way that $P_i^{\Sigma} \to \min$ (in this case value ψ is determined at the previous step). For this purpose at first we search out value ψ at which $\dfrac{dP^{\Sigma}}{d\psi} = 0$ at the areas operating nonsimultaneously ($\lambda_{ni}=0$). Then at each elementary area (on

both plates) we search out value λ_{ni} at which $\dfrac{dP^{\Sigma}}{d\lambda_{\Pi i}} = 0$

(here $P^{\Sigma}=f(P_y^{\Pi}, P_z^{\Pi}, P_y^{\Pi}, P_z^{\Pi}, \psi, \lambda_{ni})$).

According to the given technique the form of cutting rim of both RMSP of sectional drills was determined (Fig. 9) allowing minimizing resulting cutting force both at cutting-in and in steady-state drilling condition (Fig. 10).
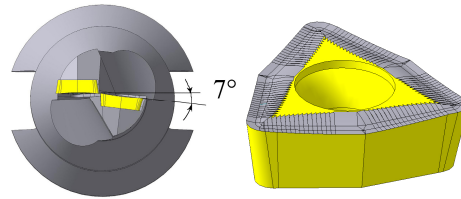

Fig. 9. *Cutting rim form and plate reciprocal orientation at which resulting cutting force is minimal both at cutting-in and at drilling by total width of cutting rims*
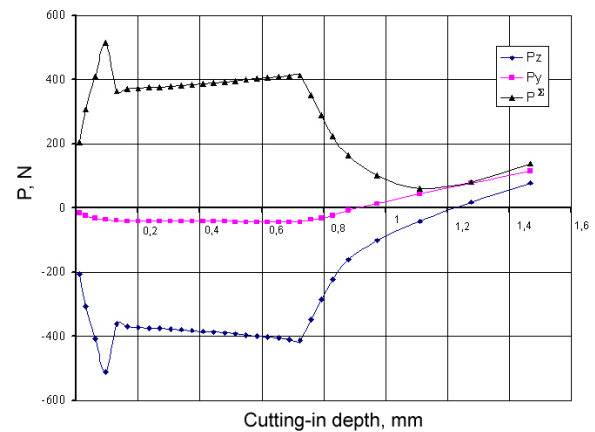

Fig. 10. *Dependence of cutting force components of both drill plates on cutting-in depth. Drill parameters: Δx=0,12 mm (central plate is advanced along axis X), γ_n=5°. Both plates are on the axis. Reciprocal angle of turn of plates ψ=7°*

Thus, the ways of construction improvement for increasing working capacity of sectional drills with replaceable many-sided plates are stated. Working capacity increase is achieved due to decreasing radial components of cutting force from each plate both at cutting-in and at steady-state drilling process. It is especially important when operating at the machine with nonrigid technological system.

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