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Technological support of the surface roughness of the spigots made from the tough "Relit" material with the help of the optimization of the centerless grinding mode parameters

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Abstract

The current lack of a regulatory database on the designation of controlled parameters of the centerless external grinding mode for new hard-to-work powder construction materials, which include Relit, a two-component material, does not allow reasonably designate a combination of centerless grinding mode parameters that would provide the required quality indicators for surface roughness. On the basis of the developed optimization model, including technical limitations on the ranges of variation of the controlled parameters of the centerless grinding mode and the required roughness of the ground surface, supplemented by the adopted optimization criterion - maximum performance, polygons for solving the system of equations of the optimization model were established. On their basis, the quality maps within the *Ra* parameter of surface roughness were developed. These maps are used as normative guidance materials for technologists on the choice of a combination of controlled mode parameters in the design of centerless grinding operations.

Keywords: spigots made from the "Relit" material, surface roughness, centerless external grinding, optimization model, quality maps within the *Ra* parameter of surface roughness.

INTRODUCTION

To improve the product reliability and durability within modern engineering industries, new structural materials are used, and the quality of the main functional surfaces of the product elements is improved. The use of new composite powder materials for the part production causes the product operational characteristics increase and makes the product elements manufacture more complex. This is fully relevant for production facilities producing oil-producing equipment of the submersible type. To improve the reliability of the elements of submersible pumps, they are made of wear-resistant and corrosion-resistant materials that are difficult to process. The specific structure and low machinability of parts made from these materials affect the complexity of machining processes and the choice of technological conditions, when machining the pump slider bearing spigots made from "Relit" material.

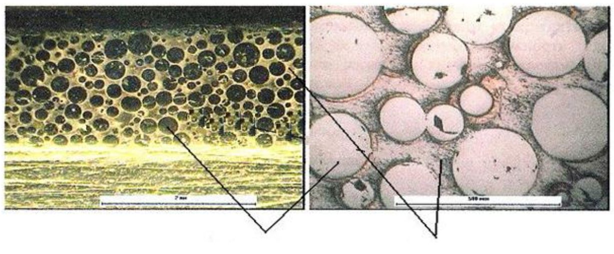
TECHNOLOGICAL WORKING PROBLEMS

The billets of the centrifugal-vortex pump slider bearing spigots made from the "Relit" material are produced with the powder metallurgy method that includes pressing operations of the relit mixture and its subsequent sintering. The processing of such billets is determined by considerable difficulties, since the basis of the "Relit" material is powdered tungsten carbide (W_2C), which belongs to the group of the materials that are difficult to process.

The relit layer is the W_2C tungsten carbide grains of high microhardness H_{V1} = 12.2 * 10^9 N/m^2 [1] that are evenly distributed in the copper bundle [1], with the copper bundle hardness H_{V2} = 1.0 * 10^9 N/m^2 [1] (Fig. 1).

The data on the hardness of wolfram carbide presented make it possible to assign the "Relit" material to the ones that are difficult to process. This provides a specific choice of the characteristics of the abrasive tool and parameters of the centerless external grinding mode.

For centerless grinding of workpieces, it is recommended to use silicon carbide grinding wheels, which ensure the required accuracy of the outer diameter of the spigot, but there are problems with the achievement of the required surface roughness. There are chaotically located coarse scratches and gouges from individual grains or blocks of grains torn out by the cutting forces from the working surface of the grinding wheel on the ground surface of the spigot. The phenomena mentioned above cause the grinding process instability, the abrasive wheel wear rate increase, the grinding process failures, the defects, the processing complexity increase.



Tungsten Carbide Grains H_{V1} = 12,2*10^9 N/m^2 — Bundle H_{V2} = 1,0*10^9 N/m^2

Fig. 1: The structure of the "Relit"

The most important task is to ensure the centerless grinding process output parameters stabilization, the required productivity and processing quality.

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Currently, there are no recommendations on the technological conditions of processing to ensure the required surface roughness during centerless grinding of the billets made from the "Relit" material. This does not allow to set the maximum parameters of the grinding mode while ensuring the required quality of the roughness of the surface processed.

OPTIMIZATION MODEL

Due to this fact, research on the determination of the optimal centerless grinding mode parameters that provide the required quality of machined parts achieving the maximum processing efficiency is relevant.

The success of the fulfillment of these requirements is closely connected with the application of knowledge on the optimization of the design decisions made. At the present time the most common optimization method is the iterative solution method which allows taking into account the limits that are set during grinding, to optimize the controlled parameters of the centerless grinding mode and their combinations according to the maximum efficiency criterion.

We will build the mathematical optimization model that includes a set of accepted technical limits and is supplemented by the accepted optimum criterion, that is, the minimum piece processing time (the maximum performance).

The performance of the operation is found in the expression:

$$P = \frac{1}{t_{sht.r}},$$

where $t_{sht.r}$ is the piece processing time depending on the controlled parameters of the centerless grinding mode.

$$t_{sht.r} = t_m + t_{wd}, \; t_m = \frac{l + B_w}{V_{lfp} \cdot 10^3}, \; t_{wd} = \frac{T_{wd}}{T} \cdot t_m,$$

where t_m is the machine time, min; t_{wd} is the grinding wheel dressing time reduced to one part, min; l is the axial size of the part, mm; B_w is the height of the grinding wheel, mm; V_{lfp} is the speed of the longitudinal feed of the part, mm/min; T_{wd} is the grinding wheel dressing time, min; T is the wheel stability period, min.

The optimization criterion F for the centerless grinding of the spigots will look like [2, 3]:

$$F(V_{lfp}) = t_{sht.r} = \frac{l + B_w}{V_{lfp} \cdot 10^3}\left(1 + \frac{T_{wd}}{T}\right). \qquad (1)$$

Then, the task to optimize the centerless grinding mode parameters can be represented as the task to minimize the goal function (F (V_{lfp}) → min) that includes the explicit controlled parameter of the grinding mode V_{lfp}. The analysis of the expression (1) shows that the goal function F (V_{lfp}) takes the minimum values with the maximum value of V_{lfp}.

In the case of the centerless grinding of the spigots made from the "Relit" material we will set the following limits: on the ranges of changing the parameters of the grinding mode during surface treatment, on the maximum allowable depth of treatment [a_{pmax}], on the maximum allowable roughness of the grinding surface Ra_{allow}, which are represented as a system of nonlinear equations:

$$\begin{cases} V_{W\min} \le V_W \le V_{W\max} \\ V_{lfp\min} \le V_{lfp} \le V_{lfp\max} \\ a_{p\min} \le a_p \le \left[a_{p\max}\right] \\ Ra(V_W, V_{lfp}, a_p) \le Ra_{allow} \end{cases}$$

where V_{Wmin}, V_{Wmax}, V_{lfpmin}, V_{lfpmax}, a_{pmin}, [a_{pmax}] are the limiting values of the speed, feed rate and the depth of grinding, limited by the technical parameters of the equipment and tool.

Earlier studies [4, 5] allowed us to obtain an analytical relationship for calculating the maximum allowable grinding depth [a_{pmax}] and an empirical mathematical model for calculating the Ra parameter of the surface roughness in the following form:

$$[a_{p\max}] = \bar{r} - \sqrt{\bar{r}^{2} - \left[\frac{H_{V1}\bar{R} - \dfrac{1}{[P_{Zi}]}\dfrac{0{,}185 H_{V1} H_{V2} \bar{R} K_\delta K_s d_a^{2,5} \psi(\xi,\eta,\gamma) V_K V_W}{(V_K + V_W)^2 + V_{lfp}^2}\sqrt{\dfrac{d+D}{dD}}}{2(H_{V1} - H_{V2})}\right]^2} \qquad (2)$$

where $\bar{r}$ is the average statistical radius of the tungsten carbide grain; $\bar{R}$ is the average statistical distance between the centers of the grains of tungsten carbides; H_{V1} is the microhardness of tungsten carbides; H_{V2} is the microhardness of copper; [P_{Zi}] is the permissible force of the retention of cutting grains by abrasive tools bonded (according to [6], the [P_{Zi}] of carbide-silicon grains for the wheels on a ceramic bond, depending on the grain size and hardness of the wheel, is in the range of 1 ... 5 N); K_δ is the parameter that depends on the volume structure of the standard grinding tool and the conditions of dressing of its cutting surface; $K_\delta = K_p * K_{sw} * K_{wd}$, K_p is the coefficient of porosity of the cutting wheel; K_{sw} is the coefficient of the structure of the grinding wheel; K_{wd} is the coefficient of dressing of the cutting surface of the wheel; K_s is the shape factor of the top of the grain; d_a is the characteristic size of the grinding grain;

$$\psi(\zeta,\eta,\gamma) = \frac{\zeta^2 + 2\cdot\zeta\cdot\sin\gamma + 1}{\zeta\cdot\cos\gamma}\cdot\frac{\zeta\cdot\cos(\eta+\gamma)}{\zeta\cdot\cos(\eta+\gamma) - \sin(\eta)},$$

where ζ is the shrinkage of the part chips; η is the angle of the chip slide friction; γ is the rake angle of a single cutter of an abrasive tool; d, D are the diameters of the workpiece and the grinding wheel, respectively; V_K is the abrasive cutting speed; V_W is the speed of the part rotation; V_{lfp} is the longitudinal feed rate of the part.

$$Ra = 2{,}42 \cdot V_W^{(0.053 - 0.397\ln V_{\mathrm{lfp}})} \cdot V_{\mathrm{lfp}}^{1{,}967} \cdot a_p^{(1{,}714 - 0{,}307\ln V_W)}, \qquad (3)$$

where a_p is the depth of grinding.

Technical limits on the controlled characteristics of the V_W, V_{lfp} processing mode are set by their variation ranges according to the technical characteristics of a centerless grinding machine. The limit on the maximum allowable grinding depth [a_{pmax}] is found from the equation (2). And the limit on the surface roughness is taken not more than 1.25 microns, according to the spigot specifications.

Taking into account formulae (1-3), the mathematical optimization model will take the form

$$\begin{cases} 60 \le V_W \le 120 \\ 4{,}2 \le V_{lfp} \le 8{,}4 \\ 0{,}01 \le a_p \le \bar{r} - \sqrt{\bar{r}^2 - \left[\dfrac{H_{V1}\bar{R} - \dfrac{1}{[P_{Zi}]}\dfrac{0{,}185 H_{V1}H_{V2}\bar{R}K_\delta K_s d_a^{2,5}\psi(\xi,\eta,\gamma)V_K V_W}{(V_K+V_W)^2+V_{lfp}^2}\sqrt{\dfrac{d+D}{dD}}}{2(H_{V1}-H_{V2})}\right]^2} \\ 2{,}42\cdot a_p^{(1{,}714-0{,}307\ln V_W)}\cdot V_W^{(0{,}053-0{,}397\ln V_{lfp})}\cdot V_{lfp}^{1{,}967} \le 1{,}25 \end{cases}$$

$$F(V_{lfp}) = \min\left[\frac{l+B_w}{V_{lfp}\cdot 10^3}\left(1+\frac{T_{wd}}{T}\right)\right]$$

Solving the reduced model with the help of the mathematical software (Mathcad), we obtain graphical representation of the solution in the form of permissible values of V_W and a_p combinations with a constant value of V_{lfp} shown in Fig. 2, 3. Let us indicate the points corresponding to the optimal combination of V_{Wopt} and a_{popt}, with which the processing time takes the minimum value.

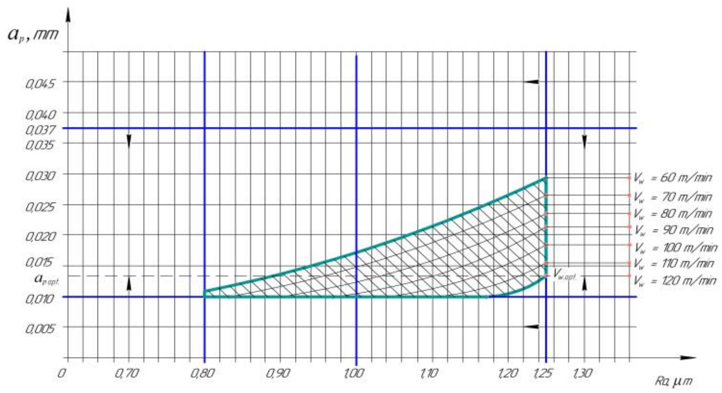

Fig. 2: Polygon solving a system of the equations of the optimization model at the longitudinal feed rate V_{lfp} = 8.4 m/min

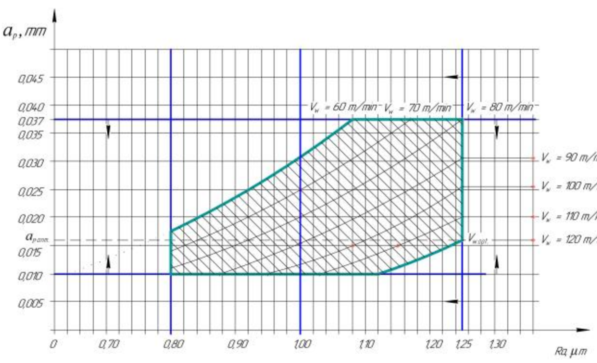

Fig. 3:. Polygon solving a system of the equations of the optimization model at the longitudinal feed rate V_{lfp} = 4.2 m/min

CONCLUSION

On the basis of the polygons solving the optimization model equations system, the range maps (shown in Fig. 4 - 7) have been developed to provide the required *Ra* parameter of the surface roughness. These maps help technologists combine the mode parameters, when designing the operations of centerless grinding of the spigots made from the "Relit" material that is of high strength.

a_p, mm \ V_W, m/min	60	65	70	75	80	85	90	95
0,010		■	■	■	■	■	■	■
0,015	■	■	■					
0,020						0,8 ≤ *Ra* ≤ 1,0		

Fig. 4: The range of the *Ra* parameter of the surface roughness in the case of the centerless grinding of the relit spigots with the 54CF46N7V grinding wheel of 1 500x150x305 at the longitudinal feed speed, V_{lfp} = 8.4 m/min.

a_p, mm \ V_W, m/min	60	65	70	75	80	85	90	95	100	105	110	115	120
0,010								■	■	■	■	■	■
0,015			■	■	■	■	■	■	■	■	■		
0,020	■	■	■	■	■	■	■	■					
0,025	■	■	■	■							1,0 ≤ *Ra* ≤ 1,25		

Fig. 5: The range of the *Ra* parameter of the surface roughness in the case of the centerless grinding of the relit spigots with the 54CF46N7V grinding wheel of 1 500x150x305 at the longitudinal feed speed, V_{lfp} = 8.4 m/min.

a_p, mm \ V_W, m/min	60	65	70	75	80	85	90	95	100	105
0,010						■	■	■	■	■
0,015			■	■	■	■	■			
0,020	■	■	■	■	■					
0,025	■	■	■						0,8 ≤ *Ra* ≤ 1,0	
0,030	■									

Fig. 6: The range of the *Ra* parameter of the surface roughness in the case of the centerless grinding of the relit spigots with the 54CF46N7V grinding wheel of 1 500x150x305 at the longitudinal feed speed, V_{lfp} = 4.2 m/min.

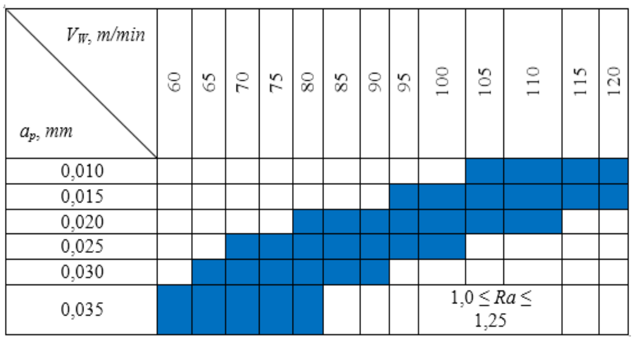

Fig. 7: The range of the *Ra* parameter of the surface roughness in the case of the centerless grinding of the relit spigots with the 54CF46N7V grinding wheel of 1 500x150x305 at the longitudinal feed speed, V_{lfp} = 4.2 m/min.

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