Technology of extending operational life of multifaceted disposable plates

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Abstract. The article presents the results of the development of MDP remanufacturing technique. The problem statement is related to the improvement of durability, strength and performance properties of MDP. Remanufacturing technique of plates provides the development of the process scheme for the resharpening of MDP along the front surface and application of TiN wear-resistant coatings. The optimal geometry of the restored tool, the sharpening scheme, the characteristics of grinding wheels and cutting modes are selected. The coating technology, scheme and surface cleaning modes are developed, and the coating quality parameters are determined. Technical and economic analysis of the efficiency is carried out.

1. Introduction
The tool with MDP is the main one in the development of operations on CNC machines. MDP are disposable, they are used no more than 3-4 times, depending on the number of tool points. MDP include carbide base and three-component coating. The cost of plates increases annually, which is explained by a significant rise in the cost of natural resources and production technology. MDP are the products that have varied and precise geometric shape, complex composition, high quality blades and precision, and, as a rule, have undergone strengthening treatment, mainly by coating. The use of MDP involves the use of the tool point once at full wear.

The MDP wear leads to a change in the shape of the front surface and the dimensions of the plates, destruction of the strengthening surface treatment (coating). In most cases, it is impossible to reproduce the original geometric shape of the front surface of the plate using diamond sharpening, so it is necessary to create a new shape of the plate. The strengthening treatment of MDP with the help of coating, used by leading companies, is developed at a high scientific and technical level. Replacement of coatings by its simpler chemical compounds should be justified by its effectiveness. Therefore, creation of secondary, full-fledged service life of MDP is a complex scientific and technical problem, the solution of which is possible on the basis of a comprehensive study of the influence of the issues of rational shaping of the cutting part by diamond grinding and the use of effective strengthening methods for specific processing conditions.

It is obvious that the content of the concept of creating a secondary resource can be different, but anyway it is necessary to present grounds.

The MDP resharpening was reviewed by many authors [1, 8-10 ], who proposed the following 3 recovery methods:
The first method is based on the resharpening only along the flank surface; this is the most approximate method concerning the geometry of the plate, but it is laborious, because it requires the use of CNC machines;

The second method uses front and flank sharpening. It requires not only high costs, but also additional adjustments when installed on CNC machines;

The third method is the most promising one because resharpening is carried out only along the front surface.

Front face sharpening with a positive rake angle has the following advantages:

- the security of the plate fastening in the tool body is preserved;
- a usual universal tool grinder is required;
- minimum labor intensity of plate sharpening.

The disadvantages of this method include decrease in the size of the plate in terms of height and strength of the cutting edge, change in the geometric parameters of the plate, in particular, the rake angle, change in the parameters of chip breaking. However, when the plates are resharpened along the front surface, there is a unique opportunity to change the geometric parameters of the cutting part in accordance with the specific processing conditions, in particular, to create a rake angle $0^\circ – 6^\circ$ instead of the rake angle of a new plate equal to $20^\circ$.

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Figure 1. Universal Tool Grinder WS54 Switzerland (a), Three-Way Clamps (b), Grinding Wheel Disk AChK GOST 16172-80 ASO 160/120 B1 (c), MDP Toolholder Sandvik Coromant PCLNR2525M-12 (d)

Figure 1 shows a tool grinder, three-way clamps, diamond tool constructions and plate toolholders. The practice of the resharpening process shows that diamond wheels with bakelite and rubber bonds are most effective. Recommendations for the selection of diamond tools are given in [4, 5]. The plate was fixed in a mandrel, which was used for processing by a CNC machine.

2. Sharpening Technology

MDP sharpening technology is carried out using diamond wheels on a universal tool grinder.

The worn-out plates are installed in the holder body with the latter fixed in the position for the given plate classification. This method does not require any additional costs for the device and provides an acceptable accuracy of the sharpening depth of cutting plates ± 0.01 mm. (see Fig. 2)
Figure 2. Scheme of Front Surface Grading of Plates during Sharpening and Actual Angles along Flank and Front Surfaces (6°) and Front Surface after Sharpening

Technological modes of grinding are as follows: \( V_p = 35 \text{ m/sec} \); \( S_{\text{not}} = 0.1 \text{ mm/double line} \); \( S_{\text{aprox}} = 1 \sim 2 \text{ mm/min} \).

Before sharpening, it is necessary to calculate the geometric parameters of the front surface of the plate and the machining allowances. The geometric dimensions of the front surface, such as length, width, angle of inclination of the main cutting edge in the axial and radial directions, are calculated by the formulas.

Length of the resharpened main cutting edge is as follows:

\[
L_p = t + (1\ldots2) \text{ mm},
\]

where \( t \) is the depth of cut equal to the allowance.

The width of the front surface was calculated from the length of the plastic contact area of the chips along the front surface \( L_3 \) [3, 7]:

\[
L_3 = S_o [K_l (l - \tan(\gamma)) + \sec(\lambda)],
\]

where \( S_o \) is the workpiece chip load per revolution, \( \text{mm/rev.} \); \( K_l \) is the shrinkage of chips along the length; \( \gamma \) is the rake angle.

After sharpening, the rake angle at the top of the plate \( \gamma = + (5\ldots7\text{°}) \), and this allows a positive rake angle of \( 3\text{°} \ldots 5\text{°} \) on the main cutting edge when processing workpieces.

The ledge with a height of 0.3-0.5 mm obtained in the process of sharpening serves as a chip breaker.

3. Coating Technology

Figure 3 shows the results of a study of the SANDVIK hard alloy chemical composition, carried out on a special unit, which demonstrated that the manufacturer used a VK6 hard alloy as the basis of the substrate. In our research, pure titanium BT-1-00 is used as the cathode.

This makes it possible to determine the coating application modes and its adhesion properties. Wear-resistant coatings are an effective way to improve the performance of replaceable multifaceted plates.

The characteristics of the units used differ mainly in overall dimensions, layout of the cutting tool in the chamber, number of evaporators, etc. Depending on the typical size of the tool, various layouts
are used, depending on the configuration of the products, the coating on them is carried out without rotation, with axial planetary rotation, etc.

The technological cycle of the coating application with condensation and ionic bombardment can be represented in the form of two successive processes [2, 6, 10]:

- ion bombardment, designed for thermomechanical activation, healing of defects and cleaning of the base surface with ions of the evaporated electrode, i.e. surface preparation before coatings;
- coating condensation.

Technological modes of the process of TiN coating of MDP are as follows:

**I) Ionic Cleaning**
- Evaporator arc current $J_0 = 90(A)$;
- Coil current $J_k = 0.4 (A)$
- Substrate voltage $U_s = 1000 (V)$;
- Residual chamber pressure $P_{cham} = 2 \cdot 10^{-5} mm Hg$;
- Product heating temperature $T = 600 ^\circ C$;
- Cleaning time $t = 10 \ min.$

**II) Coating Condensation**
- Evaporator arc current $J_0 = 90(A)$;
- Coil current $J_k = 0.5 (A)$
- Substrate voltage $U_s = 150 (V)$;
- Residual chamber pressure $P = 2 \cdot 10^{-5} mm Hg$;
- Product heating temperature $T = 550 – 600 ^\circ C$;
- Cleaning time $t = 40 \ min.$

The first stage is ionic cleaning, which removes impurities and clogs microdefects on the surface, removes impurities from the vacuum. The second stage is the condensation of the coating in nitrogen. Carbide plates coating (4 groups). Previous coating Sandvik Coromant. $U_{oil}$ was increased step by step – 200, 300, 500, 800, 1,000 V, to eliminate the formation of micro arcs. The evaporator was switched on cyclically to equalize the temperature. Highly pure nitrogen (HPN) was used.

Elemental analysis of the obtained TiN coating was carried out using JED-2300 analyzer and JEOL JSM-6390A microscope. The results of studies of the structure, elemental composition and properties of the coating from the cutting edge of the plates are shown in Figure 3.

![Figure 3](image)

Figure 3. Study of Coating Structure, Elemental Composition and Properties of Plate Cutting Surface.
The elemental analysis of the obtained coating showed that in the obtained wear-resistant coating, the mass content of nitrogen made 9.63%, titanium – 90.37%, respectively. Further research is carried out to find the optimal percentage of elements [9]. For the plates of this type, the nitrogen content of at least 8.5% is required, i.e. the obtained coating fully satisfies this requirement. Structural analysis showed good TiN coating uniformity and integrity. It is clearly seen that the coating repeats the relief of the substrate surface. The structure contains a dropping phase, about 1 to 3 microns in size.

Let us consider the use of MDP in steel 09G2S finishing on the CNC boring lathe 1A512F3.

Finishing-out corresponded to productivity $Q$ from 20 $cm^3/min$ to 50 $cm^3/min$ with modes: $V_p = 200$ $m/min$, $s = \text{from } 0.2 \text{ mm/rev to } 0.5 \text{ mm/rev}$, $t = 0.5 \text{ mm}$;

The process productivity $Q$ $cm^3/min$ was determined as:

$$Q = V_p s t,$$

where $V_p$ – cutting speed, $m/min$; $s$ – feed $mm/rev$; $t$ – cutting depth, $mm$.

To assess the efficiency of the turning process, the economic feasibility of using MDP was determined according to two criteria:

- rate of face value loss $K_u$ in €/$cm^3$;
- cost of removing 1 $m^3$ of chips $S$ ($1m^3$) in €.

The $K_u$ value shows how much money invested in the purchase of a cutting edge is lost after removing each 1 $cm^3$ of material and was calculated using the following formula:

$$K_u = \frac{Si}{Q t_{cm}},$$

where $Q$, chip removal rate (productivity), $cm^3/min$;
$t_{cm}$, durability of one face of the plate, $min$;
$Si$, price of each cutting edge of the plate, €.

The resistance of the tested cutting edge was determined as:

$$t_{cm} = \frac{V_u}{Q}, \text{ min}$$

where $V_u$ – the volume of chips removed by one edge from each processed workpiece in $cm^3$.

Volume $V_u = 500(d_1 + d_2) \cdot t \cdot l$, where $d_1$ and $d_2$ - workpiece diameters before and after processing in $mm$, $l$ - length of the processed surface in $mm$, $t$ - in $mm$.

Knowing the market value of the plate, as well as knowing the number of cutting edges of the cutting tool, the cost of one edge is calculated as the ratio of the tool cost to the number of its edges.

$$Si = \frac{S}{n};$$

where $S$ – the market value of the plate from the manufacturer;
$n$ – number of cutting edges.

The value of $S$ ($1m^3$) shows how much financial resources production will have to spend in order to remove excess material (allowance) with a total volume of 1 $m^3$ from workpieces of the same material, if you work with a $S_i$ plate with durability $t_c$, and productivity $Q$ on the machine at the cost of one standard operating hour of the machine $S_{ov}$.

$$S(1m^3) = 10^6/Q(S_{ov}/60 + Si/t_{cm}), \text{ €.}$$

Depreciation of the machine and the work of an adjuster to replace the MDP are included in the cost of the standard hour.

Comparison of $S$ ($1m^3$) and $K_u$ obtained during production tests will reveal the most effective tool (MDP), which works both with maximum productivity and minimum cost.

4. Methodology for assessing MDP effectiveness

A method is proposed for obtaining the maximum productivity of the turning process at the minimum cost of the tool from the use of purchased, remanufactured disposable plates with and without coating in experimental industrial conditions.
It should be noted that this technique did not take into account the following factors: tool rigidity, quality of cutting fluid, equipment wear, human factor, stability of the physical and chemical properties of the metal, etc.

The average cost of 1 standard hour of work of a turning-boring machine with CNC 1A512F3 was $S_{нч} = 73 \, €$.

Initial data for calculating $K_u$:

**Purchased** plate No. 1 – cost of edge $S_{ia} = 1.9 \, €$, productivity $Q_1 = 20 \, cm^3/min$, durability $t_{cm} = 23$ min.

**Reground** plate (without coating) No. 2 – cost of edge $S_{ia} = 0.34 \, €$, productivity $Q_1 = 20 \, cm^3/min$, durability $t_{cm} = 25$ min.

**Reground** plate (with coating) No. 3 – cost of edge $S_{ia} = 0.69 \, €$, productivity $Q_1 = 20 \, cm^3/min$, durability $t_{cm} = 22$ min.

The use of a TiN coating for the reconditioned plates increased the tool life by 15-25%. Analysis of the $K_u$ value showed that with a 2.5-fold increase in feed for purchased plates, the process efficiency increases 3.4-fold. For the reconditioned plates, both coated and uncoated, the $K_u$ value decreases 3-6 times. Moreover, uncoated reconditioned plates are more effective. This is due to the fact that reconditioned plates have a cost of 1 edge of 50% less.

**Table 1.** Let us draw up a comparative table and analyze the results for finishing operations.

| Parameters | Finishing operations |
|------------|----------------------|
| $S$, mm/rev | 0.2 | 0.3 | 0.4 | 0.5 |
| $\text{Purchased}$ | | | | |
| $K_u, \, €/cm^3$ | 0.0041 | 0.0023 | 0.0016 | 0.0012 |
| $S(1\, m^3), \, €$ | 64963.77 | 42817.46 | 32000.00 | 25520.83 |
| $\text{Reground without coating}$ | | | | |
| $K_u, \, €/cm^3$ | 0.0007 | 0.0005 | 0.0004 | 0.0004 |
| $S(1\, m^3), \, €$ | 61521.09 | 41033.17 | 30826.05 | 24763.18 |
| $\text{Reground with coating}$ | | | | |
| $K_u, \, €/cm^3$ | 0.0016 | 0.0009 | 0.0007 | 0.0006 |
| $S(1\, m^3), \, €$ | 62396.42 | 41472.57 | 31133.08 | 24958.57 |

Let us arrange the minute durability in descending order and note that with a feed of 0.3 mm/rev, the durability of the plates lends itself to a comparable comparison:

| Purchased MDP | MDP with coating | MDP without coating |
|---------------|------------------|---------------------|
| 28 min        | 25 min           | 24 min              |

Let us contrast how much money production will have to spend in order to remove 1m$^3$ from workpieces made of the same material if you work with purchased and reground MDP with a coating with almost the same minute resistance:

$$S(1\, m^3)_{\text{покуп}} = 42817.46 \, €;$$

$$S(1\, m^3)_{\text{п. с покр.}} = 41472.57 \, €;$$

$$S(1\, m^3)_{\text{покуп}} > S(1\, m^3)_{\text{п. с покр.}}$$

$$42817.46 > 41472.57$$

$$42817.46 – 41472.57 = 1344.89 \, €;$$

Consequently, for this 0.3 mm/rev mode, the greatest economic efficiency is traced.
5. Conclusions
1. A technology for the restoration of replaceable multifaceted disposable plates, which provides stable indicators of processing quality and durability of about 80% of the original plate durability is developed.
2. As a result of the carried out experimental studies, it is found that the resulting shape of the front surface of the plates provides stable chip breaking and coiling.
3. Experimental-industrial testing of the developed recovery technology in finishing operating modes (sharpening and hardening) is carried out.
4. The technical and economic analysis of the research carried out showed feasibility of using the technology for MDP recovery and its application in industrial conditions.

References
[1] Precast carbide tools. / Khat G. L., Gakh V. N., Gromakov K. G. et al./. M.: Mashinostroenie, 1989, p. 256.
[2] Kuklin L. I., Sagalov V. I., Serebrovsky V. B. and others. Increasing the strength and wear resistance of hard-alloy tools. M.: mechanical engineering. 1968, -139 p. 90.
[3] Sakharov G. P., Arbusov O. B., Borovoy Y. L., grechishnikov V. A. Kiselev A. C. metal-Cutting tools. M. Mashinostroenie, 1989, 327 p.
[4] Bakul V. N., Zakharenko I. P., Kunkin Ya. a., Milshtein M. Z. Handbook of diamond processing of metal-cutting tools. Kiev.: Technika, 1971. 208 p.
[5] Zakharenko I. P., Savchenko Yu. Ya., Lavrienko V. I. Deep grinding with circles of superhard materials. M.: mechanical engineering. 1988, 55 p.
[6] Methods for determining the quality of metal-ceramic hard alloys. Edited by K. p. Imshennik, Moscow: VNII, 1968, p. 70.
[7] Skuratov D. L. Forming surfaces of parts. Processing of materials by cutting. CH.: ucheb. manual./ D. L.
[8] Popova A. Yu., Radchenko D. S., Vasileva E. V. Increasing the efficiency of using modern tools with replaceable carbide plates due to their secondary resource/ UGATU Bulletin, Ufa, 2012, vol. 16, no. 4, pp. 46-51
[9] Grachev S. I. Increasing the adhesive bond of wear-resistant coatings with carbide tools by optimizing the surface preparation process: dis. on competition of a scientific degree Cand. tech. Moscow: MSTU "Stankin", 2003. -156 p.
[10] Grigoriev S. N. Methods of increasing the resistance of cutting tools. - Moscow: Mashinostroenie, 2011. -368 p.