

**MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
VOLODYMYR DAHL EAST UKRAINIAN NATIONAL UNIVERSITY**

**Kharlamov Yu.A., Sokolov V.I., Krol O.S.,
Romanchenko O.V., Mitsyk A.V.**

**ASSURANCE OF CUTTING TOOLS
RELIABILITY**

Monograph

Severodonetsk – 2020

UDC 621.9.02-049.6
A88

Recommended by the Academic council of
Volodymyr Dahl East Ukrainian National University
(protocol № 7 from 30.03.2018)

Reviewers:

- Klimenko G.P.*** Professor, Doctor of technical sciences. Head of manufacturing processes and automation engineering department. Donbass state engineering academy.
- Klimenko S.A.*** Professor, Doctor of technical sciences, deputy director of scientific work, V. Bakul Institute for Superhard Materials of The National Academy of Sciences of Ukraine.
- Permyakov A.A.*** Professor, Doctor of technical sciences. Head of technology of mechanical engineering and metal-cutting machine tools department. National Technical University “Kharkov Polytechnic Institute”.

Kharlamov Yu.A.,

A 88 **Assurance of cutting tools reliability:** Monograph. / Yu.A. Kharlamov, V.I. Sokolov, O.S. Krol and others. – Severodonetsk: publishing house of Volodymyr Dahl East Ukrainian National University, 2020. – 190 p.: tables 8., fig. 68., bibliographic 51 names.

ISBN 978-617-11-0164-7

The problems of assurance of cutting tools reliability are considered, features and recommendations for rational operation of cutting tools are described. Particular attention is paid to consideration of basic failures of cutting tool blades, and analysis of influence of tool geometry and cutting conditions on cutting tools operational properties. The data of role of surface reinforcement of tool materials in ensuring of high tool life are systematized. The experience of industry and modern scientific developments for assurance of reliability of main types of cutting tools: single point tools, drills and tools for related operations, milling cutters, gear and thread cutting tools, etc. are generalized.

UDC 621.9.02-049.6

ISBN 978-617-11-0164-7

© Kharlamov Yu.O., Sokolov V.I.,
Krol O.S., Romanchenko O.V.,
Mitsyk A.V., 2020.
© Volodymyr Dahl East Ukrainian
National University, 2020.

INTRODUCTION

The cutting tool plays an important role in processing of materials by cutting and determines in general the serviceability of technological systems of machine building. First of all, it concerns the machining operations with increased heat-power loads on the cutting tool – in conditions of high-speed cutting, in processing of hardened, corrosion-resistant, heat-resistant steels and alloys, composite materials, etc.

For assurance of cutting tools reliability, it is necessary to use integrated approach that takes into account all the structural and technological possibilities for improvement of its operational properties. The running ability of cutting tool are determined not only by the physical-mechanical properties of tool material and surface layers of tool's working areas, but also by surface texture features, design features of tool, manufacturing processes and their sequence for tool production, application of cutting fluids, the cutting schemes and other cutting conditions.

Existing tool materials, as a rule, cannot ensure high cutting tool operability with a variety of operating conditions. For example, high-speed steels are characterized by high strength properties, but have a relatively low hardness and heat resistance, and ceramic cutting materials, on the contrary, have high values of hardness and heat resistance, but has low strength properties.

Increase of wear resistance of contact areas of cutting tools contact areas surfaces can be provided by using of various methods of surface engineering (surface thermal, chemical-thermal, surface plastic deformation processing, application of resistant coatings, modification of surface layer properties of the tool, and other methods).

Enhancement of operability, and thus, the reliability of cutting tools can be achieved by optimizing the following factors:

- rational combination of strength, thermo-physical and chemical properties of tool material, provided by the use of new or by hardening of traditional tool materials;
- cutting modes, tool geometry and roughness of tool contact areas;
- reduction of contact loads on tool contact areas;
- selection of rational cutting schemes and arrangement of tool cutting blades that reduce actual cutting path and cyclicity of load occurrence;

– development of assembly cutting tools design, which increasing reliability and technological capabilities of tools.

Enhancement of operability, and thus, the reliability of cutting tools can be achieved by optimizing the following factors:

– rational combination of strength, thermo-physical and chemical properties of tool material, provided by the use of new or by hardening of traditional tool materials;

– cutting modes, tool geometry and roughness of tool contact areas;

– reduction of contact loads on tool contact areas;

– selection of rational cutting schemes and arrangement of tool cutting blades that reduce actual cutting path and cyclicity of load occurrence;

– development of assembly cutting tools design, which increasing reliability and technological capabilities of tools.

In this tutorial consider the problems of assurance of cutting tools reliability, incl. the use of modern materials for the manufacture of cutting tools and ways of their improvement, conditions for rational service of cutting tools, problems of optimizing of design and geometry of cutting tools, cutting conditions for improvement of tool running ability and the experience of their application in domestic and foreign industry for main types of cutting tools.

The monograph can also be used by students in the study of courses «Tool Production», «Technology of Tool Production», «Cutting Tools», etc., used for course and diploma design and can be useful for manufacturing engineers and technical staff.

1. FAILURE OF CUTTING TOOL

1.1. Classification of failures

The state of operability of cutting tools (blade) is characterized by a condition in which it is able to perform machining with established requirements. Failure of cutting tool (CT) is a violation of its state of operability as a result of deviation from the established values of at least one of cutting tool parameters, requirements or processing characteristics that is performed by this tool.

There are the following modes of failures:

a) Failures, leading to an increase in equipment downtime due to replacement of tool:

- low tool life;
- chipping of cutting blades;
- tool breakage;
- vibration;
- adhesion of the processed metal.

b) Failures, leading to decrease of processing quality of part. The necessary criteria for tool failure are: for rough machining – increased value of the cutting force or cutting temperature; for finishing machining – prescribed limits for quality of machining products should not exceed, expressed by roughness parameters, macro geometrical deviations, tolerance field etc.

c) Other failures.

Sudden and gradual failures of CT are possible. Sudden failure occurs, as a rule, due to brittle fracture of CT, gradual failure – wearing of the cutting edge causes loss of tool shape, reduction in cutting efficiency, an acceleration of wearing as the tool became heavily worn, and finally tool failure (loss of the sharp edge).

The causes of failures of broaches, milling cutters, drills, reamers, taps from high-speed steel M-type HSS are: breakage, shear fracture (focal destruction near the cutting edge), failure through mechanical gradual wear of tool contact areas under normal operating conditions and with considerable plastic deformation; plastic deformation and loss of the sharp edge, and adhesion seizure.

Depending on the type of used tool, a breakdown (sudden failure) is 1 to 12 % of all failures. A cutting tool gets broken due to the following factors: large cutting force, by developing fatigue cracks under chatter conditions, weak tool materials, and, high temperature and high stress. The greatest occurrence of breakdown for twist drills is 10...12 % of all failures; for shavers and shaping cutters – 5...8 %; for broaches and gear-cutting tools – 4...7 %. The causes of breakages are different and depend on tool design and cutting conditions. For drills, the main cause of failure is reduced rigidity of tool when large outreach and presence of flutes. Broaches breaks due to high tensile stresses in zone of increased concentration (cavities between teeth, metallurgical defects and sharpening defects). The most typical cause of breakages is the impact load on the cutting tool.

Spalling of tool material as the cause of a sudden failure is from 1 to 25 %. Spalling failure of shavers is 25 %, shaping cutters is 12...15 %, taps is 6...8 %, push broaches, drills and counterbore cutters is 3...6 %.

The main reason by which a HSS cutting tool can fail in machining is gradual wear. Gradual wearing of the cutting edge causes loss of tool shape, reduction in cutting efficiency, an acceleration of wearing as the tool becomes heavily worn, and finally tool failure by loss of the sharp edge. For example, gradual wearing result in loss of 61...73 % of twist drills, 88...92 % of milling-cutters, and, 93...97 % of reamers. Only 22...27 % of taps and 53...61 % of shaping cutters fail by gradual wear.

The temperature failure of cutting tools and adhesion are also typical causes of failures of HSS tools. These failures result in loss of 63...64 % of taps, of 12...15 % of form tool cutters, of 14...15 % of twist drills and counterbore cutters, and, of 7...10 % of hobbing cutter.

1.2. Gradual wear failure

Gradual wear occurs at two principal locations on a cutting tool: the top rake face and the flank. Accordingly, two main types of tool wear can be distinguished: crater wear and flank wear, illustrated in Fig. 1.1. *Crater wear*, consists of a concave section on the rake face of the tool, formed by the action of the chip sliding against the surface. High stresses and temperatures characterize the tool-chip contact interface, contributing to the wearing action. The crater can be measured either by its depth or its area. *Flank wear* occurs on the flank, or relief face, of the tool. It results from rubbing between the newly generated work surface and the flank face adjacent to the cutting edge. Flank wear is measured by the width of the wear band, FW. This wear band is sometimes called the flank wear *land*.

Certain features of flank wear can be identified. First, an extreme condition of flank wear often appears on the cutting edge at the location corresponding to the original surface of the workpart. This is called *notch wear*. It occurs because the original work surface is harder and/or more abrasive than the internal material, due to work hardening from cold drawing or previous machining, sand particles in the surface from casting, or other reasons. As a consequence of the harder surface, wear is accelerated at this location. A second region of flank wear that can be identified is *nose radius wear*; this occurs on the nose radius leading into the end cutting edge.

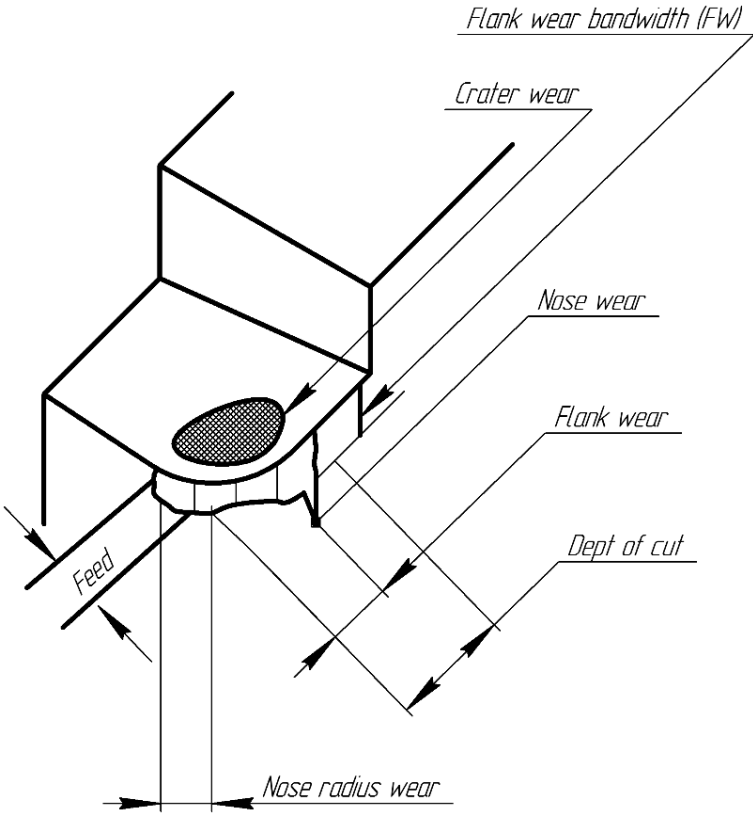


Fig 1.1. Diagram of worn single-point tool, showing the principal locations and types of wear that occur

The mechanisms that cause wear at the tool-chip and tool-work interfaces in machining can be summarized as follows:

– *Abrasion*. This is a mechanical wearing action due to hard particles in the work material gouging and removing small portions of the tool. This abrasive action occurs in both flank wear and crater wear; it is a significant cause of flank wear.

– *Adhesion*. When two metals are forced into contact under high pressure and temperature, adhesion, or welding occur between them. These conditions are present between the chip and the rake face of the tool. As the chip flows across the tool, small particles of the tool are broken away from the surface, resulting in attrition of the surface.

– *Diffusion*. This is a process in which an exchange of atoms takes place across a close contact boundary between two materials. In the case of tool wear, diffusion occurs at the tool-chip boundary, causing the tool surface to become depleted of the atoms responsible for its hardness. As this process continues, the tool surface becomes more susceptible to abrasion and adhesion. Diffusion is believed to be a principal mechanism of crater wear.

– *Chemical reactions*. The high temperatures and clean surfaces at the tool-chip interface in machining at high speeds can result in chemical reactions, in particular, oxidation, on the rake face of the tool. The oxidized layer, being softer than the parent tool material, is sheared away, exposing new material to sustain the reaction process.

– *Plastic deformation*. Another mechanism that contributes to tool wear is plastic deformation of the cutting edge. The cutting forces acting on the cutting edge at high temperature cause the edge to deform plastically, making it more vulnerable to abrasion of the tool surface. Plastic deformation contributes mainly to flank wear.

Most of these tool-wear mechanisms are accelerated at higher cutting speeds and temperatures. Diffusion and chemical reaction are especially sensitive to elevated temperature.

The first signs of wear of tool cutting edges are detected at beginning of machining, especially for carbide tools. There are microchipping in places of angular transitions, which are the places of conjugation of the main and auxiliary cutting edges, as well as the cutting edges of the blades themselves, which leads to increase of edge rounding. A level of tool wear can be selected as a criterion of tool life, and the tool is replaced when wear reaches that level.

Gradual wearing only the flank. The flank of the cutting tool in some cutting conditions is subjected to more intensive wear than the rake face. This failure of cutting tools is shown in Fig. 1.2., *a* and 1.2. *a, b, c, d, e*.

Gradual wearing of the rake face and the flank. The feed increase significantly enhances the forces, acting on the tool, but the cutting force

increases to a greater extent. This causes increase of the pressure and the friction forces, which acting on the contact areas of tool, especially on the rake face. The wearing of rake face and flank of the tool occurs simultaneously, but the wear rate of the rake face is greater than the flank. There are signs of wear on both the flank and the rake face of the blade (Fig. 1.2, *b* and 1.3, *g*). The wear on the rake face is measured by the depth h_{max} and the width a of crater.

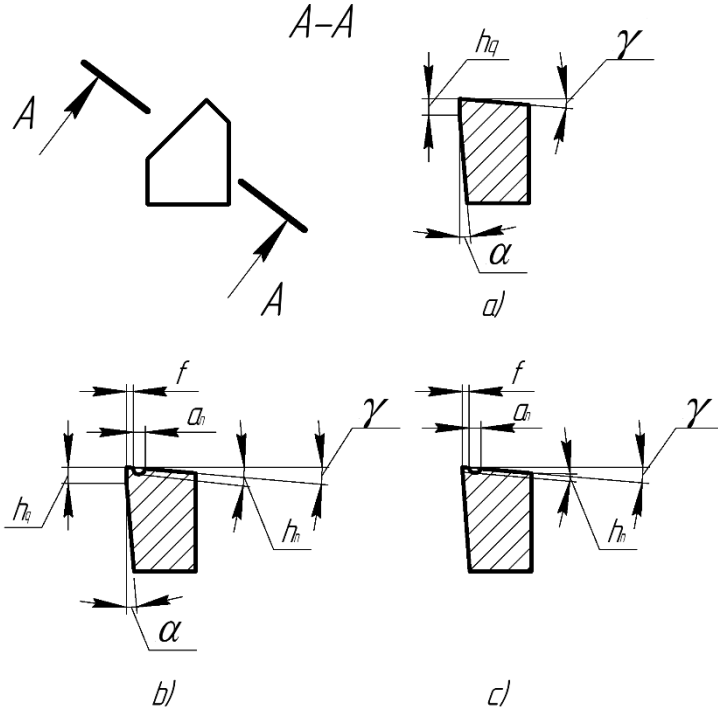


Fig. 1.2. Diagram of worn single-point tool, showing:
a – wear taking place only on the flank;
b – wear taking place as on the flank as on the rake face;
c – wear taking place only on the rake face

Gradual wearing only the rake face. Machining of metals on heavy-duty machine tools is usually carried out with large feed rates $S \geq 1$ mm/rev and are characterized by an increase of tool contact areas dimensions, pressure and friction force acting on them, as well as high temperature on rake face of the tool. Therefore, the wear rate of the rake face of the blade is much higher than

the flank. Visual signs of wear exist only on the rake face of the tool and not present on the flank (Fig. 1.2, *c* and 1.3, *f*).

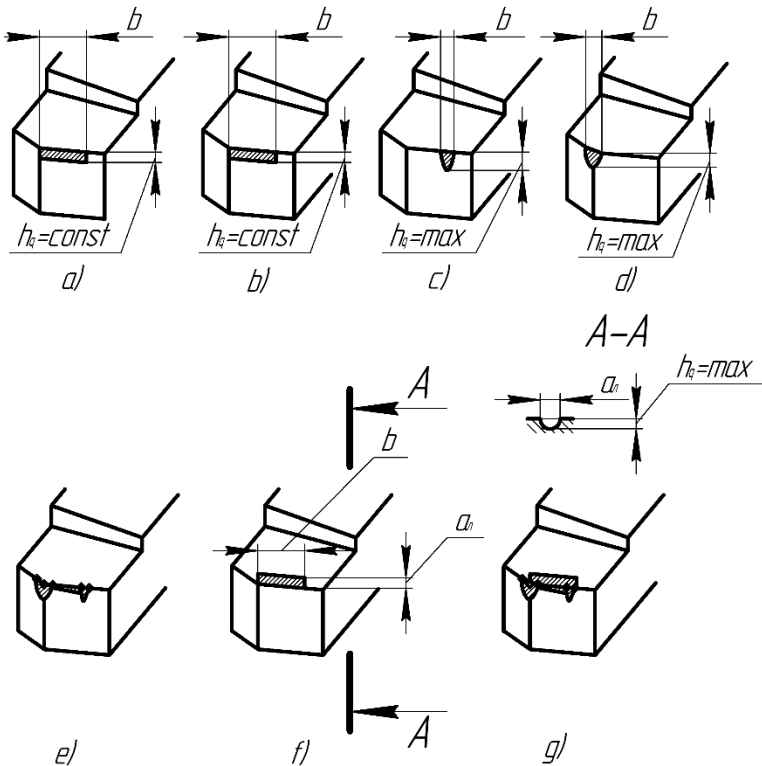


Fig. 1.3. Visually observed signs of tools wear:
a – equivalent wear of flank; *b* – nonuniform wear of flank; *c* – local wear of flank;
d – nose radius wear; *e* – combined wear; *f* – crater wear;
g – wear taking place as on the flank as on the rake face simultaneously

1.3. Low tool life

The reasons for low tool life are:

a) *Poor quality or incorrect choice of tool material.* If the rigidity of technological system and cutting speed become too low, as feed become much more, the more strong tool material must be used.

b) *Incorrect geometry of cutting tool*, selected in process of design or as result of resharpener and installation on the machine tool.

c) *Incorrect cutting mode*:

- high or low cutting speed;
- excessively large or small feeds. The minimum permissible thickness of the cut with carbide tools is 0,07 mm, and high-speed tools – 0,02 mm. This does not apply to slotting cutters.

d) *Unsatisfactory cooling of tool*. The used cutting fluid and application method do not perform all required functions.

e) *Deterioration of machinability affected by change of a work material*. Many work material factors affect machinability include hardness and strength. As hardness increases, abrasive wear of the tool increases so that tool life is reduced. A metal's chemistry has an important effect on properties and therefore affects machinability.

f) *Poor quality of tool sharpening has a very strong influence on the tool life*. Tool life can be reduced to eleven and more times, which is caused not only by a violation of the specified tool geometry, but mainly by burning and other defects.

g) *Low quality of heat treatment of steel cutting tools*: underheating or overheating during quenching, inadequate tempering after hardening;

h) *Vibrations accompanying the cutting process* not only reduce the tool life, but also impair the surface finish produced on work part, and have an adverse effect on state of machine tool.

1.4. Microchipping of cutting edges and tool breakage

Microchipping and breakage of tool are the result of two main reasons: insufficient strength of the cutting edge and tool material or tool overload. Fracture failure occurs when the cutting force at the tool point becomes excessive, causing inserts or solid tool to fail suddenly by brittle fracture. This failure leads to reduction quantity of possible tool resharpenings, or even eliminates the possibility of its resharpening, which considerably increases the consumption of tool material.

Fracture failure of tool point. Destruction of tool point can occur without noticeable plastic deformation (fracture failure) or accompanied by significant plastic deformations and change of form (plastic deformation failure). Fracture failure occurs as microchipping of cutting edges or shear fracture of tool point (Fig. 1.4).

Microchipping of cutting edges is usually associated with surface defects of tool material, heterogeneity of structure, by developing of residual stresses

and microcracks that occur when the cutting insert is soldered to the tool holder, and also with the change of loading scheme and stress state during the penetration of cutting tool and its outlet.

Plastic deformation failure. Traces of plastic deformations can be found when studying the crater wear on the rake face, or the analysis of changes of shape of the cutting blade in vicinity of the cutting edge (Fig. 1.5). Plastic deformations of cutting tool are typical for cutting with sufficiently high temperatures and contact loads.

Insufficient strength of cutting wedge and tool body is caused by the following reasons:

a) High toughness of cutting-tool material.

b) Improper heat treatment and sharpening of tool, which reduce its strength: overheating during quenching or inadequate tempering after hardening, residual tensile stresses, cracks and microcracks as a result of improper sharpening or soldering of cemented carbides inserts.

c) Weakening of tool point by choice of wrong tool geometry: large back rake and end relief angles, as well as side cutting edge and end cutting edge angles, lack of hardening chamfer with a negative back rake angle along the cutting edge on the rake face of the cemented carbide tools; unsuitable chip-breakers and chip curlers on the rake face, weakening the tool point.

d) Low initial strength of tool point or cutting tool itself. Property-enhancing operations can be performed to improve mechanical or physical of the tool material and to improve tool running ability. If it can not be achieved, then the design of the tool is improved, for example, the milling-cutters are made with a forced or parabolic tooth, fluteless taps and drills with increased web thickness are used, etc.

Overloading of the tool depends on a variety of reasons associated with the state of machine and cutting tools and their working conditions:

a) Enhanced cross-sectional area of the shear, initially selected or actually obtained due to strong beating of cutting edges of the multiple-cutting-edge tools, mainly milling-cutters.

b) Excessive blunting of cutting tool.

c) Jamming of chips in flutes of irregular shape or small volume.

d) Unsatisfactory properties and application of cutting fluids, which do not provide good lubrication of contact surfaces of tool in specific application conditions.

e) Work with impacts of cemented carbides tools with negative or zero angles of inclinations of the cutting edges or without chamfers and lands with a negative relief angle (turning of interrupted surfaces, turning of forged blanks, milling with face milling-cutters, shaping and planing, and some other machining operations).

f) Work with vibrations, leading to fatigue failure of tool edges.

If the cutting forces can not be reduced by eliminating the above problems, the tool designs should be improved by the strengthening of the tool point or the solid tool, by use of progressive cutting schemes, which is always useful, since they reduce the energy consumption of machining and, in many cases, increases tool life and cutting efficiency.

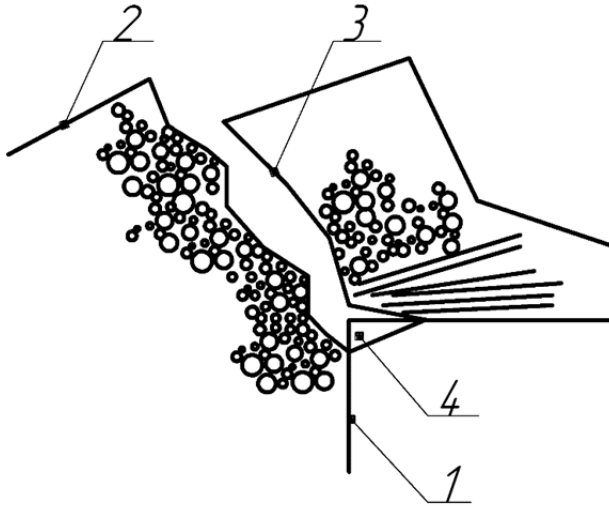


Fig. 1.4. Removal of chip from a workpart and tool fracture failure as the tool lead-out during shaping: 1 – single-point cutting tool; 2 – workpart; 3 – removing chip; 4 – removed particle of cemented carbide

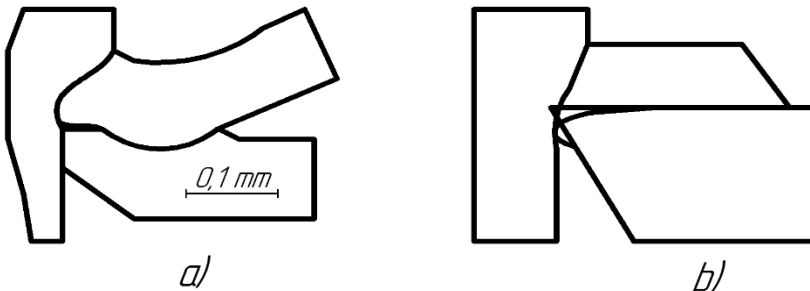


Fig. 1.5. Schemes of plastic deformations of cutting tools:
a – on the border of crater of rake face; b – on the tool point

1.5. Vibrations

Vibrations disturbs normal operation of machine tool, reduces the tool life and impairs quality of treated surfaces, and sometimes leads to tool fracture failure.

The most frequently vibrations occurs in high-speed turning and milling. The main reason of vibrations is the insufficient rigidity of the technological system as machine tool – fixture – cutting tool – work part, which depends on the condition of machine tool, fastening of the work part and the cutting tool.

1.6. Adhesion wear

Caused by formation and subsequent destruction of minute welded junctions, adhesion wear is commonly observed as built-up edge (BUE) on the top face of the tool. A BUE of piled-up work material near the tip of the cutting edge is frequently formed at intermediate cutting speeds. This typically occurs when cutting alloys that contain more than one phase, like carbon steel, cast iron and alpha-beta brass. As the first layer of work material that adheres to the tool tip is considerably strengthened by the shear strain, yield will occur in less-strained layers further from the tool surface. A continuous repetition of this process results in agglomerates that form relatively large layers of work-hardened material that accumulate to form a built-up edge.

The built-up edge is often unstable; it breaks away intermittently and is formed again. This BUE may eventually disengage from the tool, causing a crater like wear. Adhesion can also occur when minute particles of the tool surface are instantaneously welded to the chip surface at the tool-chip interface and carried away with the chip.

Depending on the materials and the cutting conditions the influence of the built-up edge may sometimes decrease or at other times increase the tool life. A stable built-up edge can be very beneficial and protect the tool surface from wear. On the other hand loose highly strain-hardened fragments of the built-up edge may adhere to the chip or workpiece and cause abrasion of the tool. At higher cutting speeds a built-tip edge is less likely to form because the temperature increases and the built-up edge can no longer support the stress of cutting and will thus be replaced by a flow zone.

Some workpieces will not ‘take a good finish’ as well as others. The fundamental reason for surface roughness is the formation and sloughing off of parts of the BUE on the tool. Soft, ductile materials tend to form a built-up edge rather easily. Stainless steels, gas turbine alloy, and other metals with high strain hardening ability, also tend to machine with builtup edges. Materials which

machine with high shear zone angles tend to minimize built-up edge effects. These include the aluminum alloys, cold worked steels, free-machining steels, brass, and titanium alloys.

The BUE can grow to such size, which leads to the tool sticking in the machining hole, causing it to fail by brittle fracture. These conditions are present in tapping. The most probable causes of adhesion wear are:

- a) Small back rake and end relief angles, including side angles.
- b) Small end cutting edge angles of drills, counterbores, reamers and taps.
- c) Large area of friction surfaces: taps are not relieved, large width of feathers of the tap, wide margins of drills, counterbores, reamers, which have zero side relief angles.
- d) Poor lubrication of tool contact surfaces: unsuitable cutting fluids or application method.
- e) Machining with large depth of cut or excessively worn tool.
- f) Poor condition of tool contact surfaces: high roughness, low surface hardness of tool, due to burns when sharpening or availability of decarburized metal layers occurs at tool production.
- g) High ductility of machining metal.

Elimination or reduction of BUE is ensured by reducing friction on contact surfaces: increasing of the tool side relief angles, increasing back taper and reducing the width of margins of drills, counterbores, reamers, relieving of taps on the profile, use of staggered and corrected taps, preventing or removing burns in grinding and sharpening of tool, complete removal of decarburized layers of tool material, reduction of friction by due to the correct selection of cutting fluids and its application method, or by means deposition of protective and antifriction films by chrome plating, sulphurizing, sulfidation, epilamination and other methods.

2. TRENDS OF ASSURANCE OF CUTTING TOOL RELIABILITY

2.1. General information

The retention of cutting tool operable state for given period of time is associated with solution of the following tasks: 1) rejecting of cutting tool (for example, by magnetic or ultrasonic flaw detection) by defects that can lead to its sudden failures in operation; 2) selection of cutting conditions, in which tool will work with uniform wear rate; 3) optimization of design and tool geometry and processing mode, which will ensure guaranteed performance of the tool (for example, by statistical optimization methods); 4) determination of critical cutting conditions, which require mandatory diagnosis of cutting tool state.

Performance of tool under changeable cutting conditions. Each unit of tool is operated, as a rule, in a constant processing mode, regardless of parts nomenclature. The efficiency of processing in automated production can be increased if cutting mode of tool is changed depending on the strategy of controlling of process productivity, tool consumption, and other.

Drilling of holes in gray cast iron workpieces by HSS drills with changeable cutting conditions during one tool life cycle, as increase or decrease of total drill life are possible. This effect is explained by the additivity of wear, i.e. the accumulated wear of the tool is the addition of wear from each cutting mode. Therefore, the use of cutting mode, which allows larger amount of wear after a mode with less permissible wear, makes it possible to increase the efficiency of tool without replacing it. Controlling of cutting in flexible manufacturing systems (FMS), this established pattern makes it possible to change the processing strategy (mode) in order to prolong the period of operation of existing tool in absence of a new one.

Increasing of tools performance by hardening processing of its surface. To this time, various methods of hardening processing of cutting tool surfaces have been developed and implemented. All their variety can be reduced to 5 principal groups:

- Coating deposition;
- surface alloying;
- heat treatment;

- strain hardening;
- combined processing by combination of different methods.

2.2. Improvement of the cutting tool designs

High productivity and precision of cutting processing are provided with a set of requirements for design of cutting tool, related to the choice: material and geometry of cutting part; strength and vibration resistance of holder and cutting edges; insert shape and dimensions; ways of insert holding (brazed or mechanically clamped); method of chip breaking; dimensions, roughness, geometry and design of the socket for insert holding, etc.

Modern automated production makes such requirements to the cutting tool as reliability, precision, adaptability to automation. These requirements meet the assembly tool with the mechanically clamped inserts. The replacement of solid tools and brazed inserts by mechanically clamped inserts is the one of the most important trends in the development of manufacturing engineering.

Distinctive features of design of modern cutting tools:

- wide use of mechanically clamped cutting-tool inserts available in a variety of shapes and sizes for the variety of cutting situations;
- application of very hard tool materials for inserts as cemented carbides, coated carbides, cermets, ceramics, cBN, and diamond;
- increasing of precision of final dimensions, tolerances and geometric attributes of elements of tool geometry and other elements of cutting tools;
- special embodiment of surfaces and elements for holding of tool;
- development of various modular tool systems. The realization of high potential capabilities of CNC machines and achieved productivity depend to a large extent on correctly chosen cutting tool that meets the special requirements imposed by the conditions of automatic machining on CNC machines.

Cemented carbides, ceramics, cBN, and diamond are the primary materials for metal cutting used in automated production, including CNC machines and FMS. Brazed inserts and solid tools are mainly used in manually operated machine tools. For automated machines and CNC centers, the use of brazed tools is inefficient due to the large loss of time to replace it.

Tools with mechanically clamped inserts do not require sharpening, since the tool geometry is provided by the shape of the insert and its corresponding holding in machine tool, and after tool wear reaches the critical value, they can be indexed multiple times. Eliminating of resharpening reduces time for tool replacement, increases quality of the tool, as the possibility of cracking is reduced. That makes possible multiple use of tool holder, which allows to improve quality and accuracy of holders manufacturing, to apply heat treatment,

corrosion resistant and decorative coatings, improve design of holders and housings. The absence of brazing eliminates the possibility of stress and microcracks appearance, which increases service life of the inserts. The losses of tungsten, tantalum, titanium and cobalt are reduced due to the secondary use of cemented carbide inserts. There is the possibility of effective application of tool-cutting materials that are difficult to braze (tungsten free cemented carbides and cutting ceramic).

A significant increase of productivity provides an increase of active length of cutting edges. These are tools, for example, broaches, combination tooling, multiple-cutting-edge tool heads, etc.

Multiple-cutting-edge tools should be designed with rational load distribution between the teeth, i.e. development of optimal cutting scheme. Due to application of progressive group cutting scheme became possible, for example, to considerably shorten the broach length with increasing cut per tooth. Similar solutions are applicable to other types of tools (milling cutters, boring heads, etc.).

The main indicator of cutting properties of tool is *tool life* for life cycle and to its full use after all resharpenings which specified by practical standards. The full tool life is estimated by *number* of processed single-type workpieces; *length* of relative working path; *square* of machined surface; *volume* of metal, that was removed from the processed workpieces; *tool life* and number of its resharpenings (or indexing); *total length* of all processed workpieces.

The tool life time is a function of complex of factors: properties of cutting-tool materials, including chemical composition (material grade), structural state, hardness, tensile strength, transverse strength, ultimate compression strength, hot hardness, wear resistance; design of tools – the optimal tool geometry, stiffness, accuracy of tool manufacture; cutting conditions – cutting speed, feed and depth of cutting, cutting fluid, accepted tool wear criterion; state of machine-cutting tool – rigidity of machine tools and production machines, vibration resistance.

The application of progressive cutting materials (cemented carbides, ceramics, SSM) as, inserts made possible to increase the reliability of cutting tools, to intensify cutting conditions, to ensure quick change of tools when they wear out, which is especially important for automated production.

Development of tools for the machining of new structural materials.

Modern engineering is characterized by a rapid development of scientific research in field of creating of new structural materials, most of which are characterized by extremely low machinability, which deteriorates with increasing of heat resistance properties. In particular, this applies to nickel and titanium alloys, to composites based on aluminum and titanium alloys reinforced with polymeric materials, as well as intermetalloids such as Ti-Al, Ni-Al and others.

The machining of some high-performance materials is extremely difficult due to the thermomechanical effect on the cutting tool, the machine tool components and the processed surface, and this effect is increased due to the refuse to use cutting fluids due to risk of gas saturation of surface layer and a negative change in the operational properties of processed parts. It is effective to use a tool equipped with oxide (Al_2O_3) cutting ceramics (CC) hardened with SiC crystals and poly-crystalline boron nitride (cBN) for dry cutting of non-free-cutting material nickel alloy Inconel 718, which allows to highly improve machining efficiency.

The increase of application of aluminum in manufacturing stimulated intensive development and introduction of new technological methods for its highly efficient processing, in particular, it was developed a line of cutting tools equipped with polycrystalline diamond inserts, as well as new machine tools that provide cutting speeds $v > 1000$ m/min.

The wide application of high-strength cast iron with vermicular graphite (CVG) is constrained due to its poor machinability by cutting. In this regard, extensive research is being carried out to study the machinability of CVG and the development of new grades of cemented carbides with a fine-grained and superfine-grained structure with a coating especially for the processing of CVG.

Such alloys have a balanced ratio of hardness and toughness, are characterized by extremely high density and homogeneity of structure, suitable for the application of wear-resistant coatings by various methods (CVD, PVD).

Development of tools for new conventional machining methods. A very promising direction of conventional machining is the so called "hard machining" of metals with a hardness ≥ 47 HRC, which is used to replace the grinding on conventional machining. Its essence lies in the fact that due to the specially selected geometry of tool, equipped with ceramics or cBN, and cutting conditions, the processed metal is heated during the cutting process, and its hardness due to tempering is reduced to a hardness of 25 HRC. After chip separation, workpiece material is rapidly cooled, and its hardness is reduced by no more than 2 HRC. «Hard turning» is more economical than grinding and is not inferior in precision to it.

High precision and quality of part surface can be achieved by using combined methods of processing, for example, by machining and cold plastic deformation of microroughnesses.

Increase of accuracy of tool manufacturing. One of the reasons for instability of tool life and breakage of cutting tools is inaccuracy in the processing of their working surfaces. The teeth beating of reamers, counterbores and drills is commensurable with permissible feeds to tooth during machining.

High requirements are imposed on, accuracy of dimensions, shape and quality of part surfaces. This tightens the requirements for the precision of

cutting tools. For example, the tolerance for diameter of a to – size (counterbores, reamers, etc.) should be 2 – 3 times smaller than tolerance for the diameter of machined hole. Tools for automated production are characterized by even narrower tolerances on executive dimensions, beating of cutting edges, quality of teeth surfaces and fluting grooves.

Innovative designs of cutting tools from very hard materials.

Improving of cutting tool design is important in view of appearance of: cutting tool materials with new cutting properties, as well as high-speed metal-cutting machines and structural materials with improved mechanical characteristics. In cutting tools based on very hard materials it is possible to use various forms of cutting inserts. The shape and dimensions of cutting elements are determined taking into account the shape and dimensions of workpieces from the very hard materials (tablets). Cutting elements have form of cylinder, dimensions of which are equal to dimensions of tablet or part of tablet, and fixed (soldered) to the interchangeable plates with fixed cutting elements of SHM and clamped mechanically to body of tool.

Polyhedral plates of triangular rhombic form can be made with brazed into one from vertices by an element of very hard material (VHM) (Fig. 2.1). Cutting elements from VHM for polyhedral plates are chosen taking into account the configuration of the polyhedral plate. Geometric parameters are formed by installing the plate or during the sharpening process when it is mounted on the body.

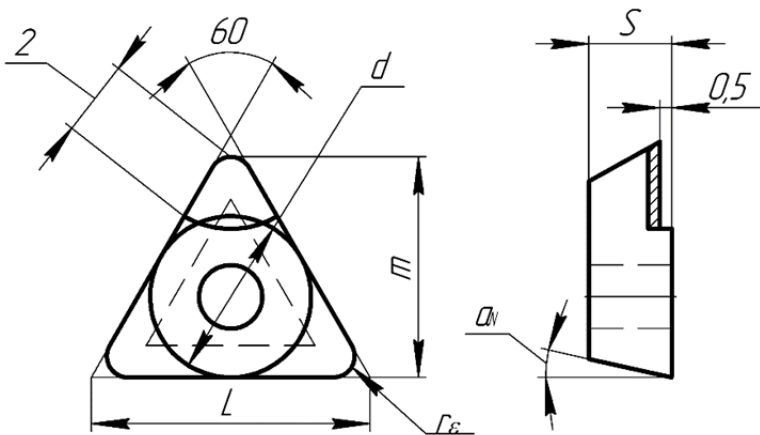


Fig. 2.1. Design of plate with cutting insert of VHM:
 L – length of the plate, m – plate height, S – thickness of the plate,
 α_n – relief angle in the normal cross, r_e – nose radius

2.3. Improvement of cutting tool materials

Physic-mechanical, thermal-physic and crystal-chemical properties of cutting tool material are greatly influenced on cutting tool efficiency, and optimal choice of a combination of these properties allows, within certain limits, to control the wear process of the tool, to transform one wear mechanism into another, to reduce the wear rate of tool contact areas. For example, at constant values of tool geometric parameters and cutting conditions, the growth of such cutting tool material properties as hardness, heat resistance, strength, passivity in relation to processed material and active reagents from surrounding media, leads to an increase in wear resistance of tool contact surfaces, and a corresponding increase of its efficiency. However, the majority of physic-mechanical and thermo-physical properties of cutting tool material are ambiguous, since the improvement of one of them, as a rule, leads to the deterioration of others. In Fig. 2.2 classification of modern cutting tool materials according to their basic properties is presented.

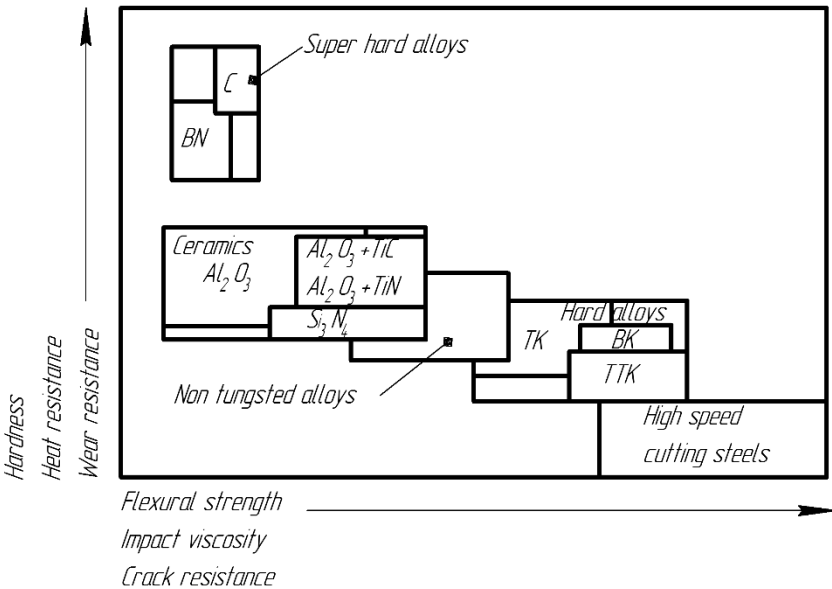


Fig. 2.2. Classification of cutting tool materials by their properties

Improvement of cutting-tool materials is carried out in a number of areas, which are briefly considered below.

1. Development and implementation of high-speed steels with optimal composition, which include those that have the best combination of operational and technological properties with a lower content of expensive alloying components in them.

2. Application of processing technologies that increase the operational properties of steels:

- optimization of heating temperatures during hardening of steels;
- vacuum heat treatment of high-speed steels;
- isothermal forging of high-speed steels at superplasticity conditions;
- application of extrusion method. A small cutting tool made of 10R6M5-MP steel (drills 1,0...10 mm in diameter, end milling cutters with a diameter of 4...10 mm, etc.) has a tool life exceeding tool life of similar tools from standard steels R6M5 and R18 (drills in 2 – 9,6 times, milling cutters in 1,3 – 4 times);
- implementation of modern technologies of production and casting of high-speed steels, which ensure an increase of their mechanical properties;
- development and application of high-speed steels for cast tools;
- implementation of welded tools with working part from high-speed steels;
- development of powder wires from high-speed steels for surfacing of tools;
- development and application of low-temperature precision method of grinding of cutting tool materials.

3. Perfection of cemented carbides (CC):

- the development of ultrafine-grained (with a grain of 0,3 ... 0,5 μm) and extra-fine grained (with a grain of 0.5...0.9 μm) HA, which have a more balanced combination of hardness and viscosity in comparison with normal (1,4 ... 2,0 μm) and coarse (3,5 ... 5,0 μm) grain size;
- creation of CC with increased heat resistance of binder (for example, alloying of cobalt binder by Re and Ru) and with more high resistance to ductile fracture at elevated temperatures in comparison with standard CC;
- development of economically alloyed, free tungsten CC with nickel-molybdenum binders, which do not contain expensive elements (W, Co, Ta);
- development of universal grades of CC with wear-resistant coatings, which at a great extent meet the requirements for cutting tools materials with «ideal properties»;
- development of layered (composite) CC, economically combining an expensive and highly wear-resistant relatively thin surface layer with a cheaper massive substrate.

Cemented carbides of the new generation are designed to solve the collection of modern technological problems:

- dry high-speed cutting;
- machining of materials with elevated hardness;
- machining of materials with low machinability rating;
- production of solid cemented carbide tools with a complex geometry (drills, end milling cutters, taps, etc.).

The use of removable inserts from ultrafine-grained and extra-fine-grained CC (especially inserts with improved geometry) contributes to a significant increase of efficiency of finishing cuts. Cutting tools, equipped with such inserts, allows to efficiently solve problems related to:

- improvement of chip breaking;
- decline of tool thermal tension and decline of intensity of diffusion wear of tool during high-speed machining;
- decline of susceptibility of build-up formation;
- increase of accuracy and quality of cutting for materials with low machinability rating.

The nanocrystalline powders are increasingly used as fillers for new cutting-tool materials, alloys and composites, and wear resistant coatings.

4. Development and application of free tungsten cemented carbides which used iron and steel binders, which are not inferior in terms of cutting properties of traditional CC.

5. Improvement of cutting ceramics. High hardness (92...96 HRA), bending strength (600...1100 MPa) and fracture toughness (5,5...8 MNm^{1/2}), including conditions at elevated temperature, and low coefficient of thermal expansion (3,2...4) 10⁻⁶ K⁻¹ and relatively low density (3,2...3,4 g/cm³) of nitride-silicon ceramics allow to successfully operate the tool during roughing (including intermittent cutting conditions) of cast iron and nickel-base alloys, i.e. in conditions when the use of cutting-tool ceramics was previously considered not only inefficient, but also impossible.

This is confirmed by the results of the tool life tests of ceramic inserts HOC-60 (high content oxide ceramic, Russian grade) and others, based on silicon nitride, conducted during turning of grey cast iron (32, Russian grade). At cutting conditions as $v=500$ m/min, $S=0,5$ mm/rev and $t=1,5$ mm, from ten inserts HOC-60 eight plates were out of service. Five of them did not work for 5 minutes, and for the others macro-disruption of cutting edges of the plates was noted after working for 6...8 min. At the same time, of the same number of nitride-silicon ceramic plates, only two were destroyed during turning. The average durability period for the rest was 9 minutes at root-mean-square value (RMS) $T=10,65$ min (as a tool life criteria was used a flank wear bandwidth $FW=0,5$ mm). Reduction of feed to 0,15 mm/rev during turning leads to a change of the ratio by performance characteristics of researched inserts. In this case, for the inserts HOC-60, the average tool life was 16,8 min, $\sigma_T=5,63$ min,

while for the silicon-nitride ceramics the same indices deteriorated ($T = 14,3$ min, $\sigma_T = 8,32$ min).

6. The application of composite cutting-tools materials, for example, two-layer composite polycrystalline materials (diamond-bearing layer on a carbide substrate) and combined removable inserts, consisting of inserts of various forms from of cutting tool material and base of a plate made of cheaper material.

7. Creation of cutting tool materials with increased physic-mechanical and cutting properties on the basis of a composite-layered system of three basic elements with a gradient of properties in the volume of the geometric body of tool (high-strength composite ceramics with coating).

8. Development and application of composite materials based on cubic boron nitride.

2.4. Increasing of rigidity and vibration resistance of technological cutting system

Increasing of rigidity and vibration resistance of cutting tools can increase their tool life, to increase feed, and consequently, the productivity of cutting process. For axial tools, this is achieved by increasing the cross-sectional area of the tool bodies and maximally reducing the length of tool, in treatment of deep holes – by using additional supports as guides, stem like posts, vibration dampers and other devices.

The random nature of change of static and dynamic rigidity of machine-tool is one of the main reasons for occurrence of vibrations in the technological system, an unforeseen change in the tool life, as a rule, in direction of decreasing or increasing of its breakage probability. Decrease of system rigidity part-carriage of lathe machine-tool from $1,87 \cdot 10^7$ to $0,37 \cdot 10^7$ N/m, leads to a decrease of cemented carbide tool life (T15K6, Russian grade) in turning of steel 30XГСА (Russian grade) from 36 to 6 minutes or 6 times.

In process of cutting due to instability of the cutting forces there are vibrations, that leads to a deterioration of quality of the processed surface. For elimination of vibrations in tool constructions, a different type of device is used to reduce the amplitude of oscillations of cutting edge.

An increase of vibration resistance of a tool equipped with cemented carbide inserts is achieved by using combined cemented carbide inserts with damping properties. For this, special cartridge is installed into the hole of the removable insert, which can have various shapes depending on method and design of insert clamping. The material of cartridge is alloys of Cu-Mn, Fe-Cr, Fe-Al systems, which have a high damping capacity and low linear expansion coefficient. Under the action of varying cutting forces, oscillations are damped

at the junction between the clamping mechanism and cutting insert. Damping of inserts from various materials reduces the auto – oscillations of cemented carbide insert relative to tool body from 10% to 40%. The assembled cutting tool, equipped with such inserts, is used in conditions of high vibrational loads (processing of shaped, threaded, discontinuous surfaces, interrupted cutting, etc.).

Another direction of improving of assembly cemented carbide tools is design of tools (milling cutters) with cemented carbide-tipped plates located along the contour of complex profile of part. Plates are arranged along the contour of part in staggered order with a shift relative to the previous row by a certain amount, which are set depending on the requirements for the roughness of product and the number of teeth of milling cutter.

2.5. Influence of edge condition on the running ability of cutting tools

The condition of cutting tool edges result in: the tool's ability to perform its functions, cutting forces and the power consumed during machining, the quality of the machined surfaces, the tool life, the cost of the tool and its resharpening.

The loose abrasive finishing of cutting-tool edges result in identical surface texture in longitudinal and transverse directions.

The increased roughness of the cutting edges after usual sharpening by grinding significantly reduces their strength. The protrusions of microroughness at the edges due to their low mechanical strength are destroyed at the first seconds of cutting. Depressions of microroughnesses are the place where microcracks appears, which then is growing in process of cutting and result in formation of spall.

If the cutting tool is used to form the surface by copying the shape of cutting edge on the product, then all defects of edge, including its roughness, are automatically transferred to the surface of the product. Destruction of grinded and mechanically weak edge at the initial stage of cutting occurs uncontrollably and leads to uncontrollable changes in its shape.

Cutting edges of tool after sharpening it is desirable to subject additional finishing processing by creating on the edge the hardening chamfer on tools for rough operations, or preliminary rounding of edges on tools of different purposes. Both, as this as the something else ensure long-term preservation of the geometric shape of edge, its increased strength and, accordingly, increased total tool life.

Cutting ability of cemented carbide tools with a rounded edge. The appearance of rounding on the cutting edge worsens the conditions for separating the allowance into chips and increases the cutting forces. The formation of chips can occur with significant excess of rounding radius ρ above the cut thickness a (Fig. 2.3). There is a wide range of ratios $\rho/a = 2,8...3,50$, at which chip formation is possible.

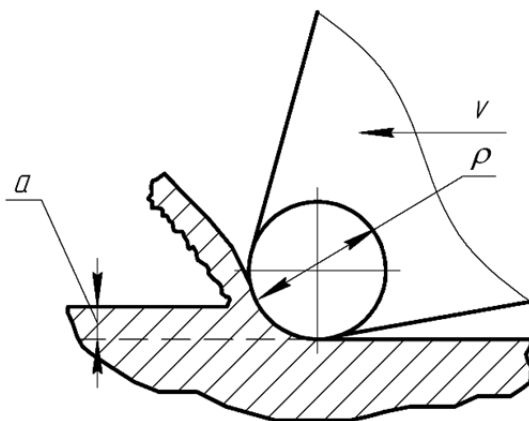


Fig. 2.3. Scheme of chips formation

The maximum strength of the cutting edge is achieved at $\rho = 0,16 \cdot a^{0,5}$; too large radii of rounding contribute to initiation of vibrations and deterioration of roughness of machined surface. The maximum vibration resistance of the single-point tool is ensured at $\rho/a = 0,11$, and in this case rounding of the edges allows to obtain an increment of the tool life from 1,5 to 4,0 times.

The experience of rounding of cutting edges on the steel tools. The effectiveness of rounding of cutting edge can be estimated by tool life increase ratio $k_T = T_\rho/T_S$, where T_ρ is tool life of single-point tool with a rounded edge, T_S is tool life of single-point tool with sharp edge. The maximum values of the coefficient k_T in the range $a = 14...73 \mu\text{m}$ linearly are increasing with growth of ratio a/ρ . Optimum radii of rounding of cutting edges allow to receive increments of tool life of single-point tools from 1,5 to 3,0 times.

Tool life enhancement for end milling cutters with diameter by 14 mm during machining of stainless steel 12X18H10T (Russian grade) is achieved by rounding of main cutting edges either manually with an abrasive bar or as a result of magnetic-abrasive processing. The maximum of tool life k_T was obtained at $\rho = 70...80 \mu\text{m}$: after manual rounding of edges $k_T = 2,6$, after magnetic-abrasive processing – $k_T = 3,3$.

The rounding of cutting edges of taps M16 from HSS steel P6M5 (Russian grade) with simultaneous improvement of quality of their surfaces was realized by magnetic-abrasive processing. Radius of rounding ρ was controlled on edges of the cutting part of the taps. The maximum effect of increasing of tool life on taps during threading in holes of high-strength steel was much more than on the turning single-point tools: $k_T \geq 12$. The optimum value of the radii of rounding was $30 \mu\text{m}$. With increasing of durability of tools, the roughness and accuracy of surfaces processed with such tools was also improved.

The state of cutting edges also significantly effects on strength of the wear-resistant coating of tools. The radius of preliminary rounding of cutting edge must be in a certain ratio to the thickness of the wear-resistant coating h_C . The occurrence of chipped cutting edge could be result of the rounding lack on edge before coating deposition. For tools from high-speed steel, the ratio $\rho/h_C > 4$ is recommended. At the same time, rounding of edges has the greatest effect on milling operations. Thus, during milling of steel 40X (Russian grade) by end milling cutters made of steel P6M5 (Russian grade) and coated with TiN, with $\rho = 27 \mu\text{m}$ ($\rho / h_C > 5,2$) before coating deposition tool life was 4 times more than milling cutters with $\rho = 3 \mu\text{m}$ ($\rho/h_C > 0,6$).

2.6. Application of cooling and lubrication media (CLM)

Improving of tool life of cutting tools is facilitated by effective use of various cooling and lubrication media (CLM). They are providing a reduction of cutting temperature, improving the quality of the machined surface and obtaining a transportable shape of the chips. Typically, as CLM used various cutting fluids (CF), aerosols, compressed air, etc. The efficiency of reducing of cutting temperature is increasing with increasing of speed of CLM flow through cutting zone, supplied in form of liquids, as well as aerosols (minimal quantity lubrication (MQL)). The objectives of CLM application are: protection of tool, parts and machine-tool from excessive heating, increase of tool life, reduction of the influence of build-up and reduction of the roughness of machined surface, cleaning of cutting area of fine chips, reduction of friction on contact tool surfaces with part and chips, improvement of quality of machined part surface and its performance characteristics.

The high cost of CLM (up to 16 % of total cost of part processing) is the one of reason for development of dry machining, meaning that no cutting fluid is used. In cases when dry machining is impossible, for example, during drilling, processing with minimal quantity lubrication (MQL) is recommended, which consists in cooling of cutting zone with a small amount of cutting fluid supplied under pressure to 0,6 MPa by stream of air. The flow rate of CF, which in this

case is converted into an aerosol, usually does not exceed 80 ml/h. This eliminates the costs on preparation and disposal of CF, cleaning of chips, etc. So, for example, according to the company "Gühring" (Germany), during deep drilling of holes by 10 mm in diameter and depth of 200 mm in an aluminum alloy with this method of supplying of oil CF (through internal holes in drill) it was possible to increase the tool life in 4 times, feed – in 3 times, and increase the cutting speed from 130 to 160 m/min.

The cutting efficiency with MQL, estimated by the wear and durability criteria of tool, exceeds the dry machining and achieves the potential of standard cutting technology using CLM, and in some cases exceeds it. This is confirmed by the practice of applying a minimum cutting fluid in turning, drilling, counterboring, reaming, thread-cutting, gear-cutting, etc.

For example, the increase of HSS tool life during drilling, counterboring and reaming with using MQL was 494, 223 and 148 %, relatively, compared to dry cutting. At the same time, the wear rate of tool in all cases was the least in cutting with a MQL.

Another method of minimizing of CLM feed to processing zone is its microdosing and delivery to processing zone in special microcapsules 5-20 μm in size, inside of which there is a droplet (dose) of CLM.

2.7. Optimization of cutting tool shape and rough cutting conditions

For rough machining on heavy lathes are used: tools with brazed inserts; tools with mechanically clamped inserts and modular tooling.

The tools with brazed inserts are characterized by simplicity of design and allows to work at heavy cutting conditions, since set of insert and holder is a rigid system. However, process of brazing of inserts can result in formation of cracks, which during machining are increasing and causing the tool fracture failure.

Since the life of large cemented carbide inserts, which are operated with large feeds, is relatively small and is about 3...5 hours of operation, it is advisable to use assembly cutting tools for roughing. The single-point tools with cast inserts of "Uralmash" with brazed cemented carbide inserts fixed in holder with help of a «wedge swallowtail» are showing high efficiency. However, the design of the swallowtail limits the use of large sections of cut-off layer because of insufficient strength of these inserts.

In severe working conditions, the tools, equipped with cemented carbide inserts of standard designs, are found limited application because of relatively low strength of inserts holding. For heavy cutting operations, it is used tools

equipped with several inserts, which makes possible to remove significant allowances by relatively small inserts with equal distribution of allowance between them.

Application of CLM in rough turning of steels, as a rule, doesn't give a significant effect. This is due to very high power of heat sources and lack of methods for its removal, which would allow to increase density of heat drains to a level comparable to cutting power. Often, CLM have weakly influence on intensity of wear and tool rigidity, and in some cases (for example, at interrupted roughing cutting) even reduces the tool life. The positive effect of application of CLM can be obtained with a large flow of cutting fluid due to a decrease in temperature in cutting tool, which is favorable for form stability of tool. However, an increase in flow rate of cutting fluid is undesirable by environmental reasons.

One of directions of improvement of roughing machining operations is introduction of additional energy, for example heat, into the treatment zone. In some cases, technological heat is used in processing of workpieces (casting, stamping, rolling), in others –cutting zone is artificially heated by various methods (inductive heating by high-frequency currents, plasma and radiant heating, local heating in the electrolyte).

However, existing cutting tool materials (high-speed steels, cemented carbides, superhard materials) do not satisfy the condition of diffusion resistance and heat resistance and are not suitable for cutting of steels with high-temperature heating. In preheating a special problem is chip breaking and chip splitting. During lathe operations, methods of heating by currents of high and industrial frequency and heating with a plasma jet are most widely used. For workpieces with large diameters, heating of cut layer is energetically unprofitable because of large required power (up to 1 MW).

In severe rough turning conditions, efficiency of inserts with wear-resistant coatings decreases with increasing thickness of depth of cut and, therefore, as a rule, used solid cemented carbide inserts without coatings.

Selection of cutting tool material. During roughing there are significant fluctuations of allowance and cutting forces, and in the presence of casting skin, as solid inclusions in form of sand, and so, it is used more durable but less wear-resistant cemented carbides. With an increase of hardness of treated hardened steel, more durable and less wear-resistant alloys (W-8Co) are used. In conditions of increased rigidity of technological system or with a smooth work of tool and the absence of scale, alloys of mixed (black) ceramics VOK-63, VOK-71, VOK-200 are effectively used.

For heavy conditions with large areas of the shear plane (width of cut layer is $b \leq 45$ mm, depth of t cut $a \leq 2$ mm), cutters or plates with brazed inserts are most often used. It is connected with fact that for mechanical clamping of

cutting plates they must be larger than plates which fixed by brazing. Usually, cemented carbide cutting plates longer than 50 mm are not used.

The thickness of cutting plate to ensure required strength, as a rule, should be tenfold more than the thickness of cut layer ($T_{pl} \geq 10a$). In work with a large thickness of cut layer in heavy engineering, cutting plate is placed in holder (or insert) so that its height (in direction of resultant cutting force) is greater than width (in direction of chip removal).

The shape of the rake face, crater, chamfer, nails. To increase fragile strength of the cutting tool, a hardening chamfer at an angle $\gamma_f = -10^\circ$ must be made on its rake face. The width of reinforcing chamfer in processing of relatively small hardness steel (HB <1800 MPa) with rational rake face temperatures ($\theta \approx 800 \dots 1000^\circ\text{C}$), as a rule, should not exceed depth of cut. With the increase of rake face temperature and hardness of processed material, the width of reinforcing chamfer must be reduced. For example, in turning of hardened steel HRC35 by single-point tool with inserts of mixed ceramics VOK-60 at maximum rake face temperature $\approx 1300^\circ\text{C}$, the width of hardening chamfer should not exceed $0,25a$.

In roughing of steels, the rake angle behind the chamfer is almost always advisable to make positive ($\gamma \approx 10^\circ$). In roughing of parts on non-rigid machine-tools, with insufficient rigidity of technological system, it is advisable to increase the rake angle up to $15 \dots 20^\circ$.

In some cases, to simplify design of cutting plate and increase its strength, it is recommended to use a negative rake angle ($\gamma \approx -7^\circ$). At the same time, due to the increase of cutting forces and occurrence of vibrations, the feed should be substantially reduced. The reduction in productivity can not be compensated by an increase of cutting speed due to an increase of deformation temperature caused by a decrease of rake angle of the tool. More effective shape of rake face for turning with large depth of cut has two chamfers: 1. reinforcing at an angle $\gamma_f \approx -10^\circ$ and 2. stabilizing at an angle $\gamma \approx 15 \dots 20^\circ$.

During roughing of small parts, the tools with mechanical holding of replaceable inserts are often used. The cutting forces acting on the inserts must support its holding in groove of tool holder. The reliability of plate holding in groove of tool holder will be higher if the angle between base surfaces will be less than 90° . This also refers to holding of brazed inserts. Reliable holding of inserts is ensured by using a slot in form of wedge. In this case, functions of chip breaker can be performed by a part of surface of cutting plate or by surface of holder itself. In this case, this surface is hard-faced by a layer of high-speed steel.

Inclination angle of cutting edge. For large areas of shear plane, the cemented carbide plate is positioned at an angle of inclination of main cutting edge ($\lambda \approx 5^\circ$), so that the height of plate is greater than its width. Positive angles of incline of cutting edge contribute to appearance of favorable compressive

stresses in the cutting plate, that is necessary to increase fragile strength of cutting plate. At the same time, the resulting chips is interfeared with the machined surface of part, which promotes to chip breaking. However, on processed surface there are characteristic traces that substantially increase its roughness.

Relief angles. In roughing, the relief angles of tool are set within $6 \dots 8^\circ$. The rounding of cutting edges or sharpening of a small chamfer with zero relief angle (up to $0,2 - 0,3$ mm) have a positive effect on the strength and the wear resistance of the tool. A preliminary truncation of tool, which is intended for roughing, is usually not done and the tool receives it during cutting process.

The shape of the cutting edge in main plane. At large allowance, for roughing straight turning tools, in practice, side cutting edge angle $\varphi = 60^\circ$ is most often used. It is recommended to use nose radius $r = 0,8$ and $r = 1,2$ mm, feed $S = 0,4 - 0,8$ mm/rev. With the ratios $S/r > 0,1$, an increased wear of tool is observed in the vicinity of nose, and at ratio $S/r = 0,1$, the wear is equalized. The radius at nose r must be not less than 10 feeds.

For large feeds, the shape of cutting part of the tool in plan can be adopted in form of wiper and transient edges. The length of wiper edge must not be less than feed rate: $l_s \approx (1,1 \dots 1,2)S$. The wiper edge provides the required roughness of processed surface and can be either curvilinear (radius $r \geq 10S$) or rectilinear. To ensure preservation of shape of wiper edge and prevent it from intensive wear it is advisable to sharpen the transient edge before the wiper edge, length of which l_t should be approximately equal to (or slightly larger) length of the wiper edge, and the angle in the plan φ_t should be within $5 \dots 10^\circ$.

The nonuniformity of wear of rough single-point tools are increasing sharply when tool angles in plan larger than 90° . In this regard, facing tools with angles in plan more than 90° are advisable to apply only for small depth of cut. In this case, the actual angles in plan at working sector of cutting edge must not exceed 90° .

The increase of width of cutting, which connected with decrease of number of passes, can be limited by occurrence of vibrations. In some cases, the maximum width of the cut layer, which allowed by occurrence of vibrations, is used as a technological constraint.

Determination of maximum permissible feed and the least angle in the plan due consideration to allowed forces. At this stage, the maximum depth of cut, length of wiper and transient edges, nose radius, width of strengthening and stabilizing chamfers, distance to chip breakers must be determined.

Up to 40% of equipment downtime is associated with low tool life and insufficient reliability of cutting tool. Tool wear and fracture failure are often preceded during roughing by considerable plastic deformation of cutting edge. In

appliance of feeds more than 1 mm/rev in processing of steel workpieces, brittle fracture of cutting plates is main type of tool failure.

The widespread concept of breaking feed is largely connected not with fragile strength, but with plastic destruction of cutting blade at elevated temperatures. Reducing of cutting speed from condition of a constant wear rate of the tool (or constant temperature) allows to increase the feed without tool breakage. In addition, at lower speeds (temperatures), it is more reliably ensured chips fall under desired rake angle behind the hardening chamfer, which is necessary for curling and crushing of chips. However, the use of depth of cut more than 1 mm in processing of steels is impractical. This is due to the fact that a possible slight increase of processing capacity is associated with an increased probability of breakage of cutting plates and a reduction in the allowable number of tool resharpening.

Consideration to the uneven wear. The ratio between feed and nose radius result in significant effect on the uneven wear of cutting edge. For even wear of cutting tool, ratio between feed and the nose radius, in which angle in the plan at a distance S from nose does not exceed $5 - 6^\circ$, and coefficient of uneven wear is equal to 1, is most favorable. For this it is necessary that ratio must be $S/r < 0,1$.

An increase of radius r can cause vibrations. Therefore, it is used average ratios of $0,1 < S/r < 0,67$, or formed transient and wiper edges of limited length. At the same time, it is necessary to take into account the limitations of uneven wear and roughness of processed surface.

If only dimensions of cutting plate are limited, rather than the allowable cutting forces, it is advisable to choose a large plate or design single-point tool with two cutting insertss. The value of admissible feed should not exceed two thirds of nose radius of tool ($S/r < 0,67$).

Selection of proper cutting speed. Selection of proper cutting speed is usually based on the one of criteria for wear resistance of tool, it is usually the tool life. However, more complete and correct information can be obtained by simultaneous analysis of several criteria of wear resistance (area of processed surface, cutting path) and wear mechanism. From a physical point of view, it is advisable to set cutting path $L = vT$. During cutting steels by cemented carbide tools with small areas of share plane, it is possible to achive cutting paths of order of 15...20 km or more, which at a cutting speed 50 m/min corresponds to a tool life about 300 min.

2.8. Optimization of cutting conditions for finishing operations

More wear-resistant but less robust cutting tool materials are used for finishing operations. In processing of heat-resistant alloys on a nickel basis, the best results are achieved by application of cemented carbides VK10-OM and VPK-15 (Russian grades), which are characterized by higher strength and form stability than all the others.

For more wear-resistant and fragile cutting tool materials, as well as for inserts with wear-resistant coatings, it is characteristic to use a higher cutting speed and smaller depth of cut.

In processing of high-strength materials (for example, nickel alloys), the uneven wear of single-point tools, which is accompanied by the formation of furrows on flank, is associated with an insufficient fragile strength of cutting edge. The uneven flank wear on a wiping edge determines the profile of processed surface, and increasing its roughness. The shape of cutting tool with a limited curvilinear transitive-wiping edge should be considered more perfect. To avoid the occurrence of vibrations, the length of transitive-wiping edge must be limited. The rational distance from main cutting edge to nose is approximately $1,5S$. In this case, a segment of length S serves as transition edge with a sufficiently small angle in plan (Fig. 2.4). It is characterized by a combination of large radii on the transitive-wiping edge and rational angles in plan on the section of main cutting edge. The increase of radius r favorably affects not only roughness of processed surface, but also intensity of tool wear in vicinity of nose.

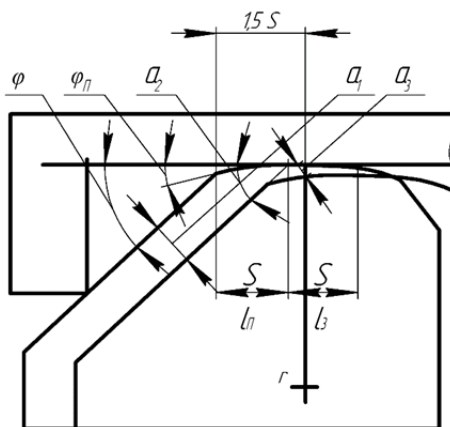


Fig. 2.4. Scheme of variation of depth of cut on sections of main, transitional and wiper edges

The shape of cutting blade with a limited curved transitional-wiper edge of a large radius makes possible to substantially increase the feed rate, the processing productivity and area of processed surface. Reducing the intensity of wear on section of wiping edge contributes creation of rational angles of main and wiper edges. The wiper edge must be located in main plane, i.e. at an angle $\lambda = 0^\circ$, which is necessary to ensure the least roughness of processed surface.

It is advisable to tilt transition and main cutting edges at an angle $\lambda = 15^\circ$ (Fig. 2.5). In this case, the wear intensity at section of wiper edge is significantly reduced.

Another effective way to reduce intensity of wear is to flank pre-blunting in sections of transitive-wiper edges by sharpening the chamfer at zero relief angle, width of which ensures a reduction in temperature of flank and, as a consequence, a decrease in the wear rate. Such measures made possible to reduce the minimum wear intensity in processing of nickel alloy from $0,8 \cdot 10^{-6}$ до $0,05 \cdot 10^{-6}$, i.e., 16 times. Increasing the length of wiper edge increases the wear resistance of the tool.

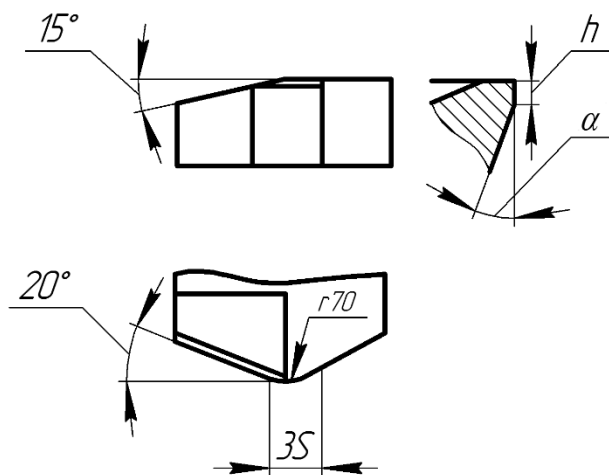


Fig. 2.5. The shape of cutting tool with a curved transitive-wiper edge, different angles of inclination of wiper and main edges and pre-dulling of flank

The flank wear bandwidth is increasing faster at section of cutting edge, more slowly at the first section of wiper edge with length equal to feed S , and even more slowly in second section of wiper edge. At the same time, even wear (without furrows) of flanks was observed on wiper section.

2.9. Assurance of tool serviceability for high-speed cutting

The cutting speed of 500...1500 m/min cause the temperature increase of flank and rake face of cutting blade, which result in softening effect on both processed and cutting tool materials. Since the temperature distribution along length of contact of chips with rake face is very uneven, softening of processed material does not occur everywhere, but only in the region of high temperatures.

One of conditions for ensuring of tool serviceability for high-speed cutting is development of new cutting tool materials with higher hardness and heat resistance (Fig. 2.6). So, for example, harder and more heat resistant cemented carbides allowed to increase the permissible cutting speeds by 3 – 5 times in comparison with less heat-resistant and less hard high-speed steels.

New cutting tool materials (cemented carbides with wear-resistant coatings, ceramics, superhard materials based on cubic boron nitride) are more heat resistant and harder than traditional cemented carbides, and could be used to machine parts at more high speed. Along with reduction of depth of cut, another condition for effectiveness of new heat-resistant, harder but less durable cutting tool materials in processing of refractory materials is work with small values of flank wear bandwidth. This is due to fact that an increase in temperature of flank with increasing cutting speed is observed only after reaching a certain width of wear band. At small values of the width of wear, the temperature not only does not increase, but, on the contrary, decreases with increasing width of the wear band, because small flank wear bandwidth is suitable for high cutting speed machining. However, if necessary, to increase the blunting criteria (the permissible flank wear bandwidth), it is necessary to reduce the cutting speed.

High-speed cutting of refractory materials (including steels) is possible only with small depths of cut and relatively small values of flank wear bandwidth. Possibly, this is associated with much smaller cutting paths than those that can be achieved with large blunting criteria.

Relatively high cutting speed for processing of hardened steel with hardness HRC = 45...62 by solid cemented carbide milling cutters with coating on basis of aluminum nitrides correspond to a very low tooth feed rate ($S_z = 0.01$ mm/tooth) and a small allowable flank wear bandwidth.

Processing with small diameter milling cutters attributed to high-speed cutting by feature that for the cutting speed of 100 – 160 m/min, high spindle rotary axis speed is required: 3000 – 5000 rpm. These speeds are not high, which even at high hardness of processed material corresponds to relatively low temperatures (about 900°C) on flank and rake faces of sharp tool. However, with an increase of flank wear bandwidth the temperature of rake face sharply increases and already with width of wear band 0,1 mm is occurring a catastrophic wear of tool.

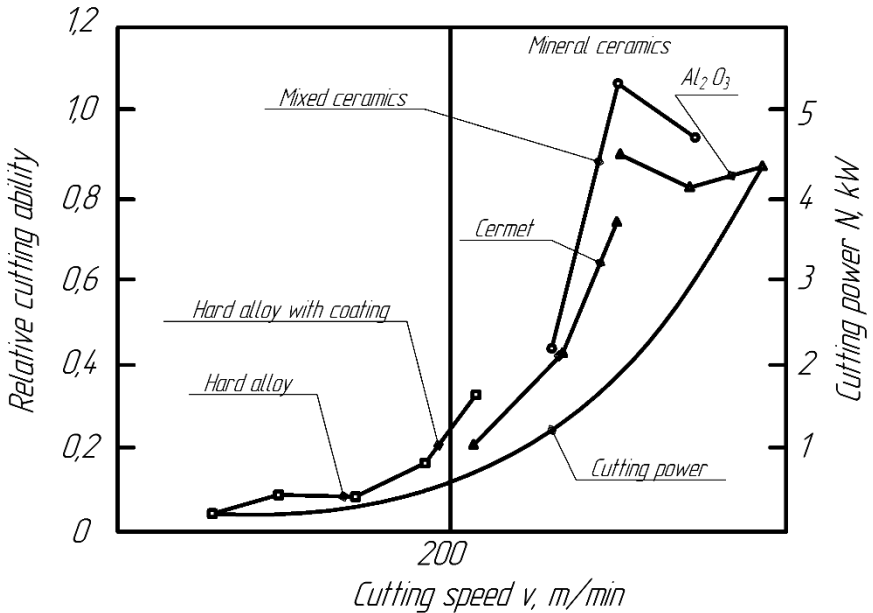


Fig. 2.6. Cutting power and relative cutting ability of cutting tool materials at different turning speed. Processing conditions: material – steel 45 (0,45 % C); feed $S = 0,1$ mm/rev; depth of cut $t = 0,5$ mm

Work is underway now to introduce high-speed and ultra-high-speed cutting and processing with minimal costs for CLM. At ultrahigh speeds, the tool wear rate decreases compared to conventional cutting.

3. ASSURANCE OF SINGLE-POINT TOOLS RELIABILITY

Despite the fact that design of single-point tool is a relatively simple, a number of serious requirements are imposed on it; those requirements must ensure high productivity and processing accuracy.

The reliability of single-point tools is ensured by the right choice of:

- cutting material;
- geometry of tool;
- shape and dimensions of inserts;
- method and design of holding of insert (for inserts with mechanically clamped inserts);
- chip breaker;
- dimensions, roughness, geometry and design of socket for holding of insert;
- strength and means for ensuring of vibration resistance of tool holder and cutting edges.

3.1. Optimal periods of single-point tool life

Changing the cutting conditions affects not only on basic time, but also on time of workstation servicing (for replacement of tool due to its blunting, for adjusting of machine tool, etc.). The cutting speed, which ensures the greatest period of cutting tool life, is minimal in range of optimal cutting speeds, and maximum productivity speed is maximum speed (Fig. 3.1). Differences in values of v and T , which optimizing cutting mode by various economic indicators, are caused the following factors:

- with increasing τ_{cm} , S_T , $1/m$ and reducing of cost of machine-minute of machine tool E , optimum speed and stability values are shifted closer to the values corresponding to $S_T = \min$;
- with increasing τ_{cm} the range of optimum cutting speeds is narrowed;
- with E increases and S_T decreases, values of highest productivity and lowest cost are approached;

– speed optimums converge with tougher technological constraints, such as accuracy of part.

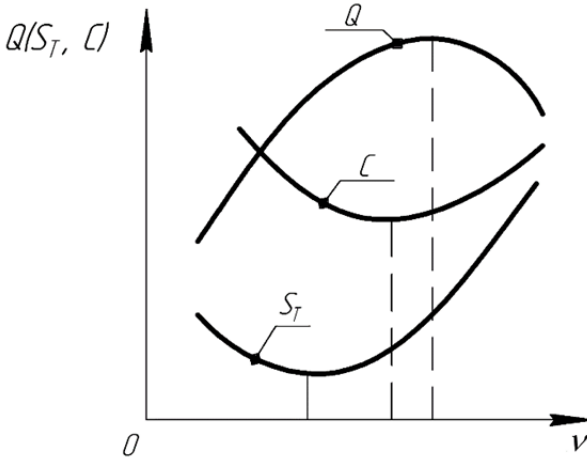


Fig. 3.1. Performance Q , cost price C and cost of operating of cutting tools S_T as a function of cutting speed

Dispersal of a number of parameters of the cutting system leads to a large discrepancy between calculated values $T = f(v)$ and actual value of tool life period and optimum cutting conditions determined by this parameter. In addition, dependence $T = f(v)$ was obtained on basis of conditions for its failure due to wear. Meanwhile, it is necessary to take into account other causes of failure, for example due to fracture.

The best use of the particular cutting tool means choosing a speed that provides a high metal removal rate, and minimum cost per piece yet suitably long tool life, especially in case of parts machining on CNC machine tools and machining centers. However, as the higher cost of equipment, then the tool life should be closer to the value which corresponds a maximum production rate.

The increase of tool life is less effective than the increase of cutting conditions and production rate of machining. Increasing tool life by 50% reduces costs by only 1%, while an increase in cutting conditions by 20% ensures a 15% reduction in costs.

3.2. Criteria of cutting tool selection

The right selection of cutting tools can indirectly affect a number of economic indicators. In particular, it is possible:

- increase of cutting conditions, which increases production rate and reduces the cost of machining;
- dry cutting, which can reduce cost of machining up to 17%;
- hard machining, which greatly simplifies the technological process of machining;
- high speed machining;
- cutting tool monitoring and automatic tool changing, which allowed to reduce the number of service personnel and work round-the-clock;
- reduction of tool change time, i.e. elimination of equipment downtime;
- increase of tool life, and therefore, reduction in number of their replacement and related equipment downtime;
- reduction of dissipation of cutting tool life periods, which effect on duration of reliable operation of equipment, frequency of tool replacement and equipment downtime;
- application of universal cutting tools, which reduces the total tool quantity and cost, and can significantly effect on tool storage drum capacity – the number of tools not used in machining of this part, but waiting for application, is reduced;
- expansion of technical limits of machining (increase of maximum cutting force, rigidity of mandrel, etc.);
- improvement of quality of machining surface, changing of conditions for chips breaking, etc.

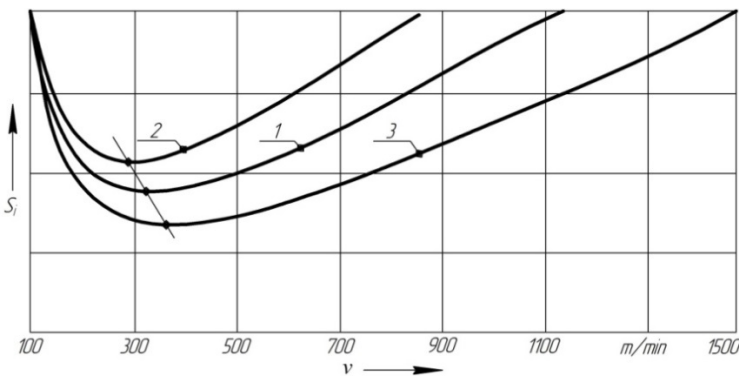


Fig. 3.2. Influence of tool life period on cost of part machining:
1 – $T = 100\%$; 2 – $T = 50\%$; 3 – $T = 500\%$

If processing is performed under constant conditions, and only tool life is changing (tool of another firm or with another geometry, etc.), then cost of machining is changing according to dependencies shown in Fig. 3.2. If machining by each tool is carried out at the optimum cutting speed, then latter is increasing with increasing of tool life (but not more than 3...4%), which reduces cost of machining by 1...2%.

The dependencies in Fig. 3.2 are typical for use of re-sharpened cutting tools and assembly tools. In the latter case, however, cost of replaced insert is more important (increase of cost by 4 times increases cost of machining by 8...9%), while cost of holders, bodies, etc., decomposed into tens and hundreds of tool life periods, does not have practical impact on cost of machining.

When analyzing the efficiency of machining, it is important to connect cost of tool with its operational capabilities. Often a more expensive tool also has higher optimum cutting speeds. If this is not taken into account, then it is possible to make an erroneous decision in choice of tool (Fig. 3.3). Thus, tool 2, with cutting speed v_1 , optimal for tool 1, turns out unsuitable, and reduction of cost of machining it provides at speed v_2 .

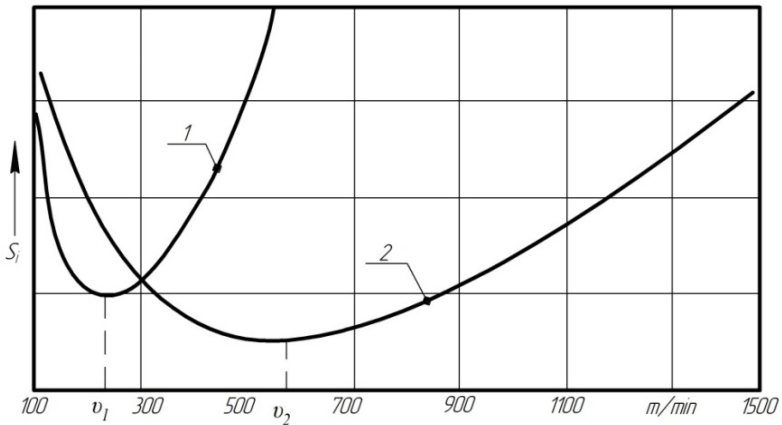


Fig. 3.3. Influence of cost and quality of tool on cost of operation

3.3. Application of replaceable polyhedral inserts

3.3.1. Wear features of replaceable polyhedral inserts

The complex wear topography of front surface is result of combined effect of cutting regime, geometric parameters of blade, direction of chip removal, shape of contact spot between chip and front surface, and physical nature of this contact. At the same time, a combination of these factors is possible, when a peculiar balance is observed between front and rear wear of surface, to which corresponding maximum use of inserts cutting properties.

To extend the tool life of inserts, it is necessary to strive to reduce the wear of front surface by:

- reduction of chip contact length;
- creation of conditions for even contact of chips with front surface of inserts;
- selection of conditions for chip removal in such a way that the axis of symmetry of formed crater is parallel to working section of insert cutting edge.

With a decrease of angle between direction of chip removal and direction of mean normal to working section of cutting edge, resistance of various shapes inserts increases (Figure 3.4). A straight section of transitional cutting blade with length 1,0 mm on cutter with $\varphi = 90^\circ$ allows to obtain same tool life as a cutter with an angle $\varphi = 60^\circ$.

The shape of insert significantly affects both the absolute tool life of cutters and the index of their relative tool life. This is due to massiveness of top of insert, which affects on conditions of heat removing from cutting zone. The smallest heat-conducting cross-section has a trihedral insert of regular shape with end relief angle, which has the largest value. Then follows a trihedral insert of irregular shape, presence of holes and chip grooves on which worsens heat removing from cutting zone. For the same reason, a square insert with a hole has a worse heat removing compared to insert of regular trihedral shape.

The shape of the inserts and side cutting edge angle of cutters have influence on tool life and cutting speed. For the areas of high cutting speeds $V \geq V_n$, tool life and cutting speed increase with decreasing of side cutting edge angle. The greatest value of tool life and, correspondingly, cutting speed is observed for cutters with a pentahedral insert ($\varphi = 45^\circ$), which can be explained by minimum values of effective thickness of cut and chip exit angle in comparison with cutters and inserts of other shapes.

Increasing the cutting properties of cutters with intermittent turning can be achieved by selecting of cutter with certain shape insert and required geometric parameters, using cutters equipped with a square shape inserts ($\varphi =$

45°) instead of cutters with hexagonal shape inserts and angle at vertex ($\varphi = 90^\circ$) leads to an increase of tool life by 2,5 times. This increase of tool life is fully consistent with a decrease of increase speed of cutting square at cutting site area, decrease of dynamical coefficient and dynamic force.

In intermittent turning, inserts from traditional tungsten-containing hard alloy T15K6 (Russian grade) have the greatest tool life. The inserts from TH20 (Russian grade) alloy under these conditions are practically inoperative. Cutters from KHT16 (Russian grade) alloy occupy an intermediate position, approaching T15K6 (Russian grade) alloy.

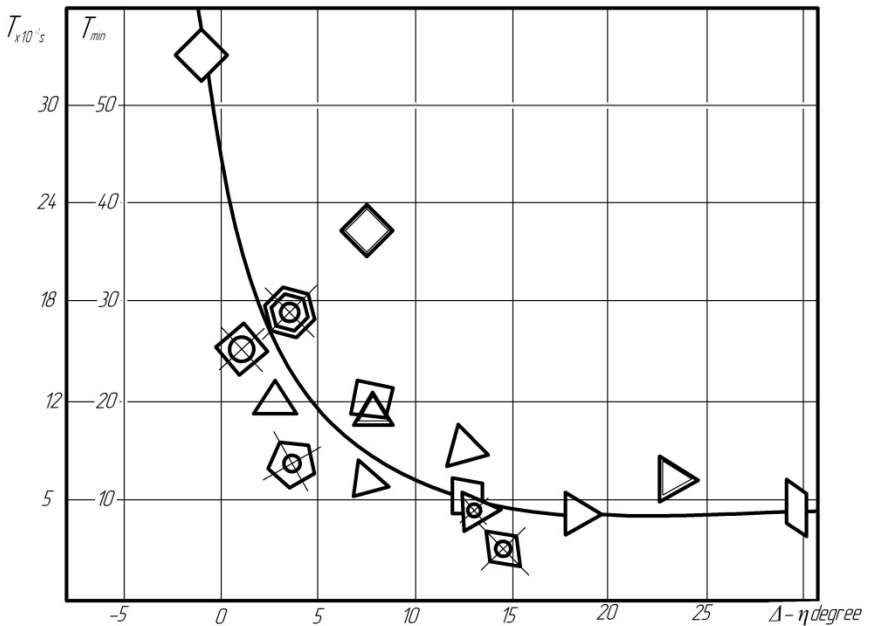


Fig. 3.4. Dependence of cutters tool life on angle of chip removal.
 CH 25 - BK6 (Russian grade). $V = 1.3$ m/s; $t = 2$ mm; $S = 0.5$ mm/rev

3.3.2. Assurance of even wear of replaceable polyhedral inserts

In non-free cutting of materials, the wear of working surfaces of cutting part of the blade tools is uneven. This is manifested in form of locally large wear areas on back surface of the blade, uneven width and depth wear crater on front surface.

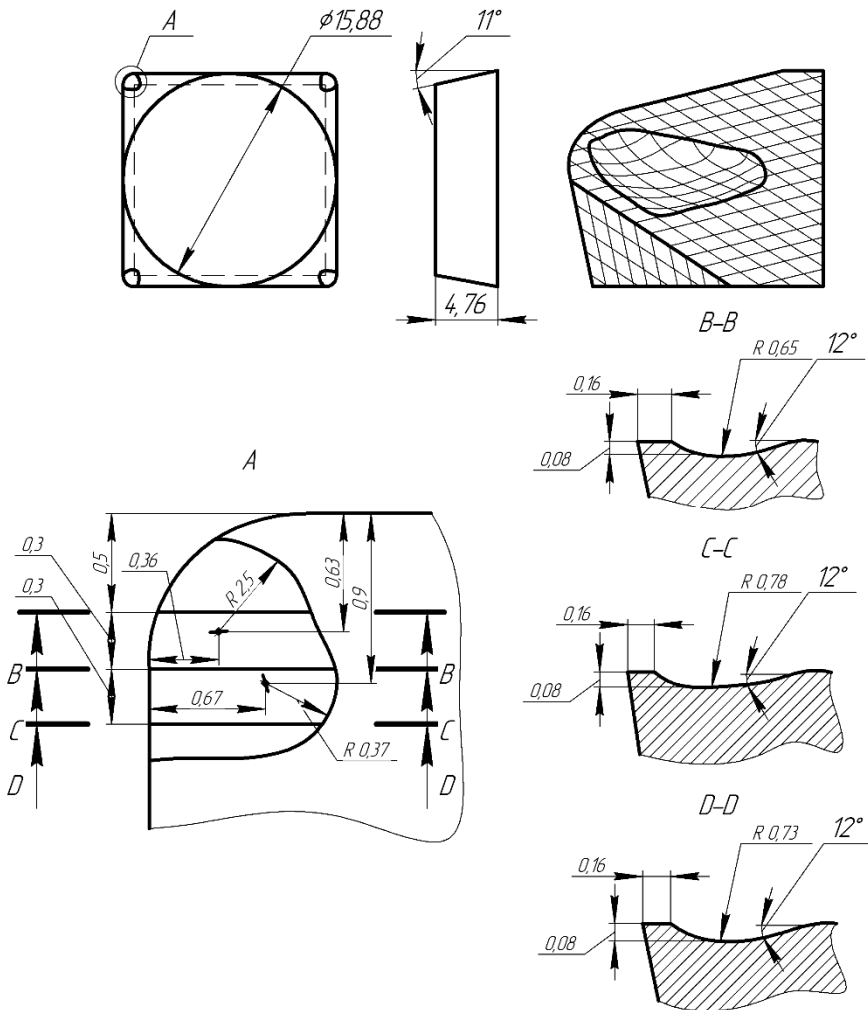


Fig. 3.5. The construction and three-dimensional model of insert top with even wear of front surface: $V = 290$ m/min, $S = 0,26$ mm/r, $t = 0.5$ mm, steel 40X - MP7 (Russian grade)

The tool, as a rule, failure because of more intensive wear on any limited area. The causes of such phenomena are primarily in the non-rational form of cutting part of the tool, which does not correspond to force and thermal contact loads acting in process of cutting. Achieving even wear of cutting part by

varying geometric parameters of blade, it is possible to significantly increase tool life or the productivity machining by cutting (Fig. 3.5).

Tool life of new plates increases by 14% – 15% compared to the standard inserts with a flat front surface.

3.3.3. Replaced cutting inserts with high thermal conductivity

To reduce the temperature deformation and wear assembly cutters, lathe changeable inserts with increased thermal conductivity have been developed (Fig. 3.6). These plates significantly reduce thermal resistance of contact between the cutting and supporting inserts, which leads to a redistribution of heat flows (Fig. 3.7, a, b). This reduces the temperature deformation and wear of cutter (Fig. 3.8).

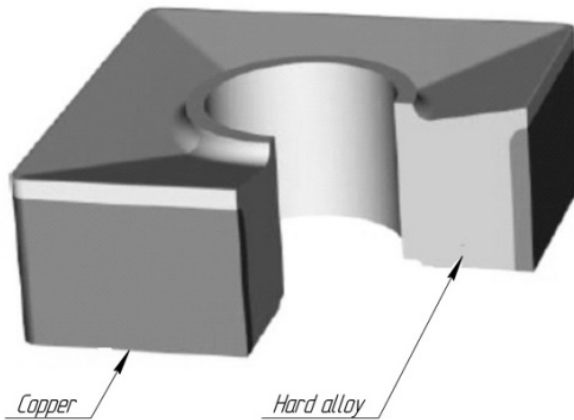


Fig. 3.6. Carbide-tipped insert with high thermal conductivity copper layer

The cutters of this design exceed the standard by tool life up to 2,5 times in finishing machining modes, and also have a higher stability of cutting properties.

The reinforcement of cutting inserts by high-conductor copper insertions is also used to improve heat removal from cutting edge and to increase tool life. Optimum results are obtained when insertion is pressed into the groove in the form of a "swallowtail".

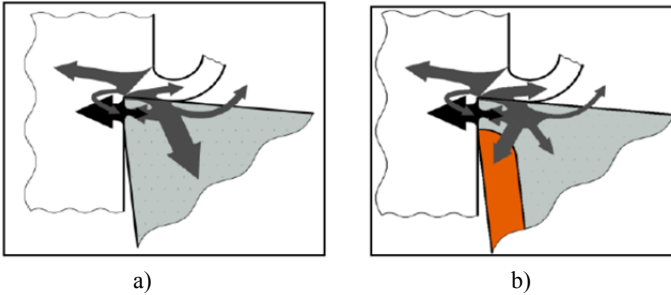


Fig. 3.7. Heat flows through contact surfaces of a standard cutter (a) and insert with increased thermal conductivity (b)

The discrete design of cutting edge of insert ensures an increase of blade machining productivity due to combination of the finishing turning with other types of turning, and an increase in tool life due to the separation of heat flows.

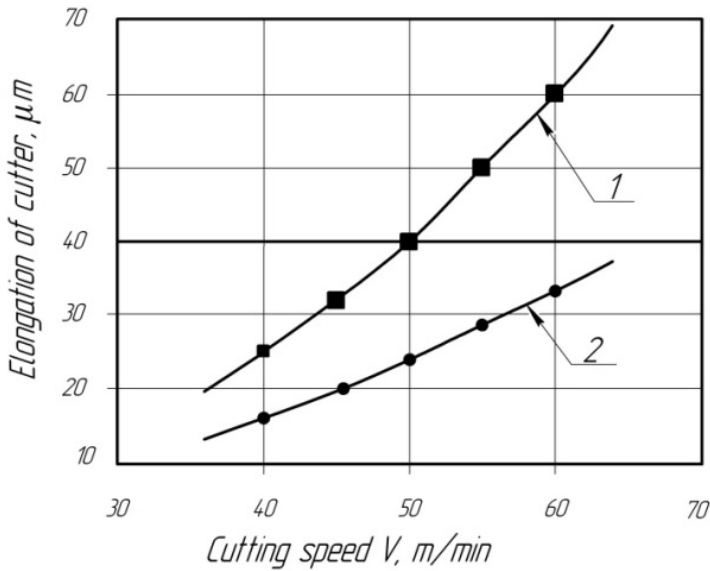


Fig. 3.8. Dependence of the tool's temperature elongation on cutting speed:
 1 – standard insert, 2 - new insert
 (T15K6 - 120Г13 (Russian grade), $S = 0,1 \text{ mm/r}$, $t = 0,5 \text{ mm}$)

Application of inserts with separation of cutting edge into areas with specified functional purpose and radius of forming section of first stage equal to 10 mm under conditions of semi-finishing (with a cutting speed of 210 m/min, feed rate 0,39 mm/rev and cutting depth equals 2 mm) of group P of materials (steels 45X1 and 30XГCA (Russian grade) achieves a roughness of Ra 1,25 and provides an increase in productivity by 2,3 times in comparing to standard inserts.

In operation of inserts with two stages and cleaning cutting edge at finishing turning (with a cutting speed of 300 m/min) of group M of materials (steels 08X18 H10T and ЭИ 654 (Russian grade), a given roughness of machined surface is achieved with a doubled feed rate and an increase in 2,5 times durability of finishing stage due to separation of heat flows in relation to inserts of standard design.

3.3.4. Temperature compatibility and stresses intensity in cutting insert

Each machined material has its own maximum machinability temperature $\Theta_{m.m.}$, at which minimum load on tool and minimal roughness of machined surface are observed. This temperature is determined by changes in the physical-mechanical characteristics of materials as a function of temperature. In turn, each tool material has its own temperature of maximal operability $\Theta_{m.o.}$, at which its ability to withstand loads increases, accordingly wear decreases and reliability increases.

In machining materials, the ideal is to match these temperatures. This can be achieved by selecting the appropriate cutting tool material and maintaining the required temperature in the cutting zone (by assigning appropriate modes).

Coefficient of temperature compatibility:

$$K_{t.c.} = \left(\frac{\Theta_{m.o.}}{\Theta_{m.m.}} \right)^n$$

where $\Theta_{m.o.}$, and $\Theta_{m.m.}$ – the temperature of maximum operability of hard alloy and workability of material; $n = 3$ for $\Theta_{m.o.} < \Theta_{m.m.}$, $n = 3$ for $\Theta_{m.m.} < \Theta_{m.o.}$.

Reliability indicators are significantly influenced by geometric characteristics and basing schemes and fastening, they should be taken into account when assessing the quality of assembly turning tools with help of tension coefficient K_t .

Factors affecting the intensity of stresses in cutting insert are:

1. Clamp in an angular groove.

2. Clamp by base surface (first two points depend on the scheme of basing and fixing of insert).

3. Cutting edge angle φ .

4. Angle at vertex ε .

5. Thickness of insert.

6. Carbide substrate and its thickness.

Tension coefficient can be represented in the following form: $K_t = k_{cg}k_{cbs}k_{\varphi}k_{\varepsilon}k_{t1}k_{cst}$, where k_{cg} – coefficient of clamp in an angular groove (depends on the scheme of basing and fastening of insert).

1. The values of coefficient of compression in the angular slot k_{cg} for various schemes of basing and fixing by an expert method are given in Table. 3.1.

2. The coefficient of clamp by base surface k_{cbs} , depends on the scheme of basing and fastening of insert).

From action on cutting insert of load forces arising during cutting, the base zone of tool body deforms. With clamping of insert by base surface, the level of stresses, and, consequently, deformations on the back edge of holder decreases.

The values of coefficient of clamp by base surface k_{cbs} , for various schemes of basing and fastening are given in Table. 3.1.

Table. 3.1.

The values of coefficient of clamp in an angular groove k_{cg} and clamp by base surface k_{cbs}

Scheme of basing and fastening of insert					
Scheme of fastening by ISO	C	P	S	M	-
k_{cg} / k_{cbs}	0,56 / 1,00	1,00 / 0,25	1,00 / 1,00	1,00 / 1,00	0,56 / 0,25

3. k_{φ} – cutting edge angle coefficient. For the most commonly used angles, the following coefficients are set:

φ	0°	45°	60°	75°	90°
k_{φ}	1	0,53	0,21	0,13	0,06

For round inserts, this angle φ equals to 0° .

4. k_ε – coefficient of angle at vertex ε . The most significant effect on the stress-strain state of insert makes the angle at vertex ε :

k_ε	0,18	0,20	0,28	0,29	0,30	0,60	0,64	0,68	1,0
ε	55°	60°	80°	85°	90°	108°	110°	120°	180°

5. The thickness of insert significantly affects on distribution of stresses on the flank surface. In thin plates, stresses that arise in base zone from contact of cutting insert with holder of cutter have a noticeable effect on distribution of stresses on flank and rake face. The thickness of insert is connected with cutting feed by relation $t = (8...12)S$. Increasing of thickness above this value does not increase its strength

With thickness of insert $t = (8...12)S$, coefficient k_{t_i} is taken to 1, and for $t < (8...12)S$ is 0,5.

6. Presence of carbide substrate and its thickness.

The failure of cutting inserts arises due to deformations of base zone of body, which loses flatness under load.

The cutting inserts from hard alloy, characterized by high hardness and brittleness, do not work well for bending and can not take form of deformed base surface of tool body.

At $l/t = 1$, deformations and stresses in holder are minimal. Therefore, in order to reduce deformation of base zone of tool body, it is necessary to place base insert with thickness $t_1 = (0,8...1,1)t$ from hard alloy or hardened steels under replaceable insert.

When thickness of base insert $t_1 = (0,8...1,1)t$, coefficient is assumed to 1, at $t_1 < (0,8...1,1)t$ or in case when substrate is absent is assumed to 0,5.

3.3.5. Assurance of strength of replaceable inserts

Among failures of tools with replaceable inserts from cemented carbides for insert destruction account for 70 – 75%. Typical types of destruction are roughening, shear fracturing, failure.

Inserts from cemented carbides have different design parameters, basing schemes and fastening in body of tool and get a complex stress-strain state (SSS), determined not only by external force and temperature loading, but also by internal temperature micro-residual stresses.

Design parameters, scheme of basing and fastening have big influence on stress-strain state of inserts. Scheme of basing of inserts by base and two lateral surfaces when fastened by lever-type mechanism provides the minimum values

of dangerous tensile stresses σ_1 , which differ from other schemes by 2 or more times.

With an increase angle ε at the top of insert, the tensile stress σ_1 on the main and compression σ_2 on the auxiliary cutting edges decrease. The maximum tensile stress σ_{1max} on main cutting edge of inserts differs by 5 or more times depending on shape in compare to standard polyhedral. Standard inserts can be arranged in series by strength in direction of its increasing in following sequence: 3 – edge, rhombic, 4 – edge, 5 – edge, round. Inserts of new shapes set a special place ($\varepsilon = 90^\circ$, $\varepsilon = 120^\circ$).

To reduce dangerous stresses of stretching, use inserts shapes of which differ from standard by enlargements of angle at vertex ε by performing lateral edges along the cylindrical and conical surfaces for entire length and half length of side of base polyhedron.

The designs of high-strength inserts with curved-linear cutting edges for entire length (Fig. 3.9, *a*) and half-length of insert (Fig. 3.9, *b*) have been developed.

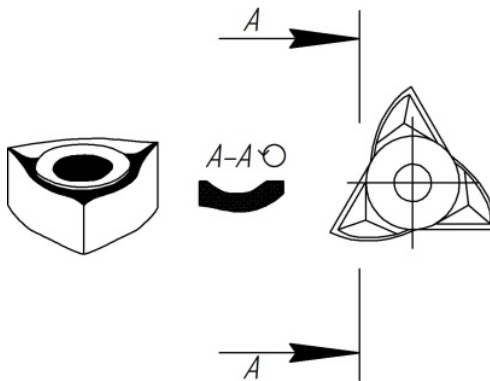
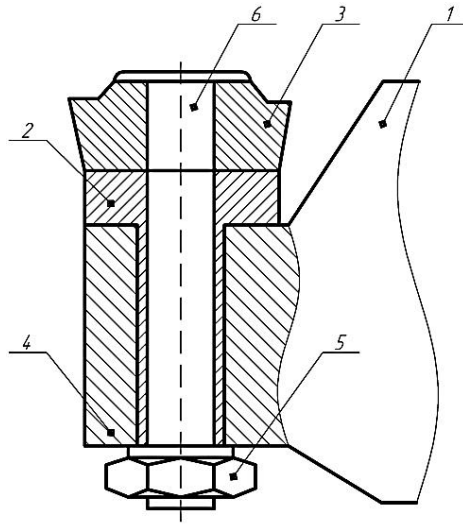


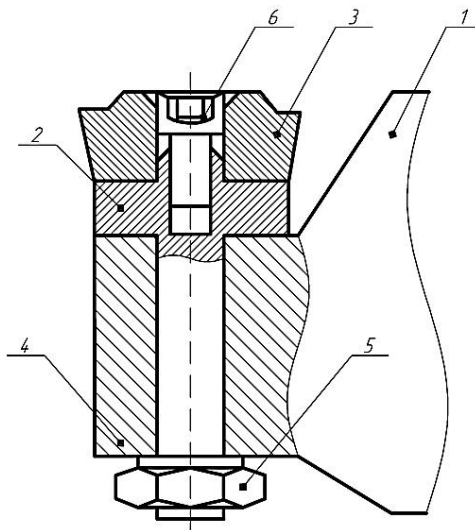
Fig. 3.9. Replaceable inserts of increased strength

The cutters showed a decrease in failure rate due to breakage by 3 – 4 times and an increase in performance by 20 – 25%. The number of machined parts by one cutting edge, before turning of insert, increases about 3 times (draft turning, T15K6, 40X (Russian grade).

For turning of profile of wheel rim surface on wheel-turning machine tools for roughing and finishing use cup cutters with brazed) or mechanically clamped inserts of various diameters from hard alloy grade T14K8 or T5K10 (Russian grade).



a)



b)

Fig. 3.10. Basic (a) and improved (b) construction of assembly cup cutter

The improved design of assembly cup cutter (Fig. 3.10, *b*) consists of holder 1, mandrel 2, cutting insert 3, an elastic split sleeve 4, bolt 5, nut 6. The end surface of cylindrical protrusion of mandrel is conical and contacts with conical part of thrust split sleeve, the opposite side of which contacts the end part of bolt head. The mandrel is pressed to holder by nut 6. Using an elastic split sleeve allowed to increase rigidity of fastening of insert in radial direction, as well as strength of cutting insert by reducing stresses on cutting edge by 2 times. The machining efficiency of wheel pair has increased due to reduction in number of breakages of cutting insert.

3.4. Modification of contact areas of cutters

Diffusion coating (titanonborating, chromotitanization, chromoniborating and one-component chromium plating) to depth of 3 – 10 μm increases the hardness of carbide inserts with simultaneous increase of microhardness of surface (from 1530 to 2190 HV units). A significant increase in wear resistance gives the carbide tool layers of titanium carbide. A slightly smaller increase in resistance is provided by layers of vanadium carbide and tantalum carbide. Then follow NbC, Cr₂₃C₆, ZrC, MoC and WC.

Increasing the tool life of blade tool from high-speed steel P6M5 (Russian grade) is achieved by creating a surface boride coating by combining tempering with low-temperature borating after quenching. For example, at speed 25 m/min, tool life of cutters with coating is 60 – 65 min, and without coating is 14...16 min. Share fraction of surface layer was not observed. Cases of share fraction of hardened layers surface and brittle breakage of cutting edge were not observed and when cutting accompanied by intense vibration.

Thin-bladed cutters from nitro-cemented steel 4X5MΦC (Russian grade) have wear resistance and performance properties no worse than identical ones from high-speed steels and cemented carbides in machining of ceramic and composite materials.

Laser surface alloying (LSA) provides an increase in hardness of low-alloy steels up to 18000-19000 MPa. Laser surface alloying reduces impact strength, but when hardened tool is heated due to friction during cutting, this decrease in impact strength is leveled. The heat resistance of tool, hardened by laser surface alloying, exceeds heat resistance of more expensive steel P6M5 (Russian grade) by 200-300°C. At cutting speeds up to 30 m/min for cutters made of high-speed steels P6M5 type (Russian grade), it is possible to use economically alloyed steels of type XБГ (Russian grade) and even Y10 (Russian grade) after surface hardening by laser surface alloying.

Finishing of working surfaces by diamond burnishing (DB) leads to an increase of resistance of round cutters by 2,5 times. Diamond burnishing was used for round cutters with diameter of 50 mm from high-speed steels P18, P9M5 (Russian grade) (HRC 64 ... 66) with a wear resistant TiN coating with an initial roughness of $0,38 \mu\text{m}$ by Ra scale. The dependence of wear W from passed distance by tool L is shown in Fig. 3.11.

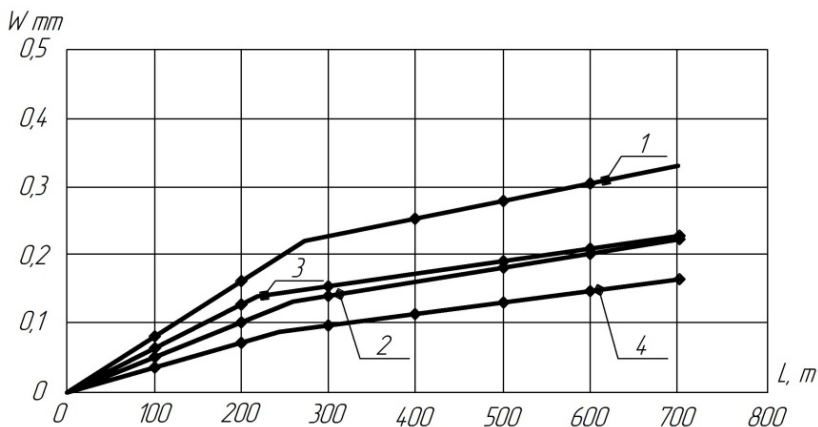


Fig. 3.11. Wear of flank surface of cutter W depending on cutting path L :

- 1 – grounded round cutters from high-speed steel P18 (Russian grade);
- 2 – round cutters, hardened by diamond burnishing after grinding;
- 3 – round cutters covered with wear-resistant nitride coating;
- 4 – round cutters coated with wear-resistant TiN coating and treated with diamond burnishing

Nanorestructuring of carbide particles in surface layer of a metal-ceramic alloy when irradiated in a xenon-containing or (xenon-nitrogen) plasma of gas discharge minimizes coefficient of friction and increases hardness of cemented carbide in cutting of metal up to 20 times or more.

Hardening of working surfaces of the cutters from steel P6M5 (Russian grade) by electro-acoustic spraying-alloying with cemented carbides BK8, T5K10 (Russian grade) and W raises the level of optimal cutting speeds by 1,15 ... 1,5 times. Wear intensity of a hardened tool is reduced from 1,1 to 1,8 times, length of cutting path is increased by more than 2 times. In order to obtain more wear-resistant surface layers, electro-impulse alloying is more expediently made in an oxidizing medium with an energy in impulse $E = 0.25 \text{ J}$.

3.5. Coatings on contact areas of cutters

The wear resistance of coatings depends largely on cutting modes. At moderate cutting speeds (250 m/min), wear resistance of cutters with tetrahedral quick-change inserts based on TT8K6 (Russian grade) with usual coatings (TiAlN) is higher than filter coating, due to a favorable combination of hardness and adhesion with substrate (Fig. 3.12). But wear resistance of such coating is significantly reduced at cutting speeds above 350 m/min. Oxidation wear of tool predominates during high-speed machining. Filtered coatings with high resistance to oxidation have a higher wear resistance at high cutting speeds in the range of 450 m/min.

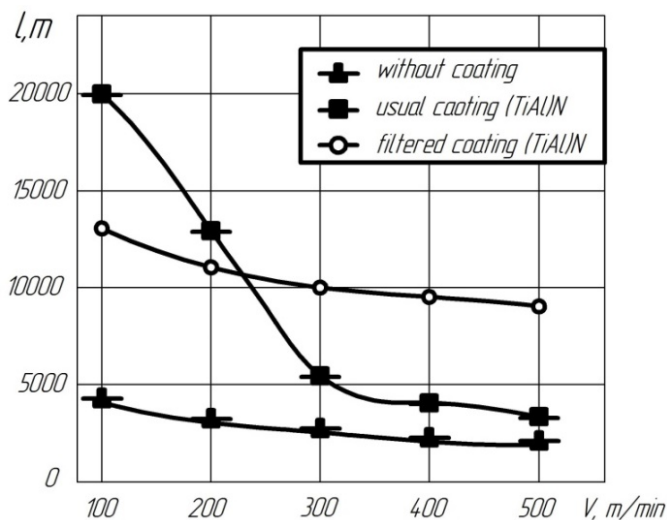


Fig. 3.12. Influence of cutting speed on cutting path (at $h_s = 0.3$ mm) in turning of steel 40X (Russian grad) by cutters from TT8K6 (Russian grade) with different coatings ($S = 0,11$ mm/rev; $t = 0,5$ mm)

Two-layer coatings with top layer from TiZrN and TiCN and a lower layer of TiN (TiN-TiZrN and TiN-TiCN) allow to increase the period of tool life in comparison with TiN coating in 1,7 – 4,4 times (depending on design of coating and cutting mode). Tool life of turning cutters with carbide non-sharpened inserts is up to 2,8 – 3,7 times higher than uncoated cutting tool and up to 1,5 – 2,0 times in compare to TiN, depending on coating composition, turning material and the cutting mode.

Application of vacuum-arc protective coating based on NbN on cutting tools equipped with super hard tool materials based on cubic boron nitride allows to reduce wear rate:

- for finishing of hardened steels (55 – 62 HRC) up to 25 – 30%;
- for machining of hard faced nickel alloy 08X18H9Г7T (Russian grade) up to 20%;
- for machining of magnesium-doped cast iron CЧ 35 (Russian grade) up to 10%;
- for machining of hard alloys of BK group (Co > 15%) up to 25 – 35%.

3.6. Combined methods of hardening of cutters

Carbonitration increases wear resistance and heat resistance of steel, and also increases its thermal conductivity. Laser processing by optimal mode increases wear resistance and reduces the thermal conductivity of steel P6M5. Carbonitration and laser processing, as well as their combination with TiN vacuum-plasma coating, significantly change the seizure of cutters rake face surface from steel P6M5 (Russian grade) with processed material, which can be used in practice for purposeful correction of this important property of the tool.

After burnishing by diamond tools, high-speed steels, which hardened to high hardness, with TiN coating, are well suited for surface plastic deformation, porosity of coating and surface roughness are decreasing, surface layer is hardening, compressive residual stresses is arising.

In Figure 3.11 shown results of tests for resistance of round cutters from high-speed steel after grinding $R_a = 0.16 \mu\text{m}$, after diamond burnishing $R_a = 0,08 \mu\text{m}$, with TiN coating ($R_a = 0,38 \mu\text{m}$), and with TiN coating, hardened by diamond burnishing at optimal modes ($R_a = 0,1 \mu\text{m}$). Sharpening of cutters was made after treatment of flank surface. Machining of steel 45 (Russian grade) was carried out in following modes: cutting speed 40 m/min, feed 0,025 mm/rev.

In the run-in stage, cutters treated by diamond burnishing have a lower wear value. Reducing amount of wear on run-in stage is achieved due to higher degree of finishing, hardening and reducing porosity of coating after diamond burnishing. Diamond burnishing allows to reduce the wear rate of run-in and thereby increase the resistance of round cutters with TiN coating up to 2 – 2,5 times.

3.7. Increasing of reliability of cutting and grooving cutters

Consumption of cutting-off bit and grooving tools exceeds consumption of straight turning and boring tools more than on 50%, which is caused by insufficient strength and rigidity of them. Their wear occurs with different degree of intensity on four surfaces: flank, rake face and two lateral auxiliary flank surfaces. With increasing depth of cutting groove the cutting force increases due to:

- change of cutting speed;
- difficulties in chip breaking;
- frictional forces arising between walls of cutting groove and chips;
- resistance to chip breaking from cut slot.

The loss of operability of cutting-off bit and grooving cutters is caused by: brittle roughening of cutting edge due to unfavorable working conditions and insufficient strength; improper sharpening and fastening of tool, leading to abduction and bending of cutter's head of; change of kinematic rear angle to zero values at cutting, as a result of which increases probability of cutter's chipping at approaching to axis of part rotation. The main cause is fragile microchipping and shear fracture of cutting part (more than half of failures of cutting and grooving cutters).

The average value of breaking force for cutters with shape of sharpening of front surface by criterion of equal strength (Fig. 3.13) is 14% higher than for tools with a flat front surface.

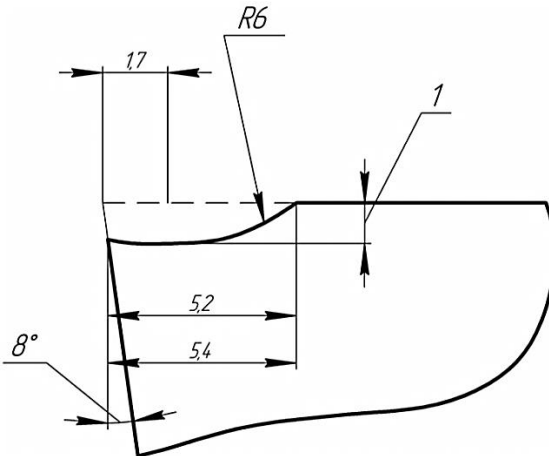


Fig. 3.13. The form of sharpening of cutting part of cutting-off bit and grooving cutters

This form of sharpening of cutting and grooving cutters does not affect on wear and does not lead to decrease in strength, dependence of cutting force components on depth of groove, cutting speed and feed rates are similar to those obtained with a flat rake surface, and also, it allows to reduce cutting force by an average of 30%.

Solid carbide groove cutters are broken due to insufficient strength of the cutting part. Its stressed state is characterized by significant tensile stresses, values of which in certain points approach to hardness limit of cemented carbides. The change of geometrical parameters of the cutting part of tools, in particular, an increase in of back rake angle up to $\gamma = 10^\circ$ and height up to 3,2 mm (Fig. 3.14), significantly increases their strength.

Maintaining of constant cutting speed also reduces the likelihood of brittle fracture of cutting part during cutting, cutting and end turning on CNC machine tools.

The turning of grooves with a width of 0,5 mm compared to free cutting is accompanied by an increase in chip shrinkage and cutting temperature, so wear flank surface of groove cutters is 2 times. The diameter of turn of chips increases in 2 – 6 times due to braking effect exerted by side walls of grooves.

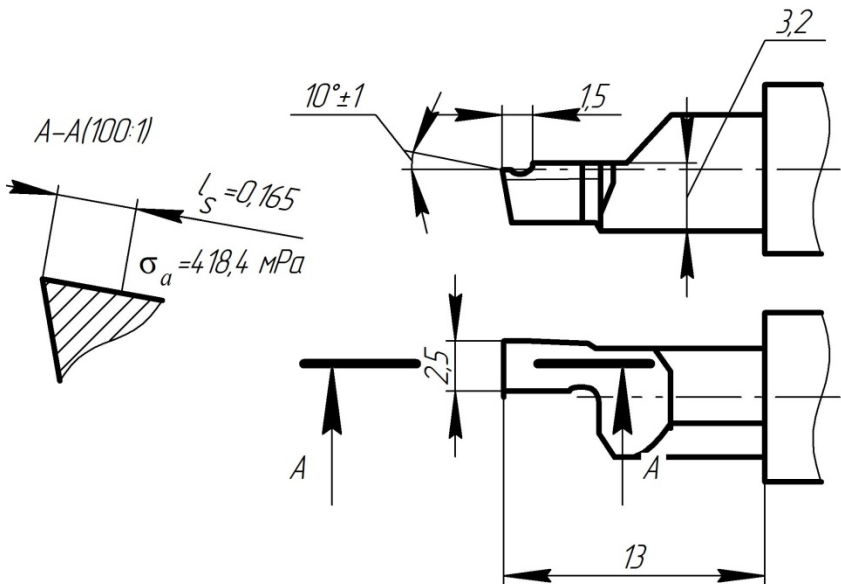


Fig. 3.14. Loading scheme of a carbide-tipped cutter, with a modified geometry of the cutting part

The use of assembly groove cutters with hard-alloy inserts with wear-resistant coatings and optimal cutting modes increases productivity of turning of grooves of turbine disks in 3,3 times in comparison with brazed cutters.

Rational designs of multilayer coatings (MC), which allow minimize wear of turning cutters are: total thickness of multilayer coatings is 6 – 7 microns; thickness of top layer is 40 – 60% from total thickness of coating. The use of two-layer and three-layer coatings increases tool life of cutters in 1,8 to 2,6 times in processing of workpieces from steel 30XГCA (Russian grade) and 1,7 – 2.2 times from steel 12X18H10T (Russian gade) in comparison with TiN coating (Fig. 3.15).

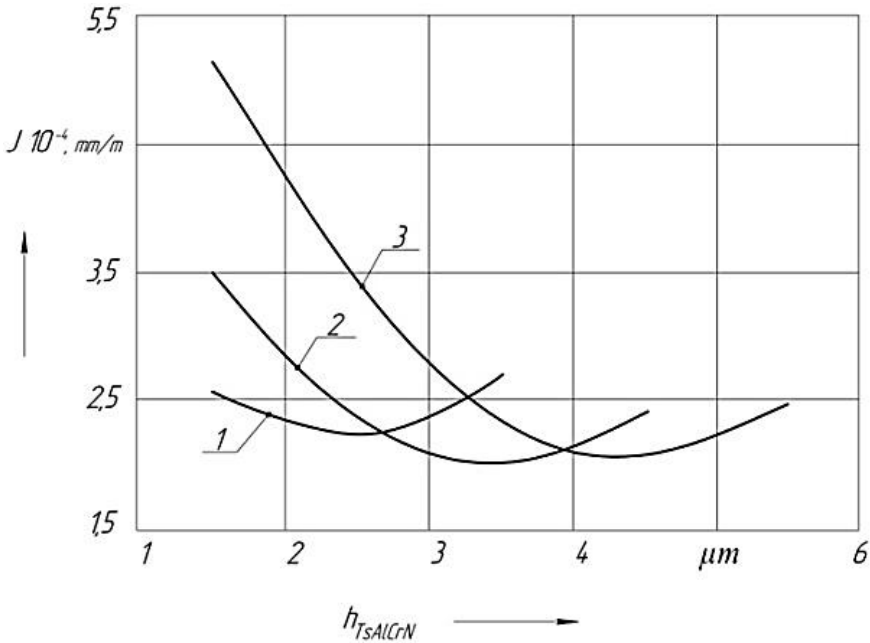


Fig. 3.15. Influence of thickness of top layer $h_{TiAlCrN}$ on wear of cutting tool with $TiAlN-TiAlCrN$ coating: total thickness of multilayer coating: 1 – 5 μm ; 2 – 6 μm ; 3 – 7 μm ; part material - 30XГCA (Russian grade); tool material - H13A; $V = 88 \text{ m/min}$; $S = 0.2 \text{ m/min}$; $t = 4 \text{ mm}$

A set of designs was developed: a cutting insert – holder – machine tool, in which cutting fluid is fed through a channel in cutting insert; while the cutting fluid gets directly to rake face surface of tool near cutting edge and directed to lower surface of chips, which contributes to significant improvement of heat removal, decrease of wear of insert working surfaces and favorably affects on shape of chips.

4. ASSURANCE OF RELIABILITY OF HOLE MAKING TOOLS

4.1. Influence of geometry and design features of hole making tools

4.1.1. Geometry and design features of drills

Tool life of drills is influenced by a large number of factors, the main of which are:

- accuracy of cutting elements of drills;
- cutting part geometry: double angle at vertex 2φ , angle of inclination of helical chips groove ω , end relief angle α ;
- method of sharpening;
- rigidity of the drills and technological system, and amount of drill overhand;

– applicable cutting modes and operating conditions.

The accuracy of hole drilling is affected by:

- cutting tool geometry;
- the inaccuracy of installation and reinstallation phase, which causes the deflection of the axis of drilled hole from given position relative to accepted base;
- plastic deformation of workpiece surface layer during chips formation, which contributes to roughness appearance;
- the direction and size of chip grooves on which surface roughness of resulting hole depends;
- ingress of chips in cutting zone;
- beating of hole, which causes non-straightness of the axis;
- machine – tool accuracy;
- frequency of tool oscillations, which contributes to appearance of faceting.

The main directions in development of modern designs of high-speed twist drills are:

1. Increasing of drill dynamic characteristics – strength, stiffness and vibration resistance – by establishing a core rational thickness, increasing of clearance diameter of drill, reducing length of spiral and drill overhand, applying various methods of drill sharpening and core resharping, application of heat treatment, providing a maximum strength and rigidity, increasing rigidity of drill fastening by applying tapered studs for cylindrical drills, finding new designs, and so on.

2. Improving the accuracy of geometric parameters of drill cutting part – an approximation to ideal drill, which has zero beating of margins along entire length of spiral and complete symmetry of blades.

3. Research and application of modern cutting tool materials that provide high redability at high strength and sufficient elasticity, for example, by replacing high-speed steel P6M5(Russian grade) in severe drilling conditions on high-performance steels.

4. Improvement of structure and heat treatment of steels by use of high-speed steels with minimal carbide heterogeneity, ensuring receipt of guaranteed heat treatment according to a single technology for this steel grade.

Standard spiral drills are increasingly replaced with special drills, which correspond to specific conditions of parts drilling and, first of all, taking into account the machinability of various materials. Special drills are distinguished by shape of cross section profile, forms of sharpening and sharpening of drills tops.

The shape of the cross-section profile of drill influences chips removal conditions, rigidity and strength of tool. When choosing the cross-section profile of the drill, the following dilemma must be solved: cross-sectional square should provide sufficient strength and stiffness of tool when it is loaded by cutting forces; on the other hand, the sectional square of groove must be sufficient to effectively remove chips.

The system of cross section profile shapes of working part of twist drills consists of three groups:

I – standard profile shapes. Their area is about 35 ... 45% from cross-sectional square of circle with same diameter D . The main cross-sectional square of drill is in peripheral part. The change of core thickness of drill makes possible to increase drill mechanical strength and improves chips removal conditions.

II – construction modifications of profile forms of group I. The core thickness of these drills is constant over entire length of their work part. Such drills are used for heavy drilling modes with high speeds. Strength and stiffness indices of helical drills of group II profiles do not decrease, as they are compensated by increasing of core thickness above $0,15D$.

III – profile shapes of drills cross-section is similar to parallelogram and has an equal strength. Here, the core thickness of drill increases up to

(0.3 ... 0.4) D , which increases drills strength and allows use the heaviest drilling modes.

These drills are designed for drilling of deep holes (in combination with supply of cutting fluid to the top of the drill through internal channels), as well as for drilling with high cutting speeds.

4.1.1.1. Drills with improved operational properties

Screw drills (Fig. 4.1) are designed for drilling of deep holes in cast iron and steel parts without periodic tool outputs for chip removal. Their design features:

- 1) increased inclination angle of helical groove $\omega = 45 \dots 60^\circ$ (standard – 33°);
- 2) triangular shape of grooves;
- 3) core thickness is 2 ... 3 times higher than standard drills, about $(0,3 \dots 0,35)d$, and constant along entire length of drill;
- 4) front and back surfaces are flat;
- 5) cutting part angles do not depend on inclination angle of helical line ω , since they are obtained by special sharpening of front surface. This makes it possible to obtain the necessary cutting angles from the viewpoint of stability, and provides necessary direction of chip removal, as well as its braking;
- 6) margin width f is 0.5 ... 0.8 of standard drills size (for standard drills with diameter of 1 ... 50 mm $f = 0,2 \dots 2$ mm);
- 7) conditional presence of two parts: cutting and transporting.

Tool life of high helix drills for steel parts drilling is 1,5 times higher than standard one, that allows to use such drills on machine tools and automatic lines.

The design of drill of Kuibyshev Polytechnic Institute has the following design features:

- 1) as well as a high helix drill, has two parts: cutting and transporting;
- 2) increased value angle ω equals to 45° ;
- 3) front angles do not depend on angle ω , but are provided with a special sharpening;
- 4) increased stiffness and strength due to core strengthening, diameter of which $K = (0,3 \dots 0,35)d$ – for carbon and alloyed steels, as well as for non-ferrous metals, and $K = (0,4 \dots 0,5)d$ – for hard – to – process steels and alloys;
- 5) trough shape of chip groove in cross section normal to helical groove ensures chips transportation, braking arc-shaped rim of radius R on front surface.

These drills are used for drilling of various steels, cast iron, bronze and other materials under conditions of serial and mass production at drilling depths

(4 ... 5) d . Their durability is up to 2,2 times higher than standard ones, and allowable breaking feedings are 1,2 ... 1,5 times higher than for standard drills.

Disadvantages of drill design:

1) increased of 1,5 ... 2,5 times difficulty of sharpening in comparison with standard drills due to complication of sharpening technology of front surface and increasing resharpening layer;

2) need to drill out from hole, because when drilling to depth (7 .. 10) d , chips pressing and delay at the grooves of drill.

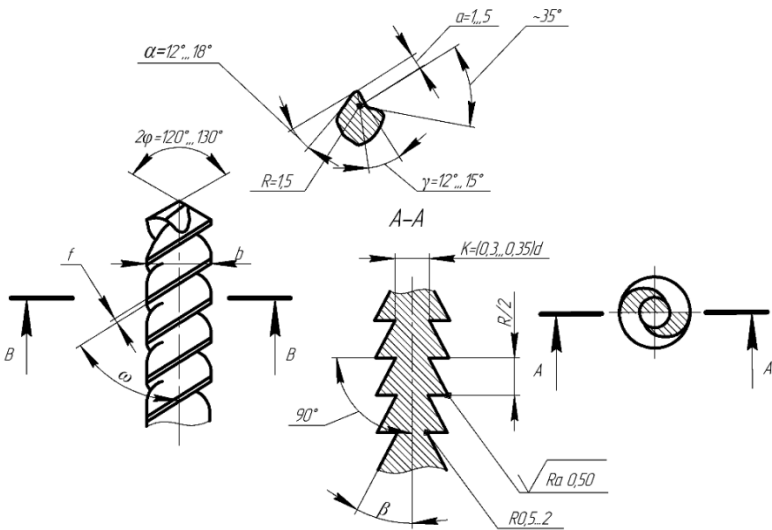


Fig. 4.1. High helix drill for cast iron drilling

Drills with an increased diameter of clearance diameter characterized by the values $q = d - (0,4 ... 0,6)$ and $K = (0,18 ... 0,23)d$. Strength increases by an average of 10% for milled drills with ground grooves and 19 ... 40% for drills with rolled grooves.

The relationship between strength and durability of these drills is expressed as:

$$\Delta T = \Delta M_{cr}^{\geq 3},$$

where ΔT – increase of tool life of drill; ΔM_{cr} - increase strength of drill on twisting.

For drills with grounded clearance diameter and grooves, in comparison with the same milled, strength is expected to increase by about 1,3 times, and an increase of their rated tool life is more than 2 times that of milled ones.

Twist drills with form-relieved margins. Maximum wear of drills is observed at periphery of main blades (in corners). On guide cylindrical margins, especially when drilling viscous steels, clumps are often formed, contributing to the occurrence of vibrations and a decrease of tool life of drill.

The cylindrical shape of guide ribbons ensures direction of tool in hole, in addition, at corners, the guide ribbons act as auxiliary blades. The cylindrical shape of auxiliary blades causes their completely unsatisfactory geometry ($\alpha_1 = 0$ and φ_1 close to 0), as a result high wear of peripheral corners is observed.

The special forms of sharpening the guide margins of drills (Fig. 4.2) improve geometry of auxiliary cutting edges, which significantly improves tool life and reduces sticking.

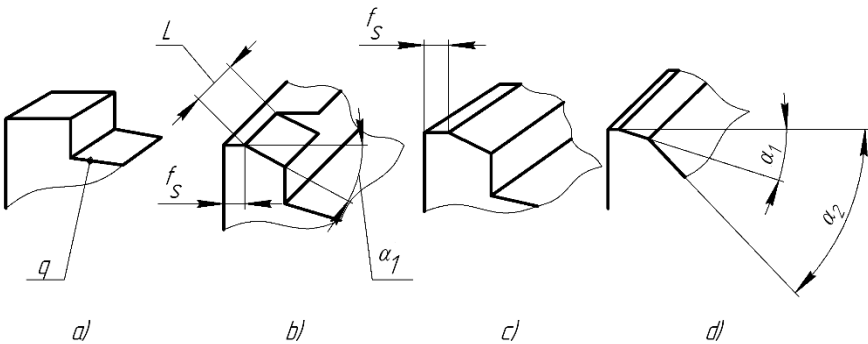


Fig. 4.2. Forms of sharpening of margins of drills:

- a* – standard margin; *b* – margin sharpened by length L with chamfering f_s at an angle $\alpha = 6 \dots 8^\circ$, $l = 2 \dots 5$ mm; *c* – margin is sharpened along its entire length, with chamfer $f_s = 0,2 \dots 0,4$; *d* – margin and the clearance diameter formed by two angles $\alpha_1 = 5 \dots 6^\circ$ and $\alpha_2 = 10 \dots 11^\circ$

The backing-off eliminates sticking on guide margins of drills and improves geometry of auxiliary cutting edges (Fig. 4.3). In this case, margins are sharpened at an angle of $\alpha_1 = 5 \dots 6^\circ$ along their entire length, besides the margins being formed either by plane (Fig. 4.3, *a*), or passes into the arc back (Fig. 4.3, *b*).

When drilling steel, cast iron and aluminum, drills with form relieved margins are 1,5 – 3 times durable than standard drills. Drill out, as well as distortion of dimensions and geometry of holes (breakdown, ellipse and tapering)

are almost same in case of drilling with usual drills and drills with form relieved margins.

The exception is aluminum, where breaking of holes drilled with form relieved margins drills is higher. Some increase in labor intensity of grinding operation of guide margins is compensated by an increase in tool life of drills and a decrease of their consumption.

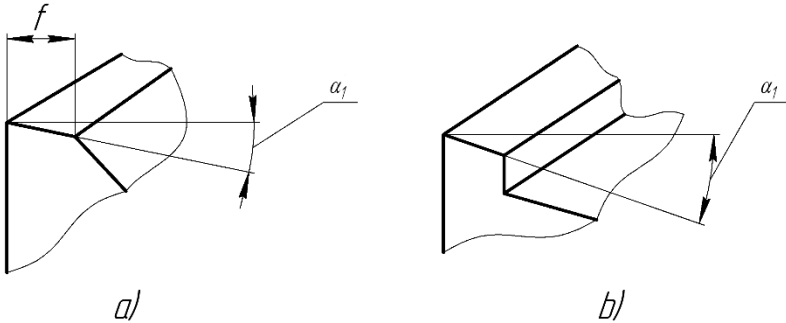


Fig. 4.3. Geometry of formed relief margins of drill

High rigidity is distinguished **drills with mechanical fastening of non-resharpening polyhedral inserts** of cemented carbides. In drilling of steels they allow cutting speeds up to 150 m/min and feed rate up to 3 times higher in compare with conventional tools.

Application of **diamond drills** provides an increase of machining productivity by 30%, an increase of drilling holes accuracy by 60%, a decrease of amount of chips at hole outlet – up to 0,05 ... 0,1 mm. Drilling accuracy is achieved by precision adjustment of diameter due to elastic deformation of body and mechanical adjustment of size of diamond cutting part of tool. Drilling of holes in details of nonmetallic fragile materials – glass, ceramics, ferrites, granite, marble, concrete and others – is provided, and drilling holes in details of nonmetallic brittle materials with diameter accuracy up to 0,015 mm is also provided.

For drilling of sheet materials, as well as soft materials and plastics, it is recommended to use **straight flute drills**. There is no effect of "screwing" of part on drill, leading to distortion of hole profile and deformation of sheet material. Such drills with carbide-tipped inserts and internal supply of cutting fluid are used for drilling of hard materials, when cutting of which discontinuous chip is formed.

Special twist drills can have three or four chip grooves. They are usually used for hole reaming and provide higher productivity, accuracy and quality of the surface layer than conventional twist drills.

4.1.1.2. Sharpening of twist drills

Flat sharpening in comparison with other methods has a number of advantages: 1) simplicity; 2) special sharpening machine tools and devices are not required; 3) sufficient accuracy; 4) durability of flat – sharpened drills when drilling carbon steels is the same or up to 1,4 – 5 times higher than for drills sharpened on a conical surface; when drilling high-temperature steel 1X18H9T (Russian grade) with drill $\varnothing 5.5$ mm, the resistance with flat sharpening is 16 ... 37% higher.

Single – plane sharpening is the simplest in technological plane, but requires large end relief angles, gives a straight – line chisel edge, which does not ensure correct centering of drill in operating without a conductor. The values of end relief angle and angle of inclination of chisel edge depend on point angle and end relief angle at periphery. Used for small drills with a diameter of up to 3 mm.

Two – plane sharpening eliminates the possibility of mashing of part surface. Widespread for carbide drills sharpening.

The helical shape allows to achieve more rational distribution of end relief angle values and more convex chisel edge of drill, which improves self-centering of drill. The disadvantages are: reduction of back rake angle to center of drill; unfavorable geometry on chisel edge; absence of end relief angle on auxiliary cutting edge; large heat dissipation and bad heat sink in peripheral areas of cutting edge, their increased wear.

Methods of twist drills sharpening:

a) *Double sharpening of cutting edge* reduces wear of the most stressed part of cutting edge by reducing thickness of cut layer on the periphery and improving heat sink.

b) *Sharpening of chisel edge* reduces its length, facilitates cutting, increases drill durability. It is recommended for machining of small and medium hardness steels, especially for large drills.

c) *Sharpening of cylindrical margins* – end relief angle is created ($\alpha_B = 6...8^\circ$) on minor cutting edge with small length 1,5 ... 5 mm. It leads to an increase in resistance up to 2 ... 3 times.

d) *Formation of chip-splitting grooves on front surface of drill* does not require their recovery after sharpening.

e) *Formation of chip-splitting grooves on the rear surface of drill* is easier in manufacturing, but grooves after resharpening have to be restored. The presence of chip – splitting grooves gives an increase in durability up to 2 times due to improved chip removal. Recommended for deep drilling.

Front surface is sharpened at drills with small angles ω at center of the drill in order to increase back rake angle. In the case of drills with large angles ω , front surface is sharpened on periphery in order to reduce back rake angle and increase strength of cutting blade.

Precise centering of drills during incision is provided by forming a transverse cutting edge convex along drill axis with decreasing values of negative back rake angles. The "centering" methods of drill flank surfaces sharpening include: screw, conical, combined, and by two planes. For drilling of holes with the accuracy of axis in the range up to 0,05 mm, it is advisable to use drills with "centering" flank surfaces and preliminary centering of holes. To ensure accuracy of hole drilling within 0,05 ... 0,12 mm, drills should not have a radial beating more than 0,05 mm and a chisel edge displacement more than 0,04 mm.

The cylindrical shanks of drills must not have a reverse taper, since its presence leads to an increase of 30 – 50% of the values dispersion of initial displacement of holes axis.

Small-sized drills differ from conventional drills by presence of four-direction guide margins and thickened core up to 1,5 – 2 times. The high rigidity of drill and its good direction greatly reduce deviation from the straightness of the hole axis. The axial beating of cutting edges at peripheral point should not be more than 0,002 ... 0,005 mm, and the difference in length of cutting edges should not exceed 0,01 mm. These drills carry two pairs of margins – two on each of the flute grooves. The second pair of margins has a large diameter compared to diameter of cutting part of drill. The first pair of margins perform only functions of auxiliary rear surfaces, and second pair of separate margins serves only to guide the drill in aligning bushing.

The accuracy of hole drilling by drills with separate guide margins depends mainly on deviation, alignment of machine tool spindle and aligning bushing. A higher accuracy of drilling in compare with standard drills is provided when alignment of machine tool spindle and aligning bushing do not deviate more than 0,15 mm.

Polycrystalline diamond tool (PCD) is made of hard alloy, on which polycrystalline diamond is soldered as cutting edges. The cemented carbides provides strength and dimensional accuracy for high-quality drilling of holes, also inside the drill located spiral channels for cutting fluid and spiral grooves for chip removal. Polycrystalline diamond cutting edges provide increased tool life of drill.

On *cemented carbide drills with diamond CVD coating* edge sharpness is limited by thickness of coating. In addition, due to the large difference in the hardness of carbide substrate and diamond coating, they are characterized by a low ability to absorb impact energy. Resistance to chipping is limited.

Optimum drill geometry with PCD. For drilling carbon fiber plastic large angles of inclination of helical line and long cutting edges with large positive back rake angle are used. A long cutting edge is provided due to small point angles. Drills for carbon fiber plastic provide low axial forces for avoiding of material spalling at the outlet. This requires a enough sharp cutting edge with a small angle of cutting wedge. End relief angles reach up to 20 degrees at angles of inclination of helix line about 30 degrees. When drilling of titanium, sharp cutting edge also can be used, but in comparison with drilling of carbon fiber it requires a stronger cutting wedge. Standard end relief angles for titanium are in range of 8 to 14 degrees. Compared with drills for steel drilling, these values are generally higher (about 12 degrees), since the thermal effect of friction forces on the back surface of tool should be minimized to reduce wear on flank surface. Since a large end relief angle in combination with standard inclination angle of helix line at 30 degrees will too much weaken the cutting edge, the angle of inclination of screw line is reduced and lies in the range of 15 to 20 degrees.

When drilling parts completely made of carbon fiber plastic, the holes for internal cooling allows blow out carbon dust through grooves for chip removal with help of compressed air. For drilling of materials from carbon fiber / titanium, a minimum quantity of lubrication (MQL) is allowed to reduce friction and reduce the amount of heat released in titanium due to its low thermal conductivity. The minimum amount of lubrication is required when working with a tool made of polycrystalline diamond, since an elevated temperature at cutting edge will lead to diamond graphitization or formation of TiC. This reaction leads to chemical deterioration near the groove and, ultimately, to dislodging of polycrystalline diamond.

Drills with polycrystalline diamond are characterized by a significant increase in durability and one type of wear, beginning with microcracks on the flank surface and resulting in significant microchipping of corners.

4.1.2. Geometry and design features of counterbores

There are two variants of counterbores equipped with inserts: without dividing of cut layer (Fig. 4.4) and with separation of cut layer. The cutting insert *1* fixed in body *2* by link *3* which moves axially by screw *5* due to stop disk *4*. The geometry of these countersinks is follows:

$$\varphi = 45^\circ; \varphi_0 = 20^\circ; \gamma = -15^\circ; \alpha = 6 \dots 8^\circ; \lambda = 8 \dots 12^\circ.$$

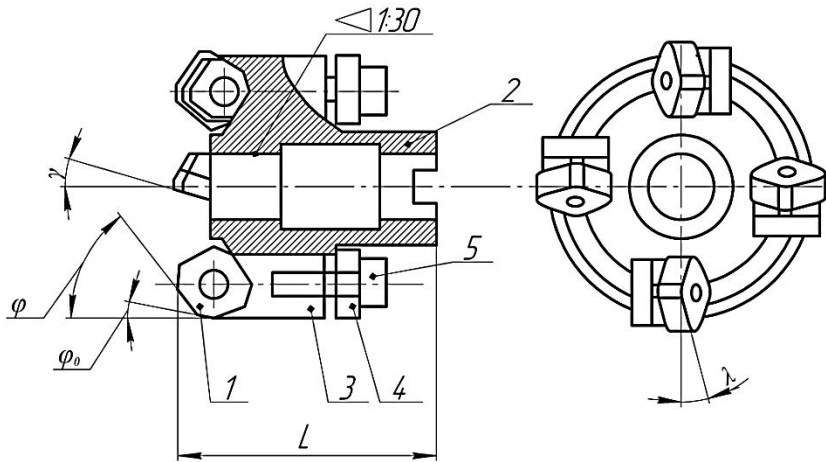


Fig. 4.4. The design of a counterbore equipped with inserts without dividing the cut layer

Advantages of this design in comparison with soldered is fast replacement of dulling insert, increased productivity through the use of cemented carbides, reducing costs for sharpening and resharpening.

It is possible to combine several types of operations in one tool, for example, counterboring and broaching. Counterbore – broach (Fig. 4.5) allow to improve the quality and accuracy of hole machining, as well as tool life. The use of an equally wide profile of the teeth increases the resistance of the counterbore – broach and number of possible re-sharpening. Tool life is also increased due to resharpening by back surface, in which the state of the rear surface is recreated to state of new tool.

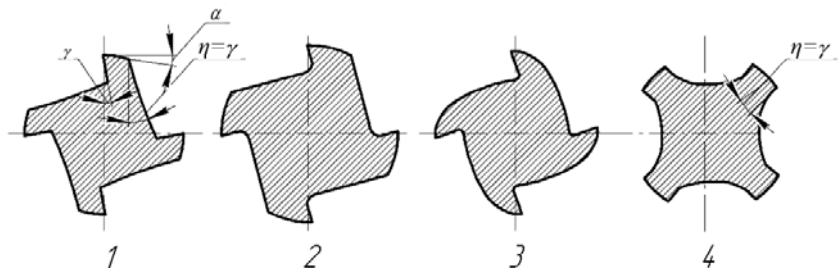


Fig. 4.5. Cross section profile of the counterbore – broach: γ – back rake angle; α – end relief angle; η - angle on back of the tooth ($\eta = \gamma$); 1 – equally wide profile of tooth; 2,3 – standard profile of teeth of counterbore; 4 – profile of calibration part

Counterbore – broaches can be equipped with inserts from hard alloy (Fig. 4.6).

The accuracy of diametrical dimensions of holes after machining by counterbore – broach increases by 1 – 2 quality classes in comparison with cylindrical counterbore, the roughness decreases by 2 – 3 quality classes.

Most of the counterbores are tools with fixed cutting elements. This leads to a decrease in accuracy of drilling (due to impossibility of changing the cutting part without changing the tool), as well as withdrawal of the tool axis. A solution to this problem can be achieved by using assembly counterbores with a wear compensation mechanism.

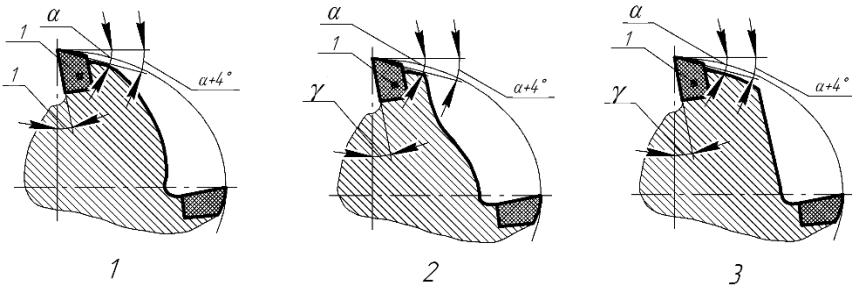


Fig. 4.6. Cross-section profile of counterbore – broach with inserts from cemented carbides:

1 – cement carbide insert; γ – back rake angle; α – end relief angle;
 η – angle at back of the tooth ($\eta = \gamma$)

4.1.3. Geometry and design features of reamers

The reamer has short tool life, therefore, it has increased requirements by assigning a tolerance to diameter. Conventional machine reamers with side cutting edge angle is inconvenient to sharpening, since it requires two installations for sharpening of intake and calibrating cylindrical part. On the other side, at a small angle, radial cutting force increases, withdrawal of hole axis and tool vibrations during cutting increases. Reamers with stepped intake part are devoid from this disadvantages (with a ring sharpening) (Fig. 4.7).

Reamers with alternate teeth increases the drilling vibrational stability due to large angle of teeth inclination ($\omega = 30 - 40^\circ$) and difference in angles of adjacent teeth $\Delta\omega = 6 - 8^\circ$, with their uniform arrangement at end of reamer.

This helps to ensure consistency of cross – section of cut layer, which excludes one of the main causes of disturbance force. At the same time, the waviness, ovality, deviations from cylindricality and other characteristics of

quality of reaming are significantly improved in drilling of deep holes. The roughness of the drilled surface of holes is reduced by 1,5 – 2 classes.

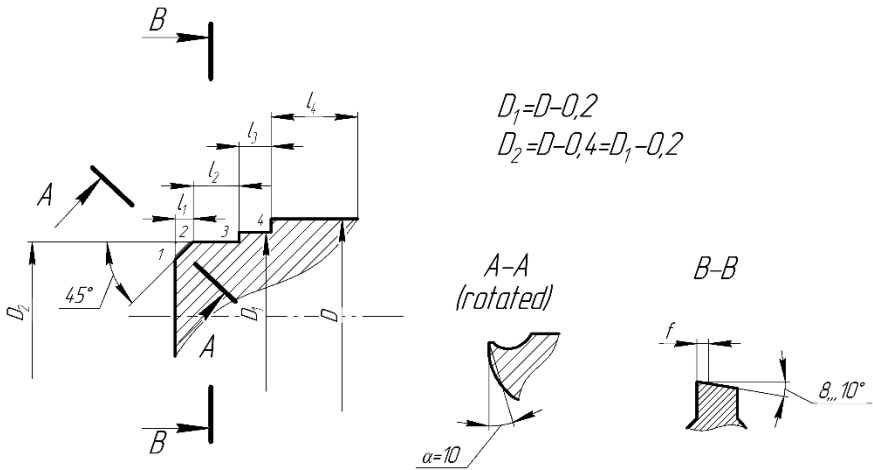


Fig. 4.7. Scheme of reamer with ring sharpening

Single – tooth reamers with adjustable position of cutting insert (knife) allow to get holes with different arrangement of tolerance fields.

The higher resistance and quality of drilled surface are provided by *cutter assembly reamers with teeth without vertices*. Its design has insertable teeth – cutters, without vertex, curvilinear cutting edge. An improved design of assembly reamer with teeth without vertices is shown in Figure 4.8. It consists of body 1, four insert teeth – cutters 2 and fixing screws 3 two for each insertion tooth – cutter. Teeth – cutters can be made from high – speed cutting steel (preferably P6M5) or equipped with cemented carbide insert T30K4 (Russian grade) for finishing.

To increase accuracy of reaming, it is recommended: use the smallest possible angles in plan of cutting and calibrating parts, minimal radial beating of main and minor cutting edges and possibly larger width of circular finishing margins. The highest accuracy of dimensions and shape of drilled holes is achieved by reamers with an circular sharpening (Fig. 4.9) with a major side cutting edge angle of 90°. In these cases, the influence of radial beating of main cutting edges of reamer on holes breaking is excluded.

Cemented carbide reamers. Equipping of reamers by cemented carbide increases their stability in several times, especially when drilling holes in difficult-to-cut steels and high strength cast irons. However, it is not possible to realize possibility of cutting speed increasing in several times when using

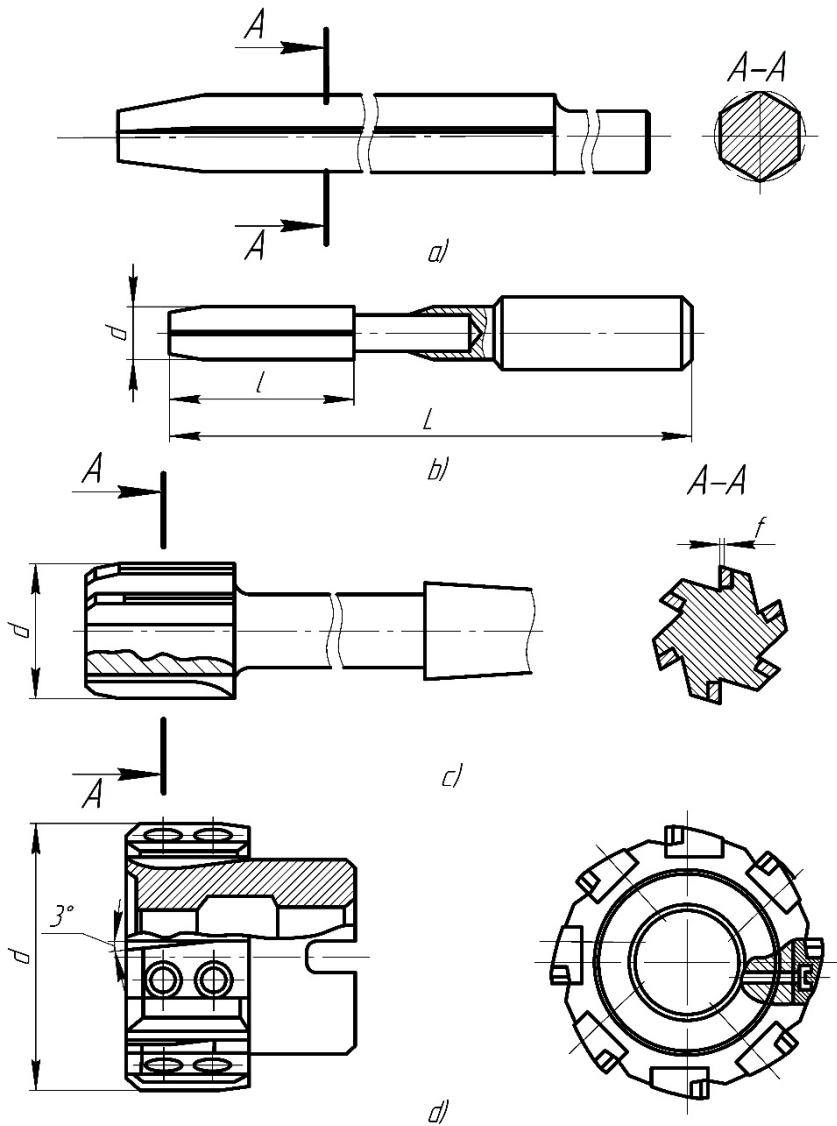


Fig. 4.10. Cemented carbide reamers: *a* – single – faceted;
b – with single cemented carbide working part soldered to shank;
c – tail with soldered cemented carbide inserts;
d – embossed assembly with knives (cutters) with a hard alloy ($\varnothing 150 \dots 300$ mm)

Equipping of conventional machine reamers with cemented carbides is possible (Figure 4.10): 1. manufacturing of working part entirely from cemented carbides; 2. soldering of standard inserts directly onto the body of reamer or on knives in assembly reamer; 3. mechanical fastening of inserts on body of reamer.

Reamers with diameter up to 3 mm are made entirely from a cemented carbides in form of a three – , four – or pentahedron (Fig. 9.11, *a*) with intake cone, without chip grooves with back rake angle at cutting edges. In this case, the removable allowances are extremely small, and the cutting process is similar to scraping.

Reamers with single cemented carbide working part and steel shank, connected by soldering, are made with diameters of 3 ... 12 mm (Fig. 4.10, *b*).

In reaming, the cutting temperature is low, so high strength adhesives can be used instead of soldering, which greatly simplifies the process of making reamers and ensures an increase of durability of cemented carbide inserts due to the absence of thermal stresses.

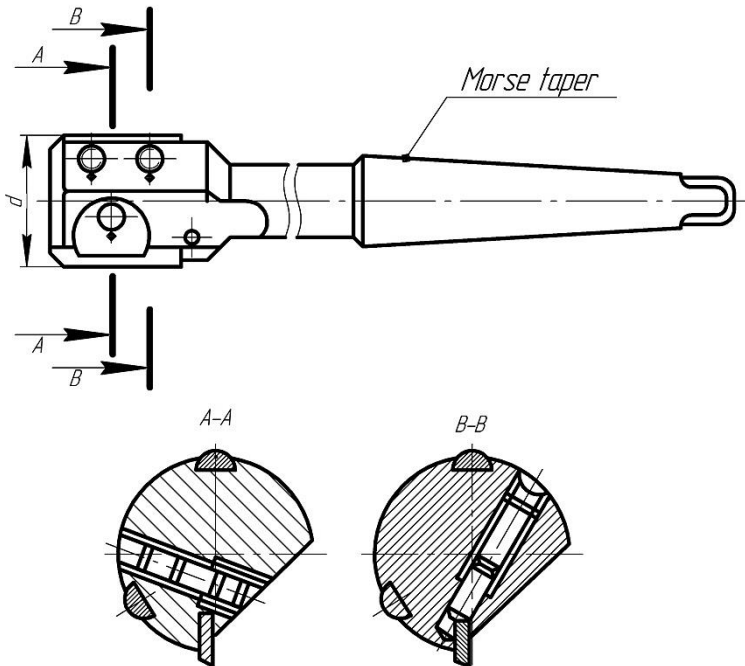


Fig. 4.11. Single – sided cutting reamer from cemented carbide

Single – sided cutting reamers are manufactured with one or more knives and support inserts. Due to the smoothing action of support cemented carbide guides, which perceive the radial component of cutting and friction forces, they ensure high accuracy of holes and low roughness of their surfaces (Fig. 4.11). Due to the use of internal chilling by cutting fluid with oil base, it is possible to achieve the following cutting modes in drilling of steels: $v = 70 \dots 90$ m/min, $S = 0,1 \dots 0,5$ mm/rev, $t = 0,15$ mm.

Cemented carbide reamers have following main differences from high – speed steels: reduced length of working part; small length of intake cone (to reduce vibration, the angle γ is increased to 45°); on cutting edges with zero back rake angles are sharpened narrow hardening chamfers with a negative back rake angle – 5° ; the back taper is usually replaced by radius rounding because of short length of calibrating part.

4.2. Influence of cutting conditions

Increasing of cutting speed above the optimum value leads to increased wear of the tool due to increase of temperature. Increased speed leads to bonding of material of workpart and cutting edge. Damaged cutting edge damages surface and reduces tool life.

Feed has less effect on quality of drilled surface and tool wear compared to cutting speed (feed can be changed over large limits without changing machining quality and tool life). Therefore, it is desirable to choose the highest feed rate from recommended ones in order to shorten machining time without significantly reducing tool life.

Allowance on reaming also affects on tool life. If the allowance is too small, large deviations in dimensions and a decrease in quality of drilled surface can occur. In presence of surface defects, the allowance on reaming is increased.

Cooling / lubrication. In some cases, use of emulsion gives a better surface quality than oil. The flow of emulsion is thinner, and it is better able to achieve and lubricate cutting edges than viscous cutting oils (especially for deep drilling of workparts).

To obtain high accuracy of reaming, it is necessary to observe a number of additional conditions:

a) *Ensure properly state of tool in re-sharpening.*

b) *Through hole.* Free release of cutting fluid and chips is ensured. The most suitable are reamers with spiral grooves.

c) *Blind holes.* For blind holes usually use reamers with straight grooves.

Back taper. The back diameter of head of reamer should be 0,05 – 0,015 mm less than front. The back taper protects reamer from seizing,

and also helps reduce the cutting force and improve the surface quality. Incorrect back taper can cause instability of reaming, rapid wear and deterioration of surface quality.

Cutting fluid. For maximum tool life and quality of the hole, internal cooling with high pressure and high cutting fluid consumption is used. For the best quality it is recommended to use an emulsion of mineral oil.

Reaming with advanced plastic deformation. Special feature of reamer design (Fig. 4.12) is conical section 2 with angle φ_y , which acts as deforming element. The teeth in this section are not form relieved and represent reinforcing margins located in axial direction, sharp edges of which, in order to exclude them from cutting process, are rounded up to $r = 0,2 - 0,3$ mm (Fig. 4.13).

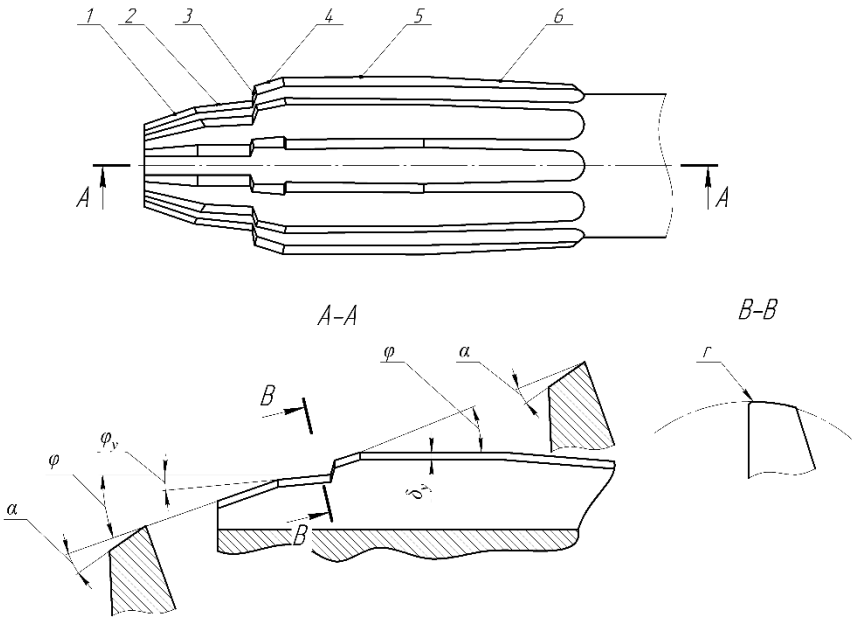


Fig. 4.12. Design of cutting part of reamer for cutting with advanced plastic deformation

Cutting edges in section 1, located at an angle φ to axis of tool, remove the main part of allowance as in ordinary cutting. The conical section 2, during rotation and axial movement of tool, plastically deforms (hardens) the material layer in contact (Figure 4.12). Sections 3 and 4 finally form the hole surface, removing a thin layer of metal with altered physical and mechanical properties. The operation of calibrating cylindrical section 5 and reverse cone 6 of reamer is same as operation of section of standard reamers. The regulation of degree of

preliminary deformation of material removed by cutting tool sections 3, 4 and 5 is achieved by changing angle φ_y and length l_y of conical section 2 which determine the radial interference δ_h (Fig. 4.13) and the corresponding intensity distribution of specific linear load (q N/m), acting on the material of cut layer during the reaming.

As a result of deformation hardening of cut layer, initial structure of material is crushed during reaming, its homogeneity is increased, more uniform texture of material surface layer is formed, scatter of microhardness readings of various sections of drilled surface is reduced. In general, the microhardness of surfaces of holes reamed with advanced plastic deformation is 10 – 12% higher than after the conventional reaming.

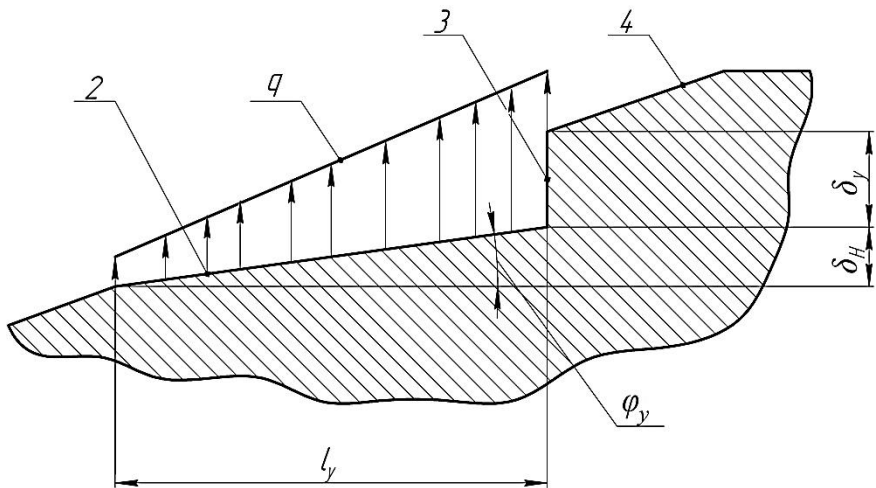


Fig. 4.13. Loading scheme of cut layer of material

Stabilization of cutting conditions also contributes to an increase in period of tool life in reaming with advanced plastic deformation in compare to reaming of standard design reamers up to 1.2 – 1.4 times. It is possible to increase the reaming capacity, since method allows clean reaming with increased allowances for drilling immediately after drilling, thus eliminating the need for reaming and prerreaming in certain cases.

4.3. Increasing of tool life of the cutting tool by electric insulation method

The rupture of closed electric circuit «machine tool – cutting tool – workpart - machine tool» allows to increase tool life in 1,15 ... 7,0 times depending on machining conditions.

In process of drilling, the tool is installed in spindle of drilling machine, into which an adapter made of a titanium alloy is installed. On the surface of transition adapter by means of thermal oxidation, an oxide film is created, so that the drill is electrically insulated. Tool life of drills according to industrial tests increased by 1,25 ÷ 2,15 times.

4.4. Hole making tools wear and ways of its reduction

The main reasons of failure of drills from steel P6M5 (Russian grade) are: disruption (10 – 12%); wear in normal working conditions (40 – 44%); wear in extreme working conditions (27 – 29%); build-up (11 – 14%).

In the surface layers of the tool, after usual sharpening without cooling at a depth of 0,01 – 0,1 mm, the presence of an austenitic – martensitic zone and the tempered martensitic zone (secondary hardening and secondary tempering zone) is characteristic. The hardening zone has a higher hardness, brittleness and a tendency to formation of microcracks, which contribute to microchipping and drill failure at cyclic load. The tempering zone is located below the first zone, usually the hardness of this layer is reduced (to 55 HRC), therefore during operation intensive wear of drills is observed.

The limiting factor in the loss of drills operability is wear of margins. To increase operating time before functional failure of drills, it is necessary to increase wear resistance of margins, for example, by applying wear – resistant coatings.

For HSS twist drills in drilling of structural steel used the criterion of functional failure in form of a critical value of wear of corners, depending on the diameter of the drill, the probability of their failure – free operation equal to $\gamma = 0,95$, in the form $\Delta d_{0,95} = 0,0062d$ mm . The wear of corners can be measured without removing drill from the machine tool.

Drilling with ultrasonic vibrations of drill in plane of the main cutting edges perpendicular to axis increases tool life from 1,8 to 2,4 times.

For twist drills change in load along the cutting edge (CE) is characteristic due to change of cutting speed and thickness of cutting layer, which leads to an uneven distribution of points stability of CE. Therefore, the resistance of drill is determined by section of cutting edge with minimal wear resistance, which

reduces tool life. The most promising is the designing of curvilinear cutting edge of drill, which has more uniform distribution resistance of CE points in comparison with standard drills.

The ratio of maximum resistance T_{max} in center of drill to minimum resistance T_{min} at periphery when changed only cutting speed V is:

$$T_{max} / T_{min} \approx 0,9 \cdot 10^5$$

Thus, the alignment of resistance of cutting edge points of drill is possible by changing of cutting edge geometry. The projection of cutting edge on a plane perpendicular to drill axis is not rectilinear as in a standard drill, but curvilinear and can be concave or convex.

Wear of counterbores. The counterbores have a short cutting edge and unfavorable cutting conditions: high temperature in cutting zone, increased wear, relatively low tool life Cutting work is concentrated on a relatively short cutting edge. Unfavorable cutting conditions cause an increase in mechanical load in area of blade where chip is separated from main material layer, which is accompanied by considerable heat release. Mechanical and thermal stresses lead to relatively low tool life.

The counterbore wear by back and front surfaces, as well as by margins. Wear of rear surface increases gradually. Wear of front surface leads to formation of crater with small depth on it (20 – 30 μm). Particularly strongly the tool life is reduced by wear of margins, which has form of transverse grooves. In processing of cast iron by HSS counterbores, the wear of corners is crucial.

Reamers wear by back surface, because its teeth cut very thin chips. Wear value for HSS reamers are $\delta = 0,6 - 0,8$ mm.

4.5. Modification of the surfaces of the hole making tools

Heat treatment of drills. The drills are mainly made up of composite parts: working part from HSS, and tail part from structural steel. Immediately after welding of these parts, the workpart of drill is subjected to annealing, and after processing – to hardening and tempering. Heating of working part of welded HSS drills is carried out in salt tanks or in furnaces. Tool life from steel P6M5 (Russian grade) after aerothermoacoustic processing is increased by 1,5 – 3 times, in some cases which is similar to tool life of powder HSS.

Working capacity of cemented carbide cutting tools, including twist drills, increases after cryogenic treatment. Cryogenic treatment is an ecologically clean method and increases tool life up to 2 times and reduces the height of microroughness of machined surfaces up to 15%.

Low – temperature carbonitriding of drills from HSS P6M5 (Russian grade) positively affects the parameters of cutting process – the torque value and axial component of cutting force decrease by 1,4 and 1,5 times, which significantly reduces energy costs of drilling, reduce the effective power of electric drive of drilling machine. Operational tool life of carbonitrided tools is 1,7 ... 1,9 times higher than standard non – reinforced tool.

Heat treatment of counterbores. To obtain hardness of HSS tool surface of working part as HRC 62 – 64 and up to 30 – 45 for tail part are subjected to heat treatment.

Tool life of tail counterbore with cemented titanium carbide which are treated by nitriding of aluminum nitride is, on average, 2,1 ... 2,4 times higher than counterbores treated in dissociated ammonia.

Chemical heat treatment of reamers. This method was applied for liquid low – temperature case hardening of reamers from steel P18 (Russian grade) with dimensions 4,38^{-0,01} mm, 5,91^{-0,01} mm, 5,01^{-0,01} mm, 6,31^{-0,01} mm, 7,04^{-0,01} mm. Reamers were treated in tank, initial composition of which consisted of 80% yellow blood salt + 20% sodium hydroxide, at a temperature 560° C during different time (15, 30, 40, 60 min.). General depth of cyanidation layer, which depends on duration of the process, is 0,025 – 0,040 mm. The maximum microhardness of layer during treatment during 15, 30, 40, 60 minutes is equal to 1829, 2200, 2200, 2300 (before cyanidation microhardness was 1025 – 1144). Despite general increase of cyanidation depth with an increase of storage, tool life of reamers reaches maximum at 30 minutes treatment, after which it falls off. This is due to thickening of the carbonitride zone, which increasing brittleness. In operation, the light layer wears quickly. Its thickness should therefore not exceed 2 to 3 µm.

Cyanidation of reamers of smaller dimensions (4,38 and 5,01 mm) produced worse results due to a greater propensity to break and microchipping. Reduction of cyanidation time to 15 min gives quite satisfactory results (the stability of reamers increases by an average of 1,5 times in comparison with non – cyanined ones).

Modification of tool by low – temperature combined discharge plasma increases wear tool life and is characterized by:

- improvement of roughness due to burn up and reflow of burrs and unevennesses formed in process of formation of close – packed carbon-nitrogen-containing layer, filling irregularities, increasing ohmic resistance of surface;
- increase of microhardness from 20 to ~ 60 GPa for a cemented carbide and from 6 – 7 to 14 – 18 GPa for HSS P6M5 (Russian grade);
- grinding the structure of cutting tool material with formation of finely dispersed phase in near – surface layer with a thickness up to 20 µm. General depth of modified layer is 300 µm;

Hardening of small – sized cutting tool in low – temperature combined discharge plasma provides significant increase of wear resistance of inserts from cemented carbide T15K6 (Russian grade) – in 3,8 – 4,4 times; drills and taps from HSS P6M5 (Russian grade) – in 3 – 5 and 3,6 – 4 times, respectively.

Increasing efficiency of modification and subsequent use of drills is possible with following recommendations:

- support of geometric parameters of cutting part taking into account the type of processed material;

- retention of geometry of cutting part during re – sharpening (especially position of chisel edge) and the preservation of modified layer;

- increase to 1,5 times normal load on surface of cutting edges by increasing values of working feeds, especially for coated drills.

Dynamic microalloying. Processing due to penetration of microparticles $10 \dots 10^2 \mu\text{m}$ to depth of order of $0 < H/R < 2 \cdot 10^3$ allows to influence on physical – mechanical properties of material of tool cutting part of and thereby on tool wear resistance. Here, H is the depth of penetration, and R is the radius of the microparticle. In dynamic microalloying process, a network of microchannels with density $(6 \dots 7) \cdot 10^2 \text{ mm}^{-2}$ is formed, which, due to microplastic deformations, introduces micro – distortions into the structure of material, which after heat treatment leads to formation of micro regions with increased density of internal energy.

Drills from HSS P9K5, P6M5K5, P9M4K8 (Russian grades) with a diameter of 4,15 and 4,05 mm, subjected to dynamic microalloying by powder composition based on titanium carbonitride with nickel, when drilling holes in parts from steel X18H10T (Russian grade) without cooling on a vertical drilling machine tool, showed 1,5 times higher tool life in comparison with the others, manufactured by serial technology.

Jet – abrasive treatment (blasting) of the hole making tools provides the solution of two tasks:

1. Surface – plastic deformation of cutting edges (main, auxiliary and transverse edges), front and back surfaces of tool and their hardening. Training of cutting edges is also carried out for the further work of tool.

2. Rounding of tool cutting edges (for high – speed steel up to value – $r = 10 \dots 15 \mu\text{m}$, for hard alloy up to value $r = 15 \dots 30 \mu\text{m}$).

The rounding of cutting edges is a necessary operation for further exclusion of microchipping processes of cutting wedge and formation of stress microconcentrators, and also designed in a number of cases to remove burrs that form during backing-off of backoff surface of the tool.

After jet – abrasive treatment of hole making tools it is necessary to restore and improve roughness parameters of tool surfaces by polishing up to $Ra = 0,08 \dots 0,06 \mu\text{m}$.

4.6. Hole making tools hardening by pulsed magnetic treatment.

The application of pulsed magnetic treatment is justified only for high – speed steels. This is due to presence of a ferromagnetic component and the technology of production of drills from high – speed steel, which includes plastic deformation, namely, knurling of grooves and twisting.

Optimal modes of pulsed magnetic treatment with using of combination of vibration and ferromagnetic powder for $\varnothing 6$ mm drills from HSS P6M5 (Russian grade) when drilling holes in samples from steel 30 (Russian grade) are: magnetic field intensity $H = 415$ kA/m; number of magnetic pulses $t = 4$; pulse duration is 0,1 s; time interval between pulses is 1 s.

When drilling steel 20 (Russian grade), general depth of drilling without pulsed magnetic treatment is 800 mm, steel 40X (Russian grade) – 600 mm, steel 12X18H10T (Russian grade) – 550 mm. After pulsed magnetic treatment without use of ferromagnetic powder, general depth of drilling is, respectively, 1150 mm, 900 mm and 750 mm. The use of ferromagnetic powder increases general drilling depth to 1250 mm, 950 mm and 800 mm, respectively. When drilling steel 20 (Russian grade), wear value of rear surface of edge without pulsed magnetic treatment is 0,35 mm, steel 40X (Russian grade) – 0,4 mm, steel 12X18H10T (Russian grade) – 0,48 mm. After pulsed magnetic treatment without using a ferromagnetic powder, wear value is 0,3 mm, 0,35 mm and 0,42 mm, respectively. The use of ferromagnetic powder in hardening of drills leads to a decrease of chamfers wear of rear surface of drill edge to 0,27 mm, 0,32 mm and 0,36 mm.

When drilling steel 30 (Russian grade), general depth of drilling without pulsed magnetic treatment is 1000 mm. After pulsed magnetic treatment without vibration and with vibration, general depth of drilling is, respectively, 1300 mm and 1500 mm, and after pulsed magnetic treatment with a combination of vibration and ferromagnetic powder – 1600 mm.

When drilling steel 30 (Russian grade), the wear value of the rear surface of edge without pulsed magnetic treatment is 0,6 mm, after pulsed magnetic treatment without vibrations and vibration, the wear value is 0,5 mm and 0,48 mm, respectively, and after pulsed magnetic treatment with combination of vibration and ferromagnetic powder, wear value of rear surface of the edge is 0,46 mm.

Pulsed magnetic treatment increases tool life of drills by 1,6 times

4.7. Application of coatings on hole making tools

Vacuum ion – plasma coatings, applied by condensation and ion bombardment, are widely used for improvement of the efficiency of hole making tools and to increase their tool life. These coatings provide a significant increase in tool life of hole made tools when performing highly loaded operations of technological process.

During tool preparation for coating, the following operations are performed: degreasing of tool by ultra sound, flushing and drying of tool. Additionally, chemical cleaning and hydroabrasive cleaning operations can be performed.

When applying a vacuum ion – plasma coating, the following operations are performed:

- nitriding of tool in a glow discharge (holding time – 30 min, atmosphere – nitriding low pressure 135 ... 665 Pa, operating voltage – 350 ... 550 V);
- ion bombardment and warming up of tool 5 ... 10 min;
- metallization of tool functional elements 3 ... 5 min;
- application of multilayer composite nitride – titanium coating (15 – 20 layers);
- cooling of tool.

For additional finishing treatment of hole making tools, the following operations can be performed:

- refining of front surface of the tool to ensure the sharpness of edge;
- glazing of functional elements of tool (front and back surface of tool) ;
- pulsed magnetic treatment.

Pulsed magnetic treatment provides a reduction in the influence of arising internal stress concentrators due to peculiarities of thermal effects on the tool. The powder HSS with a strength of 5500 – 6500 MPa and an impact toughness of 500 – 700 kJ/m² at hardness of 64 – 66 HRC are also used.

These characteristics of strength and viscosity are 2 – 3 times higher than those of standard steel P6M5 (Russian grade). There is also a slight increase in heat resistance of powder steel. Thus, ordinary HSS P6M5 (Russian grade) after tempering at 620° C for 4 hours save hardness at 58 HRC, while steel 10P6M5 – MII – at 60 HRC. Therefore, it is advisable to produce first of all a small tool from powder HSS, for which strength of the material is especially important. The most significant increase of tool life of powder tool was achieved on drills $K = 2,0 \div 9,6$.

As final operation can be used finishing plasma hardening. The applied coating on basis of carbide, nitride and silicon oxide has a number of unique properties: microhardness of the order 52 GPa, ability to withstand temperatures up to 1100° C without oxidation, low friction coefficient (for example, 0,07 for steel IIIХ15). The conditions of coatings formation by finishing plasma

hardening are also characterized by increased adhesion of coating to substrate due to active chemisorption processes.

The effectiveness of application of epilaminated tools is achieved due to retention of oil cutting fluid in cutting zone by molecular coating FTOR- surface active substance. During operations with rational technological regimes, tool life of drills increases 1,5 – 2,5 times compared to a non-epilaminated tool operating in similar conditions. During working without cutting fluids, tool life of epilaminated drills is higher than uncoated drills and corresponds to tool operating in presence of oil cutting fluids (epilam coating serves as boundary lubrication).

4.8. Application of combined methods of hole making tools sharpening

Complex modification of surface of solid cemented carbide drills from VK8 (Russian grade) by electron beam alloying with alloy NbHfTi and deposition of a wear – resistant coating (TiAl)N. When drilling polymer concrete without cutting fluid, uncoated drills wear faster than a coated drill (TiAl)N by 1,5 – 2 times. Complex treatment makes it possible to effectively use combination of hardness and viscosity of base of cutting tool material, micro hardness and heat resistance of modified layer, wear resistance, chemical and diffusion passivity of refractory compound (TiAl)N used as a coating.

Pulsed laser – magnetic surface treatment. During high – speed heating of steel surface by laser radiation in presence of magnetic field occur deep structural changes in materials, caused by their magnetic properties, intensity of laser radiation and magnetic field; during laser – magnetic hardening, in comparison with laser hardening (depending on steel grade), the following is observed: an increase of depth of heat – affected zone by 20 – 30%, an increase of microhardness by 10 – 20%, wear resistance by 1,5 – 3 times, an increase in fracture resistance 1,5 – 2 times, change in nature of fracture character with transition from brittle to brittle – viscous.

Combined vacuum – plasma surface treatment. In manufacturing of small diameter drills from widely used HSS P6M5 (Russian grade), their hardness and heat resistance are lowered compared to drills with diameter more than 3 mm. This is due to multiple operations of cold plastic deformation and intermediate annealing to which tool is subjected in process of manufacturing. That is why small – diameter drills often show reduced tool life. The most promising and modern method of increasing tool life of this type is ion – plasma treatment, including nitriding and coating deposition. The use of ion nitriding reduces wear of drill along angle by a factor of 1,7 compared with the non-

hardened one. At the same time, the value of drill wear along chisel edge decreases by 1,1 – 1,2 times. The application of a wear – resistant coating reduces wear along angle by of 2,2 times, with a decrease in wear by 1,4 times of chisel edge, compared to a non – hardened drill.

4.9. Minimizing of hole making tools failures

During operation, the tool experiences longitudinal and lateral deformations affecting on its performance. Thus, when drilling a hole in solid material, an increase in torque is observed as depth of hole increases and when boundary $L/d_0 = (3 \dots 5)$ is reached, the fracture risk of drill increases. The effect of axial force is largely appears in shaping of through holes at time when chisel edge has come out of material. At this moment, occurs sharp feed of workpart on tool, and as result happens destruction. The influence of axial force is also observed at the beginning of drilling, when a chisel edge of twist drill start to contact with workpart. The main reasons of twist drills failures are presented in Table. 4.1.

Table 4.1.

The main causes of twist drills destruction

Causes of twist drills destruction	
Mechanical	Technological
Destructions connected with increased torque: – significant allowances for drilling; – drift of drill axis; – incorrect selection of cutting part geometry of twist drill; – chip clogging in flutes.	– deviation from specified parameters of accuracy of drilled surface of part; – incorrectly calculated or selected cutting modes; – unsatisfactory condition of production accessories and machines; – low accuracy of adjustment of technological system; – presence of cutting fluid and its properties.
Microchipping of cutting edges of twist drill: – surface deformations; – poor quality of cutting tool material; – thermal stresses.	
Destruction of twist drills with insufficient strength: – heat treatment defects; – poor quality of cutting tool material; – incorrect design of cutting tool.	

The spiral drill shown in Fig. 4.14, contains a shank and working part with two spiral chip – braking flutes and core having a smooth thickening towards the shank. On working part of drill the core is made with constant

thickness, and then – with thickening of 25 – 35% for every 100 mm of length. The cross – section of drill has increased geometric characteristics (W_p , J_p), however, chip output is much more difficult due to reduction of area of chip flutes.

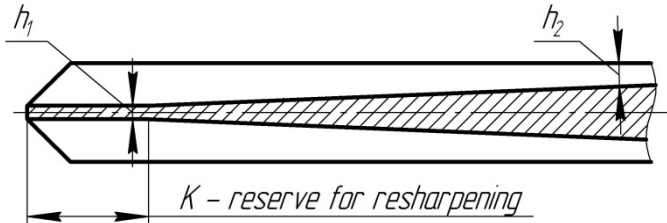


Fig. 4.14. Twist drill with thickened core

The use of flute, which is straight relative to central longitudinal axis of drill, increases the rigidity of drill and bending strength. An increase of inclination angle of helical flute ω leads to decrease of tool rigidity. Therefore, to increase tool rigidity, the inclination angle ω should be reduced.

Long drills (including for deep drilling) fail not as result of wear, but in connection with breakage at a distance of $2/3$ of length from top of drill. Radial rigidity of drills depends on diameter of its core, an increase of which from 0,1 to 0,3D effects on change in rigidity most sharply. With an increase in slope angle of flutes ω , rigidity decreases noticeably. To increase dynamic stability of drills, it is necessary to increase inertia moment of section by increasing of drill core.

KENAMETAL (USA) developed a twist drill (Figure 4.15), which has flutes containing the first, second and third spiral sections. The first spiral section (AB) is made as in standard design drills, and it smoothly passes into a second spiral section (BC) which is twisted in a direction opposite to twist direction of first spiral section. This is done in order to increase the cross – sectional area, thereby increasing tool rigidity. The third spiral section (CD) is twisted towards the first spiral portion.

The comparative stability of twist drills with a variable angle of incidence of flutes is increased by 2 times.

Small – sized tools with diameters of 2 – 6 mm are also manufacture from bimetallic material P6M7Φ6K10 – MII (Russian grade) with a uniform carbide phase, which by set of strength parameters exceeds standard HSS P6M5 (Russian grade). Promising method of small – sized cutting tools production is process of high – temperature gas extrusion.

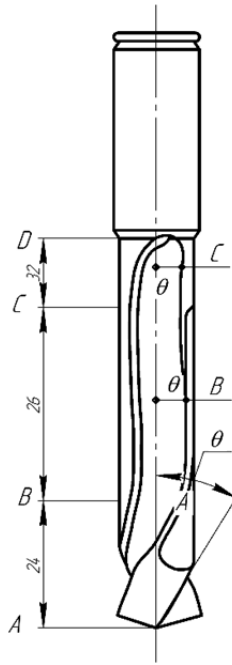


Fig. 4.15. Drill of KENNAMETAL company

The correct choice of design and geometry allows increase the tool life in several times. The measurement of torque value during small diameter holes processing showed that there is a direct dependence between it and tool life of small – sized cutting tool. However, tool life is influenced by strength of HSS, which largely depends on presence of carbide inclusions. High – temperature gas extrusion is one of the most promising processes, allowing reduce influence of carbide heterogeneity on steel properties. Tool life tests of taps and drills have shown a high efficiency of application of this process in production of hole making tools designed to process small diameter holes (tool life increased by approximately 5,5 and 1,9 times, respectively).

To eliminate harmful effects of physical phenomena, imperfections of drills design and feed method of cutting fluid with deep hole non – output drilling of holes, it is necessary:

1. To reduce harmful effect of adhesion interaction through the use of thin wear – resistant hard coatings made of nitride and titanium carbide applied to the cutting part of spiral drill, as wear – resistant coatings reduce effect of adhesion forces by 1,5 time.

2. It is possible to reduce harmful influence of mechanical interaction on contact surfaces of cutting tool only by applying polishing of flute forming surface of tool.

3. To reduce chip buildup process and chips fragments, as well as eliminating of process of forming packets in chip flutes, it is necessary to introduce chip braking elements on cutting part of tool on the front and back surfaces that allow increasing depth of hole drilling up to 10 ... 15*d* and tool life by 30%.

4.10. Application features of cutting fluids for drilling and related operations

Strengthening by cutting in medium of rapeseed oil by preliminary run – in method has revealed effect of increasing of tool life and by number of drilled holes slightly inferior to drills with wear – resistant coatings.

Composite cutting fluids based on vegetable oils and crystalline hydrates significantly increases heat removal from cutting tool blade and improves ecological parameters of cutting process. However, it is difficult to feed them into the cutting zone because of complexity of ensuring their long – term stability associated with rapid precipitation of solid component into sediment, i.e. composition stratification. The relatively high cost of ecological compounds based on vegetable oils can be compensated by improving of various technologies of their minimized consumption. Thus, when using microdoses of cutting fluids in form of magnetic micro-capsules and when amount of supplied cutting fluid to contact zone is reduced by more than 10000 times, tool life of drills from steel P6M5 (Russian grade) increases by 1,5 ... 2,0 times.

From known methods of supplying of cutting fluid into drilling area of workparts, during drilling operations, it is considered «preferred» to feed it under pressure through channels made in tool with an exit into the cutting zone. To «applicable» refers to supply cutting fluid on drill with irrigation (at a pressure of 0,02 – 0,03 MPa), or spraying in form of jet of air – liquid mixture. To «rarely used» refers pressure stream supplying of cutting fluid (from 0,1 to 2,0 MPa), through the nozzle. Basically, this method is used to wash out chips from cutting zone.

Widely known drills that contain internal channels for supplying of cutting fluid into drilling zone, their outlets located on rear surface of teeth. In Fig. 4.16 shown asymmetric arrangement of channels outlets, that connected with flutes for supplying of cutting fluid. Drill 1 contains spiral channels 2, for supplying of cutting fluid. The outlets 3 of channels 2 are disposed asymmetrically relative to longitudinal axis of drill 1 on rear surfaces 4 at cutting

edges 5 of tooth 6. Each outlet 3 is connected to a semicircular groove 7 disposed along the cutting edge 5. During the drilling of hole 8 in part 9, the cutting fluid from source of supply (not shown) flows through its channels 2, and through the outlets 3 into flutes 7 on rear surfaces 4 of each tooth 6. The cutting fluid leaves concentrically arranged traces on the surface 10 of drilling of part 9 and fits along entire length of cutting edges 5 of each tooth 6. In this case, traces of cutting fluid outflow from flutes 7 overlap each other, forming a double stream of cold liquid that cools working section of drill 1. The semicircular surface of flute 7 increases contact area of cold cutting fluid with back surface 4 of each tooth 6 and drilling surface 10, captures and transport chips along screw flutes of drill 1 by flow.

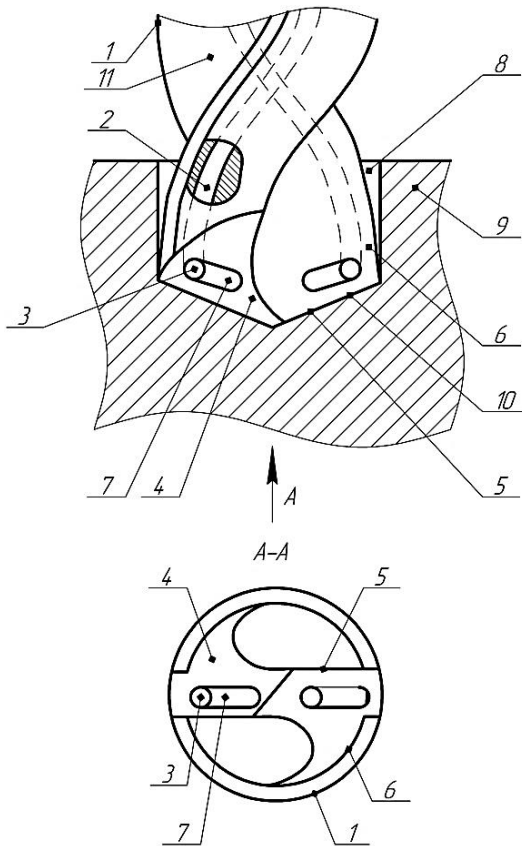


Fig. 4.16. Drill with flutes for supplying of cutting fluid

Application of this design allows to increase tool life of drill and improve quality of drilling holes. The effectiveness of epilated drills is determined by technological drilling conditions – cutting modes, availability and type of cutting fluid:

- during operation without cutting fluid, tool life of epilated drills is higher than uncoated drills and corresponds to period of tool life in presence cutting fluid;

- the greatest effect is achieved during drilling with an epilated tool using oil cutting fluid, while working with rational technological modes, period of tool life of drills is increased by 1,5 to 2,5 times in comparison with a non – epilated tool operating under similar conditions;

- the most significant technological factor that determines operation effectiveness of epilated tool is cutting speed, which must be determined from the condition of thermal degradation temperature of epilam coating.

Epilams are multicomponent systems, including fluorine – containing surface active substances and regulating additives in various solvents.

Formed in process of epilamation on solid surface a thin layer (40 – 80°) of oriented molecules of fluorine – surface active substances, reduces its surface energy, allows to regulate sticking and wetting.

- surfaces with a protective molecular layer prevent expansion of oil from friction zone due to abrasion of coating or artificial creation of areas with different surface energies,

- molecule of surface of active substances fill micro cavities and micro-irregularities (surface roughness is reduced by 2 – 2,5 times), form Langmuir structures in form of spirals with axes normal to surface of material, which allows to reliably hold cutting fluids, provide their non-flowing.

Compositions of cutting fluids are also often used in which solid materials are used as antifriction additives, in particular, powders of metals, graphite, classical diamonds, molybdenum compounds. From metals widely use powders of copper, tin, lead, silver and bronze. Very often use powders of graphite, disulfides of molybdenum and tungsten. The best antifriction properties have powders of copper, silver and molybdenum disulphide; maximum concentration of powders in oil – no more than 5%; optimum sizes of powders – not less than 1 micron. The use of these additives allows to implement of a multi – boundary friction regime, which reduces the coefficient of friction and reduces wear. Detonation nanodiamonds and diamond – containing blends are effective modifiers of friction in oil compositions and compatibility with mineral, synthetic and vegetable oils. The add-ons of АIII or ДНА (Russian grade) allow to achieve the following effects:

- reduce boundary friction and wear;

- on friction surfaces form a protective layer from nanodiamonds, which prevents adhesion and scoring;

- reduce coefficient of friction by 20 – 30%;
- increase tool life by 1,5 – 4,0 times, and wear of friction pair is reduced by 1,3 – 3,0 times;
- ensure growth of maximum loads on a friction pair by 4 times.

Drilling of deep holes. Tool life of drills for deep drilling with internal supply of cutting fluid is determined by time of formation of wear chamfer on back surface.

Increasing pressure of cutting fluid in cavity «rear surfaces of drill – cutting surface» helps to increase tool life of drills due to better penetration of cutting fluid under rear surfaces of cutting blades, i.e., into narrow gaps between rear surfaces of drill and cutting surface that are characterized. Even a slight increase of pressure in cavity «rear surfaces of drill – cutting surface» increases tool life of the drills by 3 – 5 times. In addition, high flow rates of cutting fluid contribute to better conditions for chip removal.

Application of viscous cutting fluids. Synthesis of new cutting fluids, showed a trend to refuse from chemically active additives and replace them with additives of «structural action», whose work is related to effect of surface supramolecular self – organization. The second trend is a limited supply of cutting fluid.

Increasing tool life of drills during drilling of small diameter holes is an important technical and economic problem. Until complete blunting, drilling length of holes by small diameter drills depending on grade of material is only 10 – 15 mm. In holes cutting fluid penetrate poorly, so often use a solution of oleic acid. The use of oleic acid makes it possible to increase tool life of drills between re – sharpening, but has a harmful effect on health of people. It is also possible to use different types of pencils of solid cutting fluid:

- chemically or corrosive active, with complex of various properties and forming new compounds (sulfur, chlorine, phosphorus, tellurium, etc.);
- surface active, having both a lubricating effect and an adsorbing effect (containing carboxylic acids, for example, stearic, fats, waxes, soaps, etc.).

Solid lubricant pencil is a cylinder with diameter 16 mm and length 50 mm. A pencil is a solid solution of its stearin – based components. Stearin plays positive role of both a lubricant and a cooling substance. If stearin content is more than 80%, the effectiveness of positive effect of solid cutting fluid decreases. Stearin along with good lubricating properties, has a low adhesion ability, so the effectiveness of action of stearine as solid cutting fluid decreases at forcing of cutting modes. Reducing amount of stearin to 75% and below changes consistency of composition, worsens solidification of melt of solid lubricant pencils.

Oleic acid has a lubricating and cooling effect. In proposed compositions amount of oleic acid more than 18% is undesirable, since it leads to a change in

consistencies of compositions, worse solidification during cast into forms, reduction in its percentage of up to 12% and lower impairs effectiveness of lubricant during drilling. Oleic acid, which is in a bound state, does not have a harmful effect on human.

Solar oil and solid oil increase wettability, adhesiveness and have anticorrosive properties. Solid lubricant pencils also include various additives that reduce friction coefficient during drilling and have a polishing effect.

Application of nanomaterials in cutting fluids. Nanoparticles in cutting fluids provide an increase in thermal conductivity of media and its ability to lower the temperature in drilling zone, temperature of tool and drilled product.

Both metal and nonmetallic nanoparticles can be used in cutting fluids. The basis of nanostructured cutting fluids is water, oil and other liquids.

High efficiency has cutting fluids with carbon nanoparticles – fulleroids (fullerene C-60, fullerene C-70, single – and multi – walled nanotube, multilayer polyhedral nanoparticle – astralene), fullerite (molecular crystals).

The presence in cutting fluid surface–active substances improves efficiency due to realization of Rebinder effect. However, when load in contact increases, properties of surface–active substances decrease as a result of its desorption with rubbing surfaces and possible destruction.

Increase effectiveness of use of surface–active substances is possible due to introduction of nanoparticles in cutting fluids – nanoparticles at stage of dispersion in base cutting fluid form from its molecules solvate shell, due to sorption on nanoparticles, molecules of surface–active substances acquire most favorable orientation for their subsequent interaction in contact zone with rubbing surfaces, and presence of solvate shell in nanoparticles gives them sedimentation – aggregative stability, which is necessary for formation of a volumetric grid in liquid media of cutting fluid.

4.11. Increasing efficiency of making of holes by vibration cutting

The use of vibration drilling of holes with small diameter makes it possible to obtain a finely divided by shape, convenient for removing from treatment zone chips and to reduce coefficient of friction between chips and flutes. Thus, use of special machine tool for vibration drilling of holes in nuts steel 1X18H9T (Russian grade) made it possible to increase productivity by 2,5 times and to increase tool life by 3 times.

Various tool designs (with internal, external and ejector supply of cutting fluid coolant) are used for vibration treatment of holes. However, to improve efficiency of treatment it is advisable to use special tool designs (vibration drills,

vibration counterbores and vibration reamers), geometry of which is adapted to conditions of vibration cutting. These tools are designed with internal supply of cutting fluid and differ by increased rigidity due to reduction of cross-section of flutes for chip removal.

As cutting tool material for vibration drilling is widely used, cemented carbides, in particular, BK8OM, BK10OM, BK15 (Russian grade) and etc.

Overlapping of axial vibrations can significantly increase productivity of drilling, however, in process of strength calculating of axial tool it is necessary take into account cyclic loads, which significantly effect on tool life.

Ultrasonic vibrations significantly increase cutting efficiency of hard – to – work materials, for example titanium alloys. For ultrasonic drilling of holes in hard – to – work materials by twist drills, the most suitable treatment scheme is when ultrasonic vibrations directed along cutting edges of drill.

Example 1. The drill was reported longitudinal oscillations (along the axis) and oscillations directed along cutting edges (drill was oriented, exposing the cutting edges of drill in plane of notch in concentrator, ensuring its longitudinal bending vibrations). Tool life of drills was estimated by depth of drilling of 5 mm hole in diameter in alloy BT-3 (Russian grade) per unit time (30 s).

In conventional drilling, processing is practically stopped at the 10th hole, i.e. drill is blunt and needs to be re – sharpened. When drilling with longitudinal vibrations, depth of drilling grows by an average of 40%, and the number of holes – almost by 2 times. Due to report of oscillations along cutting edges with a rational frequency to drill, depth of drilling increases almost by 2 times, and the number of holes – 2,2 times.

Example 2. Using energy of modulated ultrasonic field to superimpose oscillations of t ultrasonic frequency on drill and cutting fluid allows to reduce axial component of cutting force up to 1,9 times and reduce the torque by 3 times during deep drilling of small sized holes.

Their application in deep drilling of small sized holes in comparison with traditional technology allows:

- increase tool life by 1,6 – 1,8 times;
- reduce drift of drill axis and break holes up to 40%;
- significantly reduce axial component of cutting force, torque and contact temperature in cutting zone.

5. RELIABILITY OF MILLING CUTTERS

5.1. Operating conditions of milling cutters

Features of milling are:

- variability of thickness of cut – off layer $a = f(t)$;
- alternation of idle and working moves of each tooth of milling cutter;
- variability of contact length along margin of tooth due to presence of the angle of inclination of helical groove.

The alternation of idle and working moves, frequency of not only mechanical but also thermal load, as well as its fast removal (in case of climb cut) or appearance (with a down cut), put forward a number of requirements for cutting tool material: endurance, heat resistance, optimum value of coefficient of linear expansion. The main reason of failure of cemented carbide cutting tool is its cracking due to sharp change of temperature when idling speed changes to working one (or conversely).

Variability of contact length along margin of tooth due to angle of inclination of helical flute is absent in mills with a «straight» tooth, but all manufactured mills for production have a helical inclination. Helical incline of tooth of milling cutter softens hit when incision, reduces cutting force, time of transient process, helps to dampen vibrations, reduces total load on spindle during milling by several teeth simultaneously. In modern milling cutters, each tooth has its own angle of inclination of helical flute. Such milling cutters have a much lower probability of occurrence of vibration during milling.

During end face milling appears «unloading hit» effect. Negative impact of «unloading hit» is increase of yield stress of milled material by 1,5 to 2 times in exit zone of cutting tooth from the workpat as compared to zone of stable cutting, increase of loads acting on the cutting wedge, and also their redistribution by front and back surfaces. In this case, the bending stresses in cutting wedge increase by 1,5–2 and concentrate at vertex of tooth, which leads to sharp decrease in its durability, and under certain conditions to shear fracture and microchipping. The reason leading to appearance of «unloading hit» is sharp decrease in thickness of cut layer (practically to zero) in exit zone, which leads to a significant increase in deformation speed and decrease of cutting temperature.

Reduction of stresses in the edge zone can be ensured: a) by reducing feed per tooth (thickness of cut layer), b) width of cut layer, c) changing of physical and mechanical characteristics of the workpart; d) imposing additional physical impacts on exit zone.

To reduce negative impact of «unloading hit» and to increase tool life, it is possible to change conditions of cutting tooth exit from the workpart, for example, by changing of incision trajectory of cutting tool into milling area. One example of curvilinear trajectory that allows controlling parameters of the cut layer at outlet of cutting edges from milling area is incision and circumference of corners along an arc of circle whose radius is equal to location radius of cutting teeth of tool for end face milling of flat surface. By changing conditions of tooth exit from the workpart, tool life can be increased by 10 or more times.

Reducing thickness of cut layer can be achieved by changing trajectory of end milling cutter with curvilinear elements in form of a quarter of ellipse at areas of entrance of milling cutter and counter areas of external corners of workpart during milling of flat surface (Fig. 5.1).

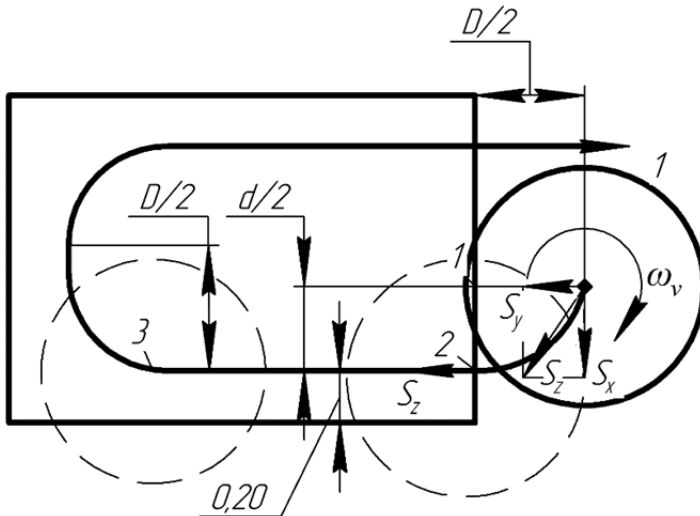


Fig. 5.1. Milling scheme of flat surface

Milling is carried out on two – coordinate milling machine tools with numerical control. The tool is informed main motion ω_v , brought to touch with workpart at point located at the end of milled surface and at a distance $d/2 + 0,2D$, point 1 (Fig. 5.1). Then tool is given two feed movements S_x and S_y , lying in milling plane. The supply vector S_y is directed to body of workpart

normally to its end, and supply vector S_x is rotated on 90° relative to vector S_y in direction opposite to the direction of main rotational motion ω_v .

The feeds S_x and S_y agree in such way that cutting path of incision of milling cutter is a quarter of ellipse whose major axis is equal to the diameter of milling cutter D , and the smaller one is determined by the formula

$$d = D \frac{S_z - 2\rho}{S_z}$$

where D – diameter of milling cutter, S_z – feed per tooth, ρ – radius of rounding of cutting edge.

The non – linearly coordinated feed movements are terminated when center of cutter reaches point 2 which located on intersection of end face and milled surface, and located at a distance of $0,2D$ from edge of workpart (position of milling cutter is presented by dashed line). Then tool is given a straight feed motion, vector of which is directed into body of workpart, normally to small semiaxis of ellipse of previous curvilinear area of trajectory, and feed value is equal to resultant feed to tooth S_z . After point 3, located at a distance $d/2+0,2D$ from opposite edge of workpart, is reached by center of milling cutter, it is again given two feed movements S_x and S_y lying in milling plane and matched in such way that incision trajectory of milling cutter is quarter of ellipse described above, but rotated on 90° relative to its original position in direction of main motion ω_v . The milling is continued in a similar manner before the final treatment of entire surface.

This method of milling allows to reduce negative effect of «unloading hit» by reducing thickness of cut layer to a minimum determined by radius of rounding of cutting edge. The length of elliptical milling area is less than length of the radial section of Sandvik type of milling, which makes it possible to increase productivity on curvilinear sections by 1,5 times.

Example 1. Wear of cutting teeth of milling cutter in end milling with different incision trajectories during milling along elliptic trajectory with ratio of small diameter to large $d/D = 0,5$ at cutting speeds $V_{cut} = 150$ m/min, feed per tooth $S_z = 0,1$ mm, the depth of cut $t = 0,5$ mm when milling of steels 45, X12, 40X13 (Russian grade) decreases to 2 times.

Productivity due to decreasing of the length of elliptical trajectory as compared with radius trajectory increases to 25% with same amount of wear.

Example 2. In milling of steel 40 and X12 (Russian grade) with end milling cutters with diameter 10 mm made of HSS P6M5 and P6M5K5 (Russian grade), wear of milling cutters working along an elliptical trajectory is reduced by 15 – 20% compared to milling cutters working along incision trajectory and contour of corners along an arc of a circle.

5.2. Influence of geometry and design features of milling cutters on their reliability

The shape of teeth of milling cutters should be following: 1) assure necessary strength of tooth; 2) allow greatest possible number of resharpening; 3) volume of flutes between teeth must be sufficient for placement of chips. According to design of teeth, milling cutters are divided into two groups: with pointed and form relieved teeth.

When *rake angle* γ is correctly selected, milling proceeds smoothly and tool life is increased. With positive *rake angle* γ , tool life is usually higher than with a negative one. Milling with negative rake angle of tools, cutting force increases. During high – speed end milling, change of back rake angle from $\gamma = +10^\circ$ to $\gamma = 10^\circ$ causes an increase of cutting force and power more than 1,25 times. Reduction of positive back rake angle by 1° causes an increase in expended power about by 1 – 1,5%. Therefore, during milling, it is reasonable to use positive back rake angles.

During milling of low strength steels and cast iron, cemented carbide milling cutters usually have *back rake angle* $\gamma = +5^\circ \dots +10^\circ$ and only in milling of special grades of cast iron, for example chromium – nickel, back rake angle is reduced to $0 \dots 2^\circ$. Milling high strength steel, especially with large allowances, allows to use negative back rake angle. But in these cases it is often enough to sharpen a small negative back rake angle ($3 - 5^\circ$) on a narrow «hardening» facet near the cutting edge, and on the other part of front surface make a positive angle back rake angle.

End relief angle α also has a great influence on tool life. To achieve greatest tool life, end relief angle must be chosen in accordance with thickness of cut layer. The smaller allowances, larger end relief angle can be. With a small thickness of cut layer, optimum end relief angle reaches $30 - 40^\circ$. End relief angle of milling cutters, which reinforced by cemented carbide, should be greater than that of high – speed ones, since tool life of cemented carbide mills is mainly determined by wear on flank surface, whereas for HSS milling cutters wear can occur on rake face. However, as end relief angle increases, the strength of cutting edge decreases and danger of its microchipping increases.

Feed less impact on tool life than cutting speed, so it is more profitable to increase productivity due to feed. Feed to tooth can be increased in two ways: by increasing thickness of cut layer, or by increasing width of this layer. If the width of cut layer is increased by 3 times, tool life of milling cutter decreases by $\frac{1}{3}$, and when thickness of cut layer is increased by 3 times, too life will decrease by 5 times. As side cutting edge angle in plane decreases, «active» length of cutting edge increases, that is, length of contact between cutting edge and milling metal.

As a consequence, heat removal from cutting edge into tool body improves, temperature of cutting edge decreases and, accordingly, tool life of milling cutter increases. Thus, increasing productivity is more advantageous by increasing width of the cut layer, leaving its thickness unchanged.

Along with increase of «active» length of cutting edge the reduction of the end cutting edge angle (with constant feed) leads to reduction in thickness of cut layer and corresponding decrease of load on cutting edge and decrease of amount of heat in cutting zone. However, the end milling cutters with a side cutting edge angle less than 30° are not used. Most often apply angles at least 45° to avoid occurrence of vibrations, especially when rigidity of machine tool or work-part is insufficient.

Increase productivity also possible due to *end cutting edge angle* φ_1 . This applies above all to work of end milling cutters in finishing operations. Working with such milling cutters with $\varphi_1 > 0$, we are limited in choice of feed, since at large feeds roughness of surface increases. To increase feed and maintain a low surface roughness, it is necessary to make a small edge with $\varphi_1 = 0^\circ$ on each tooth, this edge must be longer than the feed per turn of milling cutter. Then feed can be significantly increased up to feeds used for rough milling.

For rough milling, it is also desirable to use mills with small end cutting edge angle ($10 - 12^\circ$), which are characterized by increased tool life, if only stiffness of machine tool and the workpart allows. At small angles φ_1 sharply increases the squeezing of milling cutter from the work-part and creates favorable conditions for appearance of vibrations.

By placing a transition edge that connects the main and minor cutting edges at a small angle in the plan φ_0 , or rounding the vertex of the tooth along the radius, it is possible to significantly increase the strength of the tooth. At the same time, heat removal from top of tooth is improving, and tool life of milling cutter is increasing. The angle φ_0 is usually made twice smaller than side cutting edge angle.

The teeth of milling cutter must not only be properly sharpened, but also be smooth finished. Thorough smoothing allows to increase the tool life by 1,5 – 2 times. During check of sharpening, installation milling cutter on machine tool, replacement of worn-out teeth, it is necessary to achieve a minimum beating. Particularly harmful is beating of teeth for a cemented carbide milling cutters. The most protruding tooth usually is microchipped very fast, immediately increasing load on the next tooth, it also chipping, and behind it the rest of the teeth.

Re-sharpening of pointed teeth along flank surface, where wear is mainly concentrated during milling, allows to reduce allowance on re-sharpening, increase tool life of milling cutter, reduce volume of teeth and, most importantly, increase their number z , from this number the productivity of milling depends

proportionally. As the number of teeth of milling cutter increases, roughness of milled surface decreases and unevenness of cutting process decreases. In practice, three shapes of pointed teeth were distributed: trapezoidal, parabolic and reinforced.

The trapezoid shape is the simplest to manufacture, but tooth is somewhat weakened, so it has a small height and a small volume of chip flute. As tooth is re-sharpened on flank (chamfer $f = 1 \dots 2$ mm), its height decreases and it becomes more durable. However, this form of teeth allows for a small number of re-sharpening and is used on milling cutters for finishing treatment. In this case, number of teeth due to their small volume can be maximally possible. When re-sharpening the tooth's height decreases, so total tool life of such milling cutters is small, since they allow only 6 – 8 re-sharpenings. The radius of tooth cavity is taken to be 0,5 ... 2,0 mm.

The parabolic shape of tooth has the greatest strength for bending, since tooth back, formed on a parabola, provides equal strength in all sections along the height of tooth. Disadvantage of this shape is the need for each tooth height to have its own complicated shaped flute milling cutter. Therefore, in order to simplify the profile of back of such milling cutters, the parabola is often replaced by a circular arc with radius $R = (0,3 \dots 0,4) d$.

On the front surface of teeth of parabolic shape there is a rectilinear section, length of which determines number of re-sharpening of milling cutter. At that re-sharpening is allowed only on flank surface (chamfer f), with end relief angle α less than angle α_1 by 10 ... 15° (α_1 is angle between tangent to parabola at point A). Otherwise, the width of land will vary greatly during re-sharpening.

The strengthened tooth shape is used for heavy work instead of parabolic form. This tooth has a broken back, and also expanded thickness and height. These teeth are obtained by double milling with angular milling cutters with angles $\alpha_1 = 28 \dots 30^\circ$ and α_2 . Although number of operations is doubled, such teeth are easier to manufacture than parabolic ones. They have a larger margin for re-sharpening and high strength. In this case, standard flute cutters with rectilinear cutting edges are used. During re-sharpening teeth are sharpened by flank surface at an angle α to maximal sharpness, with obligatory sparkout to avoid beating of cutting edges. Sometimes small cylindrical lands by width $f_n = 0,02 \dots 0,03$ mm are left, they simplify control of beating of teeth of milling cutter.

The form-relieved tooth is outwardly distinguished by a greater thickness, and most importantly by shape of flank surface, which is performed in a special operation called relieving, in order to create end relief angle at all points of cutting edges. This is achieved due to radial section of tooth that containing shaped profile, as milling cutter rotates around the axis, moves towards center

with help of a shaped cutter or grinding wheel. Due to relieving, profile of cutting edge of tooth during re-sharpening along front edge in all radial sections remains unchanged regardless of its complexity. This is the main advantage of such milling cutters, along with a very simple and effortless operation of re-sharpening. In addition, teeth of this shape have high strength, and during re-sharpening, volume of flutes for chips increases, which has a favorable effect on work of milling cutter. At the same time, milling cutters with form-relieved teeth have a number of significant disadvantages, the main of which are:

- the number of teeth in form-relieved milling cutters is much less than in milling cutters with pointed teeth. This is due to the fact that the form-relieved teeth have a large thickness, since during re-sharpening by front surface it is necessary to remove a larger allowance in order to get off from wear that is concentrated on flank surface of tooth;

- during re-sharpening, a large radial beating of teeth is observed, which leads to an increase in the roughness of milled surface and a decrease of tool life of milling cutters;

- milling cutters with an ungrounded profile of teeth after heat treatment, decarburized areas on flank surface remain, reducing their tool life;

- residual thermal stresses can cause distortion of cutter edge profile.

Therefore, mills with form-relieved teeth are inferior in performance and quality of milled surface to milling cutters with pointed teeth. However, because of simplicity of re-sharpening, they are widely used in milling of shaped surfaces.

Milling cutters with pointed teeth. It is advisable to choose the largest diameter of milling cutter, since the number of teeth, their size and shape, and thickness of body are related to this. For pointed milling cutters the most common trapezoidal shape of tooth which is used finishing milling cutters. The tooth of this shape is sharpening on by flank surface. The number of teeth is selected from conditions for ensuring uniformity of milling. For screw milling cutters, the uniformity of milling is achieved in condition when milling width is a multiple of axial step of tool.

Milling cutters with mechanical fastening of inserts provide greater tool life and productivity in comparison with milling cutters of other designs, allow the use various cutting tool materials. The elimination of soldering and knife sharpening reduces the waste and makes it possible to use alloys that are difficult to solder.

For milling of hardened steels and high-strength cast irons, milling cutters equipped with synthetic diamond and cubic boron nitride materials of various grades and ceramics are used. In comparison with cemented carbide milling cutters, these milling cutters provide increased up to 4 ... 10 times cutting

speeds, but with feeds reduced by 4 times; the roughness of milled surface is achieved as in finishing.

Advantages and disadvantages of milling cutters with pointed and form-relieved teeth are:

1. During re-sharpening of pointed milling cutters, space for chip placement sharply decreasing, and in form-relieved ones, on the contrary, it increasing.

2. Form-relieved milling cutters allow more number of re-sharpening than cutters with sharp teeth.

3. Form-relieved milling cutters give inferior purity and greater roughness of milled surface than pointed milling cutters, since they are not subjected to circular grinding (teeth are located at different distances from the axis of milling cutter and have a smaller number of teeth, because of this they work unstable).

4. Profile of form-relieved milling cutter, as a rule, does not grounded, the decarburized layer does not remove during heat treatment, so the resistance of the form-relieved milling cutters is lower.

Milling cutters Form-relieved by Archimedes spiral, along with obvious advantages, have a serious disadvantages: do not allow greatly increase the main end relief angle α , because of that side relief angles are insignificant. For this reason: 1) wear of side edges increases; 2) tool life of milling cutter is reduced; 3) roughness of surface of workpart increases; 4) productivity is reduced due to necessity of milling at reduced modes.

End milling cutters from HSS with a screw cutting part have greatest distribution. They have a higher tool life than spine milling cutters. Compound and assembly construction of milling cutters with screw inserts from high – speed steel are not widely used. The main reason for this is the technical difficulties encountered in production of precise screw inserts from high – speed steel and their connection to body of tool. Improvement of manufacturing technology of end milling cutters is also carried out on basis of use of a compound tool design with helical inserts made from high – speed steel obtained by method of cold twisting.

An example of improving of design is end milling cutters with variable elevation angle of helix line. This design, compared to a constant elevation angle, gives operations much greater stability, which leads to a reduction of tool vibrations even on CNC machines. As a result – improving the quality of milled surface and increasing the tool life.

In Fig. 5.2 shown the guiding of screw surface of variable and decreasing step, located on the cylinder $T_1 < T_2 < T_3 < T_4$. If the screw parameter p for surface with constant step is a constant and is defined as $p = T/2\pi$ then for case of variable step the screw parameter p is a variable depending on the current

value of angle ν and is determined from the expression $p = (T + \Delta \cdot \nu) / 2\pi$ where T is initial value of step; Δ is value characterizing the change of step.

The variable elevation angle of screw line provides: higher feed and depth of cut at high-speed cutting; better control of work-part dimensions; reduction of microchipping of cutting edges; increasing of speed of material removal.

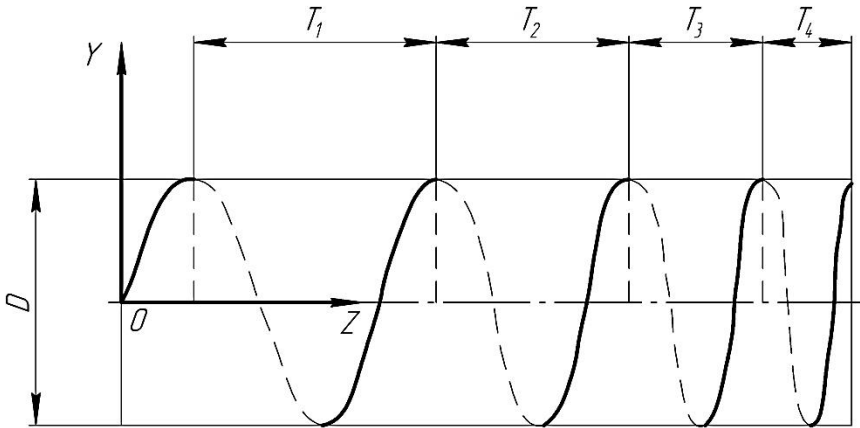


Fig. 5.2. Guides of screw surface of variable and decreasing helix lead

It was developed a combined cylindrical (end) milling cutter with inserts, which have increased serviceability, containing a number of disk modules mounted on bushing and fastened from axial displacement and rotation, and indexable inserts installed on the periphery of each disk module. When roughing operation is performed with square inserts of cemented carbide T5K10 (Russian grade) on work-parts from steel 40X (Russian grade), the number of milled parts increased approximately by 2 times.

Design features of milling cutters equipped with cemented carbide.

Soldered inserts are used only in manufacture of small – sized milling cutters, in which it is not possible to place elements of mechanical fastening of inserts. During cutting of difficult-to-cut materials, preference is given to monolithic milling cutters made entirely of cemented carbide. In designs of medium and large – sized milling cutters, the soldering on bodies of tool is used for cutting cemented carbide inserts of shaped profile.

The main directions in use of inserts are: fastening of inserts directly on body or its components; use of bushes with two or three bases under inserts; use of mechanism for adjusting position of cutting edges of inserts relative to axis of rotation of milling cutter.

Milling cutters with fastening of inserts in housings are most simple in design, compact, have a minimum number of parts, but bodies of these milling cutters are difficult to manufacture.

The serious disadvantages of these milling cutters are: danger of mechanical damage of bodies during operation and increased beating of cutting edges, caused by errors in manufacture of nests under inserts.

When using bushes for fastening of inserts body is technological, and fastening provides a low beating of cutting edges. The use of bushes for cutting inserts makes it possible to avoid damaging an expensive body in cases of inserts breaking and to make quick replacement of them.

To ensure high accuracy of location of cutting edges relative to axis of rotation of milling cutter, a number of designs of milling cutters with adjustment of position in axial direction of bushes in flutes of body with help of screws or wedges have been created, as a result of which it is possible to bring the end beating up to 0,005 mm. Besides, depending on diameter of milling cutter, radial beating is 0,05 ... 0,10 mm, which is achieved due to high accuracy of execution of bodies of milling cutters, cassettes and use of precision inserts.

For milling cutters where inserts located tangential in relation to body, their strength increases sharply under hit loading. Such milling cutters can significantly increase feed and, accordingly, the productivity, but because of the reduced length of cutting edges they are suitable only for removing small allowances.

For milling of work-parts with large allowances, is recommended to use milling cutters with a stepwise arrangement of inserts along axis, which ensures a good pressure of allowance along width and vibration-free work of tool, which is especially important for milling cutters equipped with cemented carbides.

The firm «Sandvik Coromant» (Sweden) developed disk milling cutters with a diameter $d = 80 \dots 250$ mm with direct fastening of special inserts by screws from both sides of the body. These plates have positive back rake angles. With tangential fastening, they are most durable, and with four cutting edges they provide higher tool life.

For milling planes, grooves, ledges and hard-to-work materials, face end milling cutter цшep synthetic diamond and cubic boron nitride cutting elements can be used, which allows cutting tools to be adjusted by diameter of milling cutter (Fig. 5.3).

The cutters are divided by vibration accelerations amplitudes A into two classes. The first class includes milling cutters with wedge fastening of inserts, in which amplitudes of vibration acceleration have resonant peaks of the order of $1500 \dots 2000 \text{ m/s}^2$. The second class includes milling cutters, in which resonance peaks are of the order of $3000 \dots 4000 \text{ m/s}^2$.

The best indices by vibration resistance shows method of fastening of inserts with hole by screw, when inserts based on three points along the lateral surfaces, with assurance of power closure to supporting surface. The static characteristic of quality of milling cutters is compliance δ_B of cutting insert with load by force P in range from 0 to 1500 N.

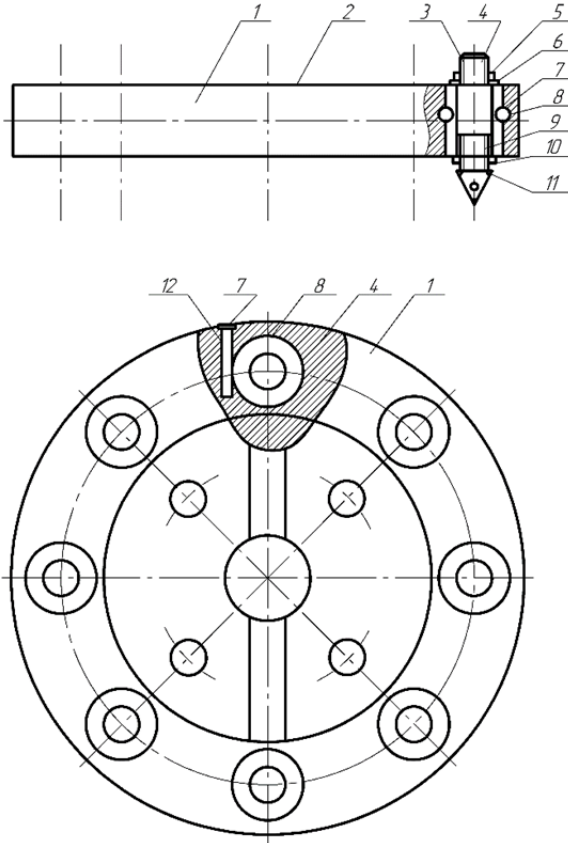


Fig. 5.3. Construction of assembly face end milling cutter, equipped with cutting inserts:
 1 – body, 2 – end surface of milling cutter, 3 – thread, 4,9,12 – cutting inserts,
 5 – nut, 6 – washer, 7 – rod, 8 – eccentric bushings, 10 – adjusting nut,
 11 – cutting elements

Milling cutter with double negative geometry. With wedge fastening of inserts from accuracy of design of elements depends from contact area of inserts with adjacent elements and gaps between them, which affect the rigidity and

vibration resistance of structure, which ultimately affects the tool's life and quality of milled surface. This is particularly important for milling cutters equipped with inserts from cutting ceramics.

Cutting cassettes are used in system of face milling cutters, on which the inserts of a wide nomenclature with various sizes and geometric parameters can be fastened. During operating in same modes, tool life of cassette milling cutters is higher than standard milling cutters, and with increasing of feed, this spread becomes more pronounced and at feeds over 0,3 mm/tooth becomes double. Rational feeds, based on maximum volume of cut material in one period of tool life, is 0,1 ... 0,2 mm/tooth for standard milling cutters, and for new milling cutters 0,3 ... 0,4 mm/tooth. Milling cutters with negative geometry have increased rigidity and vibration resistance and provide higher milling performance, but require higher power and rigidity of machine tool.

The tangential fastening of inserts in bodies of face milling cutters ensures maximum hardness of cemented carbide and allows working with a large thickness of cut layer.

During milling, the following processing errors are possible, related to the state of tool:

1. Errors of shape (nonflatness, nonstraightlinearity) when milling of work-parts with a large depth of milling, especially with unequal allowances and insufficient rigidity of system «machine tool setup fixture – tool – work-part».

2. Incorrect location of milling cutters on mandrel or wrong choice of size of milling cutters.

3. Reduced class of surface roughness due to incorrect sharpening of milling cutter, beating of milling cutter, large wear or microchipping of cutting edges of teeth, improper selection of cutting modes and cutting fluid, insufficient rigid fastening of the work-part, insufficient rigidity of mandrel etc.

4. Vibration during milling. The presence of vibration has a negative impact not only on roughness of milled surface, but also significantly reduces tool life of milling cutter and reduces service life of machine tool.

The milling cutters equipped with ceramics and superhard materials can process steels hardened to hardness 60 HRC, excluding in some cases grinding operations.

5.3. Wear of milling cutters

The wear of the cutting wedge occurs at a certain distance from the immediate zone of chip formation, in an area equal to about half the nominal contact length (Fig. 5.4), which is explained by the presence of a constrained layer. However, during milling, there is another picture. On worn cutting edges of milling tool, there is wear over along entire effective contact length.

This type of wear is due to features of operation of milling tool. In the case of counter milling, chip formation is preceded by plastic deformation of milled surface. If conditions when thickness of cut layer a exceeding rounding radius of cutting wedge ρ or when a limit value of breaking deformation e_p is reached, than «leading» crack or loosened area forms, depending on properties of milled material. During down cutting, the tooth of milling cutter starts its work with hit penetration with maximum value of thickness of cut layer and, correspondingly, with maximum load, that gradually decreasing to zero. Both variants of combination of motion lead to that zone C_1 is subjected to the greatest load, which leads to such a wear characteristic.

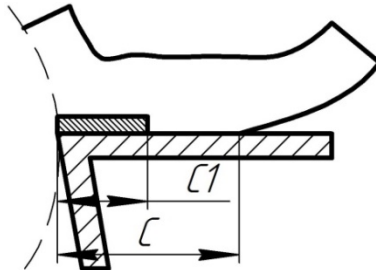


Fig. 5.4. Two areas of friction on the rake face surface

The most characteristic for cemented carbide end milling cutters is the formation of longitudinal (perpendicular to cutting edge) and transverse (parallel to cutting edge) cracks on rake face surface and brittle fracture of cutting part of the tool in the form of microchipping of shear fracturing (Table 5.1).

Brittle fracture of cemented carbide milling cutters is divided into microchipping and local shear fracturing, as an internal contact failure, and microchipping of the cutting part of tool, leading to its failure.

The main reason of microchipping is welding of chips to contact areas of tooth of milling cutter when it leaves contact with work-part. With repeated penetration, chip is detached from contact area together with particles of cutting tool material. The reason of microchipping is periodic separation of stagnation area from contact surfaces at time of chip breaking. Such microchipping of

cemented carbide cutting tools are associated with surface defects, heterogeneity of structure of cutting tool material, and serve as additional stress concentrators. Periodic separation of stagnant area from contact areas creates cyclic tensile stresses in cutting wedge, contributing to destruction of tool as a result of the phenomenon of fatigue.

The formation of cracks in cutting part of cemented carbide cutting tool, which cause microchipping and shear fracturing, is associated with fatigue failure of cemented carbide as a result of action of variable force and especially thermal loads. During idling move the surface layers of tool cooled more intensively than the underlying layers, and tend to compress, and the underlying layers obstruct it. As a result, tensile stresses appear in surface layers, which lead to formation of cracks. The appearance of longitudinal cracks relaxes stresses in this microvolume of cutting part, whereas in neighboring microvolumes, due to deformation conditions close to planar ones, high stresses remain, until a crack also appears there. As a result, a large number of cracks, perpendicular to the greatest principal stresses, are formed on contact areas of the tool. Longitudinal and transverse cracks are formed as a result of action of variable temperatures, and the mechanism of local share fracturing, whose dimensions do not exceed the dimensions of contact areas, is due to thermal cracking.

Table 5.1

Types of failure of cemented carbide milling cutters

Types of failure			
Failures, eliminated by re-sharpening	1	Wear	8%
	2	Cracks in contact area	
	3	Microchipping: a) microchipping with a size of 0,05 – 0,30 mm b) middle microchipping with a size of 0,3 – 1,0 mm c) large microchipping with a size of 1,0 – 3,0 mm	5%
Failures, not eliminated by re-sharpening	4	Share fracture: a) share fracture of vertex on entire thickness of insert b) cut of the blade along the flank surface c) large share fracture	7%
	5	Shifting or tearing of insert out of holder nest	10%

If the tool operates under less severe conditions, for example, in semi-finished and finished milling of steel, it is more profitable to equip tool with heat – resistant alloys T15K6 and T15K6T (Russian grade). For rough milling of cast iron and non – ferrous metals with small allowances, cemented carbides BK4B,

BK6, BK8 (Russian grade) are recommended for tools. These same alloys are often used for semi – finished and fine milling of stainless steel, as well as for milling of plastics.

Finishing milling of steel parts with small allowances is carried out at high cutting speeds with a milling cutter equipped by cemented carbide T30K4 (Russian grade). If the part is from cast – iron, from non – ferrous metal or non – metallic material, it is best to choose milling cutter with teeth from alloys BK2 or BK3 (Russian grade).

For the cemented carbide T5K12B (Russian grade) and cemented carbides containing 3% tantalum carbide, TT7K12 and TT7K15 (Russian grades), production tests and special studies have established the possibility of their successful application for milling. In comparison with the alloys T5K10 and BK8 (Russian grades), these alloys are distinguished by higher strength in heavy work.

Applying the alloys TT7K12 and TT7K15 (Russian grades) to remove large uneven – dimensional allowances on the crust, it is possible to increase feed rate by 1,5 to 2,5 times as compared with feed allowable for alloy T5K10 (Russian grade), without reducing of cutting speed. At the same time, with a small load on the tool, operating with small feeds, new alloys are less effective; in such conditions they are less wear – resistant than other hard alloys widely used in factories.

Along with cemented carbide milling cutters, milling cutters from other cutting tool materials are widely used. Modular shaped milling cutters, narrow cutters for grooving and some others are difficult to equip with a cemented carbide, so they are made from high – speed steel P18 (Russian grade), and in other cases, from steel P9 (Russian grade). High – speed cylindrical and end milling cutters operate well for rough milling with large feeds, if cutting speed is relatively small and temperature in cutting zone does not exceed 500 – 560° C.

Slotting cutters, shaped and end mills of small diameters, operating at small feeds (up to 0,05 mm/tooth) and cutting speeds of 20 – 30 m/min, when the temperature in cutting zone does not exceed 200 – 250° C, are often made of carbon steel Y12A (Russian grade) or from alloy steels XГ, XB5, 9XC or XBF (Russian grades).

For milling of parts from heat – resistant steels or alloys, most durable cemented carbide grades are used, as well as high – speed steels of grades P18Φ2, P9K10 and P9K5 (Russian grades), which differ from steels P18 and P9 (Russian grades) by increased content of vanadium and cobalt, and steel P24 (Russian grade), that have more tungsten than steel P18. Shaped cutters of high – speed steel P18Φ2 (Russian grade) during milling of cast high – temperature high – alloy material on nickel base have a resistance 3 – 4 times higher than milling cutters made of steel P18 (Russian grade). During milling with end

milling cutters from high – temperature alloy ХН77ТЮ (ЭИ437) (Russian grade), tool life of milling cutters from steel P9K10, P18Φ2 is 1,5 – 2,5 times higher than milling cutters from steel P18 (Russian grade). Steel P9K5 (Russian grade) has approximately same cutting ability as P18 (Russian grade).

5.4. Strength of milling cutters

With insufficient strength of cutting part of tool, its failure occurs by brittle shearing and microchipping or as a result of plastic deformation and subsequent shearing. In practice, during milling of many materials, cutting conditions are reduced in order to avoid failure of tool.

Share fracturing of cutting part of tool occurs at moment when tensile stresses in dangerous area of front surface at a distance $l = (2 \dots 2,5)l_k$ from cutting edge reach the limit of strength. A microcrack is formed, which, developing, is transformed into a macrocrack and, as a result, begins share fracturing. This type of failure is accompanied by share fracturing of relatively large volumes of cutting tool material.

The limiting thickness of cut for planing, when other conditions being equal, should be about 1,3 – 1,4 times less than for turning, and for milling – 2,4 – 2,7 times less, as l_{max} increases by 1,7 times, and limit of strength due to alternating nature of cyclic load should be understated by 1,4 – 1,6 times.

No less important factor causing brittle failure of cutting tool are thermal stresses arising in process of cutting (σ_θ). During milling of carbon steel and high – temperature nickel – base alloys in heated state, their value can reach strength of cutting tool material. For example, for a cemented carbide BK8 (Russian grade) ($E = 540 \text{ GPa}$; $\alpha = 5 \cdot 10^{-6} \text{ K}^{-1}$; $\nu = 0,22$; $\lambda = 104,75 \text{ J}/(\text{m}\cdot\text{s})$; $\omega_t = 4 \cdot 10^{-5} \text{ m}^2/\text{s}$) at $t = 0,01 \text{ sec}$ and temperature of 1273 K, the compressive stresses at a depth of 0,5 mm from the cutting edge are 3,25 and 1,95 GPa, respectively. Under the same conditions, tensile thermal stresses in air cooling process for 1 s are 0,406 and 0,325 GPa, and when cooled by water, 1,138 and 1,04 GPa, respectively. The stresses on tool surface exceed strength limit of alloy BK8 (Russian grade) under uniaxial tension and they can cause failure of tool.

To prevent formation of thermal cracks and subsequent destruction of cutting part of tool during milling, the temperature gradient should be lowered, and consequently cooling rate, using various methods, up to preheating of tool at a certain temperature, or by selecting a tool material with a low modulus of elasticity, coefficient of linear expansion, with high thermal conductivity, etc.

To prevent plastic destruction of cutting part of tool (at $\gamma = 0 \dots 10^\circ$), one of necessary conditions is requirement that tool hardness exceeds hardness of the cut layer in chip formation area by 1,4 times or more.

Increase efficiency of assembly milling cutters by removing internal stresses of inserts. Preheating of cutting part allows to increase efficiency of metal cutting tool. This is explained by withdrawal of cutting tool cemented carbide material from brittle to brittle – plastic state, which allows the tool to operate work with high loads.

In accordance with the Peltier effect, if an electric current is passed through a boundary area between two contiguous different metals, for example, inserts of cemented carbide TK (TiC-Co) (Russain grade) and titanium (Ti), than electrons passing through this area depending on current direction will be or accelerated by the contact field, or decelerated. In the first case, heat is released in boundary layer, and heat is absorbed in second layer.

However, during heating of carbide cutting insert on basis of the Peltier effect, intensive heat exchange takes place with titanium insert. In order to increase heating temperature of the insert from group TK (Russian grade) and to reduce heat removal to titanium insert, a semiconductor layer consisting of molybdenum disulphide with a liquid glass is additionally inserted between inserts, which, together with an increase of heating efficiency of cutting insert, reduces heating of titanium insert (Fig. 5.5).

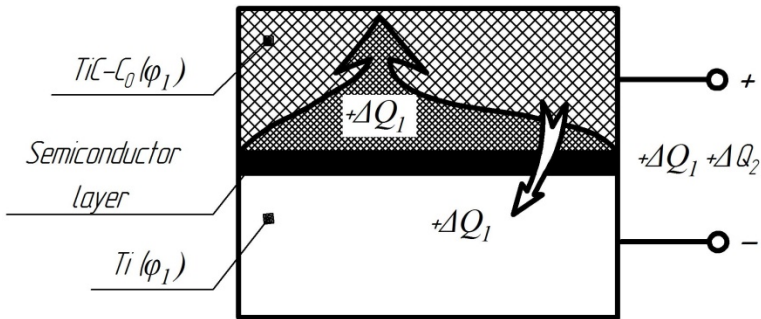


Fig. 5.5. Preheating scheme of cutting insert with a semiconductor layer

Due to the increase in crack resistance of cutting insert in the initial period of milling and its subsequent maintenance due to milling regime, the maximal cutting path of inserts of metal cutting tool before failure is increased by 60 – 70%.

5.5. Features of application of cutting fluids for milling

For heavy milling operations, a cutting fluid is needed to form strong oil membrane on the tool that does not degrade at high pressures and temperatures. Such cutting fluids are sulphofresols – sulfurized mineral oils, which are chemical compounds of sulfur with mineral oil, and sulfurized fats.

For finishing and semi – finishing milling, various emulsions are used, for example an aqueous emulsion representing a 6% solution of emulsol. Emulsol consists of 70 – 80% of mineral oil, 18 – 20% of soap, 2,5 – 5% of alcohol and 4 – 5% of water. As cutting fluid can also serve soda water; soda is added to water in an amount of 5 – 10% in order to prevent corrosion of machine tool parts and milling work-parts.

The permissible value of wear of milling cutters, the excess of which leads to a catastrophic increase in wear, also depends on cutting fluid. When milling dry ($V = 98$ m/min), the average value of permissible wear of mills along the corners does not exceed 0,3 mm (often destruction began from 0,25 mm wear), and with water coolants it was 0,35 – 0,4 mm.

With use of oil cutting fluids milling cutters retain cutting properties when wear along main rear face, equals to 0,4 – 0,5 mm, and with cutting fluid MP-4 – 0,8 – 0,9 mm. With an increase of cutting speed to 154 m/min, permissible value of wear decreases with all cutting fluids.

Wear corresponding to end of run – in period, when cut with water cutting fluid is 1,5 – 2 times higher than when working with oils, and with increasing cutting speed it decreases.

The features of milling determine technological features of feeding of cutting fluids. The traditional supply of cutting fluids by irrigation with low pressure (up to «self-flow») in case of milling is ineffective, and sometimes even has a negative impact due to a sharp temperature drop (effect of «thermal» hit). Pressure of chips on front surface of cutting edge is ten times higher than «load capacity» of cutting fluids, which leads to a rupture of continuous layer between rubbing surfaces. The greatest effect from application of cutting fluids is obtained when they flow directly into cutting zone. It is enough to supply liquid with a thin stream (but under high pressure) or in sprayed state from side of flank surfaces of the tool. In first case, a thin jet of liquid is pumped by a pump under pressure of 15 – 20 atm through a special nozzle. The liquid cools the tool and part and partially evaporates. Tool life of a high – speed tool in this way increases by 6 – 10 times, cemented carbide by 3 – 5 times. If liquid is supplied sprayed (using compressed air for this purpose), it is possible to increase tool life of the milling cutters by 2 – 4 times.

Application of cutting fluids at the stage of preliminary run – in reduces contact area of chips with rake face surface of tool and increases the level of

normal stresses, thereby strengthening the deformation processes on working surfaces of tool, ensuring formation of contact layers of a hardened wear – resistant structure.

Modern milling cutters are manufactured taking into account these features – they have internal supply of cutting fluid through special holes in the tool body. This makes it possible to deliver cutting fluids as close as possible to milling zone, and its high pressure (in some modern machines working pressure of cutting fluids is realized up to 80 atm) is able to additionally bend chips, partially fulfilling role of chip-breaker. However, such tool is on average 40% more expensive than a similar one without internal supply of cutting fluid and can only be used in machine tools of the room type.

Application of cutting fluids leads to cracking of tool due to thermal hit. Blasting of cutting zone, spraying of cutting fluid, oil mist are used for cooling of milling cutters. It is applied carbon dioxide, nitrogen, cooled compressed air. Substitution of liquid cutting fluids to air blowing leads to improved environmental conditions around machine tool, reducing of washing and drying operations, reducing of cost for supply system servicing, but air cooling is not always effective. The main disadvantage of air as cutting fluid is poor lubricity.

Application of cooled ionized air is more effective method of air cooling of cutting zone. Ionization of air replenishes lubricating function of gaseous cutting fluids due to acceleration of oxide films formation on tool surfaces.

Carbon dioxide is fed to machine tool in balloon in liquid state under high pressure (about 60 atm). From balloon through a special tip carbon dioxide is fed into cutting zone.

Leaving balloon, carbon dioxide passes into the gaseous state and is strongly cooled (up to – 40°C). Carbon dioxide cooling is successfully used for milling of hard – to – work materials (titanium, nickel, chromium and others). Tool life of milling is increased by 2 – 3 times.

In processing of austenitic grade steels, for example, steel 12X18H10T (Russian grade), one of prospect areas for performance improvement of milling cutters made of steel P6M5 (Russian grade) is use of cutting fluids on basis of vegetable oils with use of minimum lubrication technology. The use of vegetable oils (castor and rapeseed oil) significantly increases tool life of milling cutters teeth in comparison with dry milling and with such cutting fluids like MP – 99 and И – 20A (Russian grades). Application of castor oil as cutting fluid using minimum lubrication technology is the most effective for finishing milling. For milling with depths of cutting more than $0,5 \div 0,8$ mm, it is expedient to use rapeseed oil.

Single action cutting fluids. High – speed milling is characterized by deterioration in access of cutting fluid to cutting zone and a decrease in its technological and logical efficiency. Milling with the use of single action cutting

fluids is carried out, for example, by filling the space between teeth of the milling cutter by hard cutting fluids that melted during milling, or by continuously feeding of plastic cutting fluid into this space through system of channels made in milling cutter body.

In both cases, there is a transition from conventional cutting to cutting by «composite» milling cutter, working surface of which includes alternating cutting areas (teeth) with inclusions of solid or plastic cutting fluids. The latter, in addition to heat removal from heated surfaces of tool and the work-part due to melting, are efficiently transported to milling zone and lubricate friction pairs in contact, and also damped shock loads in cutting process.

5.6. Thermal treatment of milling cutters

The milling cutters are manufacture from high – speed steels P18, P12, P9 and alloyed steels 9XC, XBG (Russian grades) According to configuration and working conditions, milling cutters are distinguished: 1) in which working part is located along the entire height, and, consequently, they must be completely hardened to obtain high hardness; to such milling cutters relate worm, cylindrical, end face, face and disk, fluting, cutting (circular saws) and scoring (spline), round – shaped convex and concave; 2) with working and tail parts (end, dowel, for machine tools with T– shaped flutes); end and flute milling cutters with a diameter more than 10 mm are made by composite (welded): working part – from high – speed steel, tail part – from carbon steel.

The milling cutters of first group include disk cutters from steel P18 (Russian grade), which are treated in following order: first heating to 450 °C, the second to 830 – 850 °C, final heating to 1250 – 1290 °C, cooling in NaOH heated to 500 °C, with followed by air cooling, washing at temperatures above 70 °C and etching; washing at 20 °C and passaging; triple tempering in another unit or in furnaces at temperature of 560 °C (exposure 1 hr).

Disk slotted and cutter milling cutters of large diameter and small thickness can be deformed under influence of their own mass during heating, and therefore they should be heated in an upright position on the mandrel. It is advisable to cool slotted and cutter milling cutters in a special press for hardening in dies with cooling working surfaces. When hardening, the cylindrical milling cutters are immersed in cooling fluid in an upright position on a special tool. Worm milling cutters are cooled in a horizontal position. The process of heat treatment of milling cutters of the second group is basically the same as for welded drills.

Thermal treatment of disc milling cutters from steel P6M5 (Russian grade) with diameter up to 280 mm is carried out in a magnetic field on device

that is a double coaxial electromagnet for exciting a constant magnetic field of 1600 kA/m. The effect of magnetic field in superplasticity temperature range of steel during formation of stress and cooling martensite makes it possible to produce a deformation – free hardening of products due to «internal» dressing of product and a reduction of structural stresses level due to decay of martensite during quenching. The use of magnetic quenching eliminates the need for hardening under press, increases tool life of milling cutters up to 1,6 – 1,8 times.

5.7. Surface hardening of milling cutters

The following methods of milling cutters hardening are used: application of wear – resistant coatings; application of antifriction coatings; mechanical hardening (shot blasting and vibration treatment); chemical – thermal treatment (nitriding, carburizing, etc.); galvanic hardening; hardening using physical methods (treatment in magnetic field, laser hardening, deep cold treatment).

Hardening of cutting part of milling cutter from high – speed steel by dynamic micro – alloying is an innovative solution. Milling cutters manufactured with use dynamic micro – alloying showed a 1,24 times greater tool life compared to control ones during milling of flutes in details from alloy XH68MBTIOK – ВД (Russian grade) on vertical milling machine tool with emulsion cooling.

The use of laser – plasma treatment for hardening cut – off and slotted milling cutters from high – speed steel A11P3M3Φ2 (Russian grade) increases their tool life up to 10 times (traditional methods increase tool life by no more than 1,5 – 3,0 times). Laser – plasma treatment forms nanostructural layers in surface layer of steel A11P3M3Φ2 (Russian grade).

The technology of pulsed laser hardening of cutting, slotted milling cutters from high – speed steels P6M5, P6M5K5, P9K5, P18 (Russian grades) on a solid state technological laser model HTF – 200, allows: to increase tool life of milling cutters up to 10 times; to decrease adhesive grasp especially during milling of non – ferrous alloys; to increase cutting speed.

Ion implantation with nitrogen of milling cutters from steel P6M5 (Russian grade) reduces their wear up to 1,5 – 2 times.

5.8. Coating application on milling cutters

Formation of a large number of longitudinal cracks in coating at a certain distance from cutting edge is characteristic for a tool with a coating during face milling in the first minutes of cutting. In the future, several longitudinal cracks

are formed in tool base, which extend to cutting edge. The appearance of cracks on contact surfaces of the coated tool is faster than for uncoated tool, but the rate of growth is significantly less. In addition, transverse cracks in tool base and a grid of cracks in coating are appears on tool pads. The cause of formation of longitudinal cracks in tool base of the cutting wedge is the germination of longitudinal cracks from the coating to base. For a tool with TiC coating, obtained by gaseous phase deposition and thermodiffusion saturation methods, the later formation of cracks in contact areas and slower growth rate are characteristic than for a tool with TiN coating. The low crack resistance of TiN coating is explained by a columnar structure with a high anisotropy.

Formation of longitudinal and transverse cracks in TiC – TiCNTiN coatings of various thicknesses at face milling is caused by sharp temperature changes during working and idle strokes, difference in thermal expansion coefficients, temperature drop across the coating thickness and plastic deformation of cutting wedge. The decrease of longitudinal cracks number in coating with a decrease of its thickness is explained by an increase of coating plasticity and decrease of defects in it.

To maximize efficiency of cutting tool during face milling it is necessary to create a coating that simultaneously possesses high strength and crack resistance, low adhesion to milled material and property to minimize level of thermal and force loads on the tool.

This problem is solving by use of multilayer coatings. Multilayer coatings have an increased resistance to brittle fracture under conditions of varying mechanical loads, increased inclination of tool cutting part to thermoplastic deformation and high – temperature creep due to alternating thin layers can extremely effectively inhibit supercritical cracks development. The greatest influence on tool life affects thickness of layer (Ti, Zr)N, slightly smaller - TiN and the smallest - TiCN.

Coatings that have high values of microhardness, strength of adhesion with tool base and crack resistance, have a low wear rate. The minimum wear intensity during milling with high cutting speed and high feed rate have inserts with multilayer coatings with thicknesses of 6 μm , when thicknesses of TiCN and (Ti, Zr)N layers equal to 33% and (33 – 42%) of its total thickness.

These coatings decrease wear rate of tool by 1,6 times compared to two – layer coating of TiCN – TiN, and by 2,9 times compared with single – layer coating TiN. Due to low fracture toughness coefficient K_{mp} , these coatings more effectively restrain the processes of crack formation, intensity of which increases with milling at high cutting speeds and large feeds per tooth. During milling at lower cutting speeds and feeds per tooth ($V = 157 \text{ m/min}$, $S_z = 0,25 \text{ mm/tooth}$) thermal tension of cutting process is lower. In these conditions, tools with total thickness of coatings of 4,5 μm and a ratio of thicknesses of layers TiCN and (Ti,

Zr)N, analogous to thickness of multilayer coating of 6 μm , have a lower wear rate. Tool life with these coatings depends greater from thickness of top layer TiN and less on thickness of layer (Ti, Zr)N. The higher efficiency of these coatings during milling in this cutting mode is explained by a different mechanism of coating breaking. Milling at a low cutting speed with a smaller feed per tooth is accompanied by a much lower intensity of cracking process and adhesion fatigue processes prevail in coating destruction, which is better resisted thinner coatings. Intensity reduction of coating destruction contributes higher strength adhesion of tool base with thin coatings in comparison with coatings of greater thickness. Compared with two – layer coatings of TiCN-TiN, application of three – layer coatings with thickness of 4,5 μm in mentioned above cutting mode reduces wear rate of tool by 1,43 times, and by 2,55 times compared with a single – layer coating TiN.

Example 1. During face milling of leading final drive gear of rear axle from steel 20XH2M (Russian grade) with use of cutting fluid ($V = 92$ m/min, $S_z = 0,18$ mm/tooth, $t = 2,5$ mm, $B = 80$ mm) application of coatings TiCN – TiN and (Ti, Zr)CN – TiN increased tool life of face milling cutters with inserts T5K10 (Russian grade) by 2,1 and 3,8 times, relatively, while coating TiN – by 1,2 times. During face milling of gear body from cast iron C418 (Russian grade) without cutting fluid ($V = 94.6$ m/min, $S_z = 0,2$ mm/tooth, $t = 2.5$ mm, $B = 230$ mm) tool life of milling cutters with inserts BK8 (Russian grade) with mentioned coatings increased by 2,5 and 4,6 times, and during milling of turn fist body of front axle from cast iron K435 – 10 (Russian grade) with cutting fluid (milling cutter with inserts BK6 (Russian grade), $V = 55,8$ m/min, $S_z = 0,11$ mm/tooth, $t = 1$ mm, $B = 90$ mm) relatively up to 1,6 and 2,6 times in comparison with uncoated tool.

Example 2. During milling of work parts from steels 20 and 45 in annealed state by end milling cutters with inserts T5K10 (Russian grade) ($V = 123$ m/min, $S_{min} = 160 – 250$ mm/min, $t = 3$ mm, $B = 125$ mm) and by end milling cutters from alloy BK6 of work-parts from steels XBГ, 12X18H9T and 4X5MФC (Russian grade) ($V = 25 – 40$ m/min, $S_{min} = 20 – 80$ mm/min, $t = 1,5 – 2$ mm), as well as workparts from steels XBГ and 4X5MФC (Russian grade) in quenched state (HRC 48 ... 52), ($V = 2.5$ m/min, $S_{min} = \text{manual}$, $t = 1$ mm), application of three – layer coatings increased tool life of milling cutters in 1,3 – 3,5 times depending on cutting conditions. At the same time, application of single– layer coatings TiN in some operations did not ensure an increase of tool life.

As an intermediate layer of multilayer coating, it is necessary to use complex titanium and zirconium nitride (Ti, Zr) N, which has the greatest ability to inhibit crack growth in comparison with other coatings. By selecting properties of upper and lower layers of multilayer coating (by changing of

technological parameters of their condensation), it is possible to influence on stress state of its boundaries, strength of adhesion between layers and tool base, and thereby change its crack resistance and adhesion strength properties.

The use of multilayer coatings during milling of workparts from carbonaceous and low alloyed steels increases tool life of face milling cutters up to 2,8 – 4,8 times as compared to single – layer coating TiN, depending on coating design, cutting mode and treated material.

Methods of thin coatings by physical and chemical deposition from gas phase have significant disadvantages: high integral heating of base and energy intensity. The process of finishing plasma hardening allows to compensate marked above disadvantages, namely:

1. heating of product in finishing plasma hardening process (no more than 100 – 150 °C) does not cause deformation of parts, and also allows hardening of tool steels with low tempering temperatures;

2. finishing plasma hardening process conducted in air at ambient temperature, does not require vacuum or other chambers and makes it possible to harden products of any size.

The essence of finishing plasma hardening consists in depositing a thin (about 3 microns) amorphous coating SiC with simultaneously plasma hardening process of a thin near – surface layer. After combined hardening treatment – vacuum nitriding and finishing plasma hardening tool life of milling cutters from steel P6M5 (Russian grade) is increased by 2 – 5 times, depending on cutting conditions.

The application of electro – acoustic coating technology and electro-acoustic alloying method allows to solve the problems of increasing of tool life of milling cutters. For disk milling cutters with electro – acoustic coating technology, an increase in cutting speed with approximately same feed per tooth is characteristic. This leads to increased productivity and increased tool life, as well as a significant reduction in cost of milling. Thus, during processing cold – rolled steel with a cutting speed of 9,0 m/min and a feed 0,07 mm/tooth, volume of cut metal during endurance period of end milling cutter is increased from 85 cm³ (uncoated milling cutter) to 155 cm³ (coated cutter); at cutting speed of 18 m/min and same feed, these figures are 30 and 180 cm³, relatively. During processing of stainless steel 12X18H9T (Russian grade) with a cutting speed of 12,5 m/min and a feed of 0,07 mm/tooth and cutting speed of 25,6 m/min and same feed, volume of cut metal increases from 130 to 220 cm³ and from 180 to 360 cm³, relatively, while in second case volume of cut metal during endurance period of end milling cutter with coating after re – sharpening is 340 cm³. The end and splined milling cutters are hardened after each re – sharpening.

5.9. Application of combined methods of hardening of milling cutters

Complex surface treatment methods combining processes of ion-plasma coating deposition and surface hardening treatment (usually ion nitriding) are used. Preliminary surface treatment of cutting tool contributes to growth of cutting wedge resistance to elastic deflections and shape stability, which leads to an increase of tool life. At the same time, such preliminary surface treatment does not affect the properties of coating material and strength of adhesive connection of coating with tool base, which significantly affect the process of coating destruction. An increase of mentioned above characteristics can be achieved by additional hardening treatment after coating deposition.

Laser treatment of multilayer coating increases connection strength of coating with the tool base and cohesive strength of coating. Laser treatment of coatings, provides maximum reduction of cutting tool wear both on the rake face and flank surfaces in comparison with coatings without laser treatment. For two – layer coatings TiN-TiCN and TiCN-TiN, minimal wear of cutting tool is provided by construction with internal hard layer thickness of 75% from total coating thickness and treated by laser, at a power density of laser radiation about $2,4 \text{ W/cm}^2$. The greatest increase of tool life was observed with coating TiCN – TiN after laser treatment, and this increase was 3,67 compared to coating TiN.

Application of combined ion – laser hardening treatment makes it possible to increase tool life of slotting used in operation of slotting in tongue needles of knitting machines by an average of 1,8 – 2,5 times and to reduce roughness of treated surface about 2 – 3 times.

End milling cutters ($\varnothing 8 \text{ mm}$) made from high – speed steels S6-5-2, P6M5, P18, P6M5K5 (Russian grade) were subjected to strengthening thermo cyclic treatment and next low – temperature nanohydrochemical treatment. During milling with cutting speed of 29,9 m/min, feed of 0,01 mm/tooth, milling depth of 2 mm and a width of 8 mm, tool life increased by 1,6 – 10,8 times compared to milling cutters after conventional heat treatment. As a criterion of wear, a 0,25 mm wear crater was used.

6. RELIABILITY ASSURANCE OF BROACHES

6.1. New means of broaching

Speed broaching, for example, of compressor blades locks from titanium alloys BT8 and BT3-1 (Russian grades) and heat – resistant nickel alloys ЭИ787ВД and ВЖЛ14 (Russian grades), at cutting speeds of 25 – 30 m/min compared to low – speed method (1,5 ... 4 m/min) contributes to establishment of optimum process temperatures and significant reduction of broaches wear, cutting forces and chips shrinkage. At an optimum temperature (for example, 700 ° C for alloy ЭИ787ВД), material plasticity (minimum of reduction of area ψ and elongation δ) sharply decreases with a decrease of its strength properties. High –speed broaching by cemented carbide broaches reduces machine time by 10 or more times, provides an increase in average tool life of broach, for example, by 10,5 times when broaching of compressor blades locks from heat – resistant alloy ЭИ787ВД (Russian grade), and up to 27 times in broaching of locks from titanium alloy BT3-1 (Russian grade) and up to 31 times in broaching of locks from steel ЭИ736Ш (Russian grade).

The minimum wear rate of broaches was observed at different optimal cutting speeds V_0 for different feeds per tooth S_z , but at the same optimum cutting temperature $T_0 = 700$ °C, which coincides with plasticity failure temperature T_p .

To eliminate accelerated wear of expensive broaches that arise when heat – resistant and alloyed steels processing, for example chromium, and also hard – to – work materials with low surface quality, mandrels and cutting – smoothing broaches have been developed. The first ones, working with large oversizes, are difficult to design and do not remove defective layer, the latter do not solve the problem of low resistance of cutting teeth. Therefore, method of *deforming – cutting broaching* (DCB) has been developed, which allows to solve the problem of cutting teeth tool life by reducing cutting force along mechanically hardened layer and simultaneously improve processing quality. However, disadvantage of deforming – cutting broaches, main difference of which is cutting with advanced plastic deformation, is chipping of support ends of bushings, which arise from over-cold-hardening and increasing of cutting allowance to base end and formation of steps on treated surface because of elastic shrinkage of bushings.

Deforming – cutting broaching allows to intensify broaching process and apply shorter tools (improve process performance). When cutting a previously mechanically hardened surface layer with a thickness of 0,02 to 0,07 mm, despite increase in hardness, cutting forces are reduced by 30 – 40%, and a reduction in cutting force contributes to an increase in dimensional stability of cutting teeth.

High precision and hardening of surface layer is provided by deforming – cutting broaching with oblique – coal cutting (Fig. 6.1).

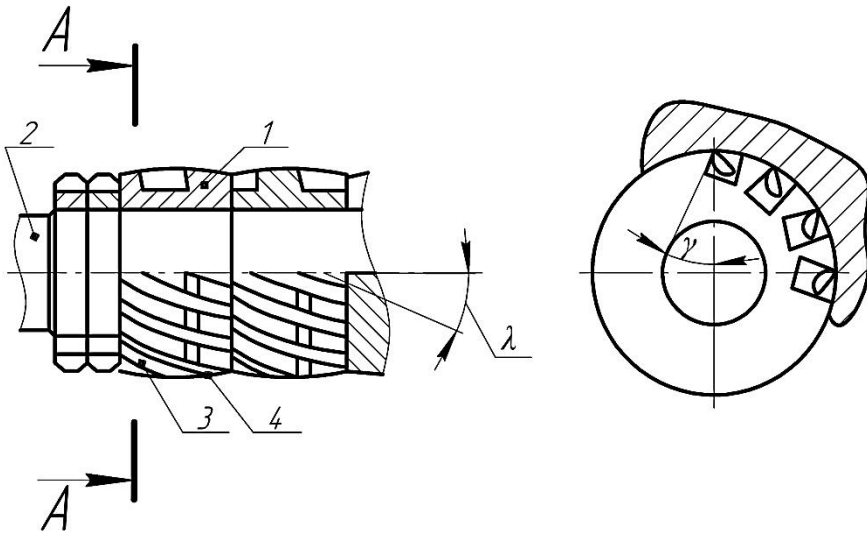


Fig. 6.1. Deforming – cutting broaching with oblique cutting

Location of deforming – cutting elements 1 mounted on mandrel 2 showed on Fig. 6.1. The width of flutes 3 on work surface is equal to width of formed projections 4. The flutes are made at an angle γ to broaching axis in cross section plane, and at an angle λ to broaching axis in horizontal plane. The high degree of cutting teeth resistance allows processing with high oversizes to increase microhardness and hardening depth.

6.2. New materials and protective coatings of broaches

In addition to traditional high – speed steels for broaching tool production are widely use powder high – speed steels R6M6F3-MP, P7M2F6-MP, P12MF5-MP, P6M5K5-MP, P9M4K8-MP (Russian grades), etc. Such steels, as compared to similar chemical composition steels manufactured by traditional technology, have a homogeneous structure, are more durable and are better grinded, and their use makes it possible to increase the tool life by 1,3 ... 2 times. However, when processing heat – resistant nickel – base alloys ХН77ТЮР (ЭИ437БУ), ХН73МБТЮ (ЭИ698), ХН62БМКТЮ (ЭП742) (Russian grades), etc., which are used to manufacture turbine discs, tool life of broaches from powder high – speed steel is not always sufficient. The broaching process of this materials is accompanied by an increased wear of broaching tool.

The thickness of cut, equal to step, has a great influence on broaching process. The more it is, the shorter the broach, the lower its cost and the higher the broaching performance. However, with an increase of cut thickness, the cutting forces are increasing, which can lead to broach rupture, deterioration of treated surface quality, and an increase of tool wear rate. With a very small cut thickness, the rounding radius of cutting edge becomes commensurable with cut thickness and some teeth of broach are pressing material from work-part instead of cutting. This leads to an increase of cutting forces, wear intensity, uneven loading of cutting teeth, deterioration of stretched surface quality. Therefore, the thickness of cut layer should not be taken below 0,015 mm. Tool life of broaches is formed by wear amount of only rough teeth that take on the main job by general allowance removing.

The broaches with cutting part made from a composition of high – speed steels, for example, from compositions of two high – speed steels P18 and P18K5Ф2 (Russian grades), have a higher working capacity.

Example. In broaches according to Russian standard ГОСТ 25160 all cutting parts were made from steel P6M5K5 (Russian grade). All tested broaches were same length. Rough (20 pcs.) transitional and finishing (12 pcs.) teeth of cutting part of composite broaches were made of high – speed cobalt steel P18K5Ф2 (Russian grade). The last 11 calibrating teeth were made of steel P18 (Russian grade). In contrast to standard broach, composite broach had a 71% increase in rough teeth step.

Application of high – speed steels composition (P18K5Ф2 and P18) allows to increase tool life of broaches in 6,7 – 8,2 times.

Widely used broaches with protective coatings, incl. with vacuum – plasma coatings. The increase of coating thickness favorably affects wear resistance, on the other hand, it is increasing the number of coating defects, is decreasing adhesion strength of coating with tool material, and coating ability to

brittle fracture resistance deteriorates. Effect of coating thickness on cutting tooth flank surface wear from the steel P6M5 + TiN at constant broaching length of work-parts from steel 45 (HB 300) ($V = 15$ m/min, $S_z = 0.15$ mm/tooth, $L = 75$ m) is shown in Fig. 6.2.

The least wear have cutting teeth with coating thickness $h_c = 3 \dots 4 \mu\text{m}$. As with a decrease of coating thickness, and as with an increase of its thickness from 3 to 4 μm , wear of cutting teeth increases.

The greatest coating thickness, due to location of tool relative to plasma flow, is observed on flank surfaces and tooth back, the smallest thickness on rake face and lateral surfaces, which is decreasing with distance from flank surface.

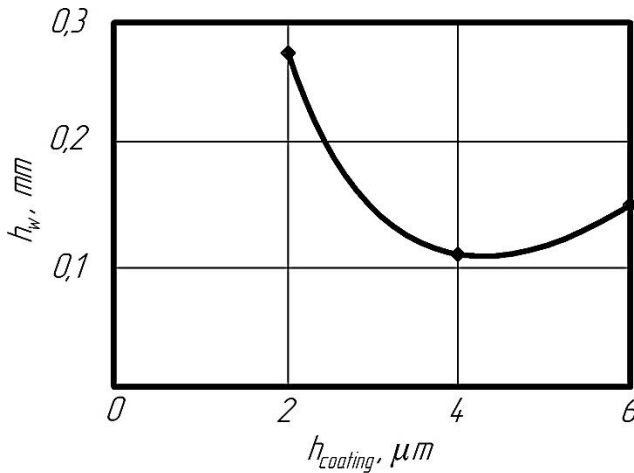


Fig. 6.2. Effect of coating thickness on wear of broach tooth flank surface from steel P6M5 + TiN

Ion nitriding in a non – hydrogen media, as a method of tool surface modifying, is distinguished by high manufacturability, possibility of obtaining required physical and mechanical structure properties, phase composition and operating parameters of coating, economy, safety of working conditions and environmental friendliness.

6.3. The influence of cutting wedge geometry and design features of broaches

At high requirements for treated surface roughness, a combined scheme should be used, in which last two or three cutting and calibrating teeth work by profile and remaining ones by generator scheme.

Broach teeth must satisfy to following basic requirements:

- provide as many resharpenings as possible;
- have a certain margin of safety and thereby resist to forces acting on it;
- have a geometry, which provides the greatest tool life of broach;
- the shape and dimensions of flute must ensure chips swirling in tight turn, and the flute volume must be sufficient to allow free placement of chips that cutting during contact of tooth with work-part.

The flutes surfaces are recommended to be polished in order to improve chips curling and easy release from it after cutting process.

The teeth of inner broaches are reworked only along the rake face surface and, when resharpening, their diameter decreases, on rough teeth end relief angle $\alpha = 3^\circ$, at fine teeth $\alpha = 2^\circ$, and on calibrating ones $\alpha = 0 \dots 1^\circ$.

These values of end relief angles are much less than the optimal ones, as a result tool life is reduced. However, they can not be increased, since this would lead to a rapid loss of broach size at resharpening.

The peculiarities of external broaches include the ability to assign much larger, close to optimal, end relief angles ($\alpha = 8 \dots 10^\circ$), since the size of the broach by height does not depend on part size. It can be adjusted with wedges, screws and linings. Thanks to this, the total tool life of external broaches is much greater than the tool life of internal broaches.

To ensure continuous removal of chips from the cutting zone when broaching long surfaces the outer broaches teeth are made inclined with an angle $\beta = 70 \dots 80^\circ$. This ensures uniform operation of broach.

Application of cemented carbides for equipping of broaches. The working conditions of broaches teeth are unfavorable for equipping them with cemented carbides, since they remove thin and wide chips and operate at low cutting speeds. This causes broaching force fluctuation and can lead to destruction of cemented carbide. In addition, application of cemented carbides significantly increases cost of broaches and is limited by their manufacture complexity. At the same time, the use of cemented carbides allows to increase tool life of broaches at several times, especially when processing cast irons, high – alloyed steels and alloys, as well as accuracy and quality of treated surface.

Cemented carbides are used for internal broaches in form of solid rings or with soldered inserts (Fig. 6.3, *b*). The rings are mounted on steel holder of broach and fixed with nuts. In this case, the interchangeable rings are displaced

relative to each other by turning around the axis in such a way that spaces between inserts play role of chip – splitting flutes.

The disadvantages of cemented carbide broaches with soldered inserts are the following (Fig. 6.3, a):

1. Cracks in cemented carbide from stresses during heating and cooling are observed in process of soldering and sharpening of broaches teeth;

2. Resharpener of broaches is carried out unevenly along rake face and flank surfaces individually for each tooth, which changes differences between the teeth, leading to premature exit of broach from work;

3. Fragile catastrophic destruction of one or two teeth leads to removal and replacement of entire broach;

4. Deterioration of teeth is uneven, and replacement of broaches is carried out according to the weakest tooth, although the remaining teeth can still work for a long time;

5. The body of the broach is not used again;

6. In mechanical shop for broach resharpening it is necessary to have a sharpened compartment with qualified sharpeners, high – precision equipment and high – quality abrasive wheels.

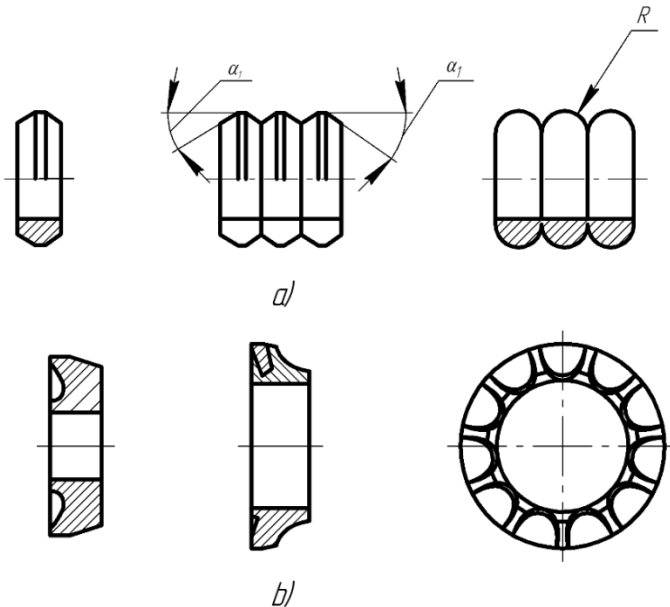


Fig. 6.3. Smoothing and cutting cemented carbide teeth of internal broaches: a – smoothing rings and blocks; b – cutting solid and soldered carbide rings

Fastenings with wedges or pins with flats (Fig. 6.4, *b*) provide good conditions for the placement of chips in flute, ability to adjust teeth height with the help of pads and secure fastening of inserts. This eliminates internal stresses in the inserts.

Broaches with inserted knives (Fig. 6.4, *c*) provide the possibility of: separate sharpening of knives with subsequent exact assembly; quick replacement of knives without removing broach from machine tool; fastening of cemented carbide inserts on knives by methods of soldering or mechanical fastening; adjustment of tooth sizes in height outside machine tool. However, because of need to locate fastening elements, size of broach increases.

For high – speed broaching of high – temperature and titanium alloys ЭИ 787ВД, ВЖЛ14 and BT8 (Russian grades) special constructions of broach with soldered inserts from cemented carbide BK8 (Russian grade) are used, which have a ten to fifteen times higher resistance than HSS broaches. At the same time, the broaching speed increased from 2 m/min to 26 m/min.

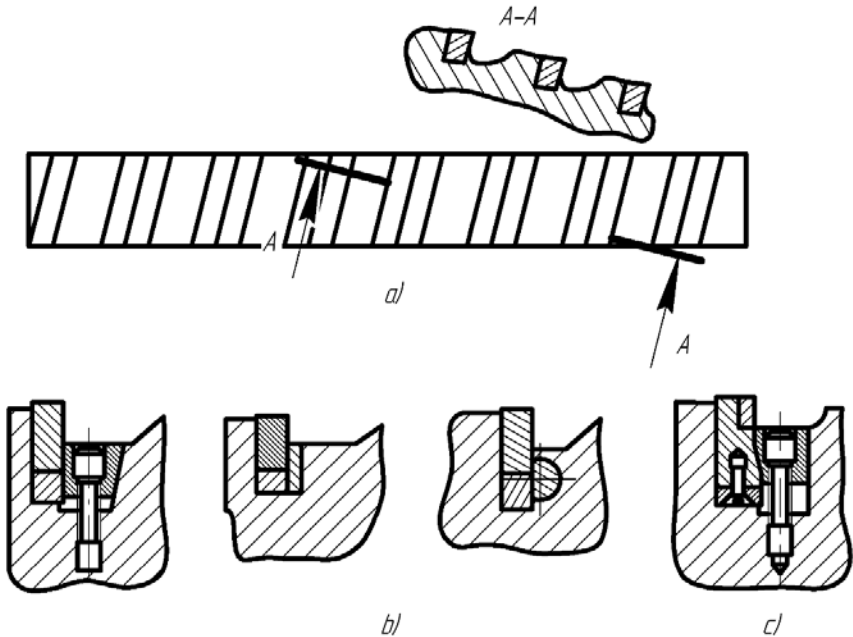


Fig. 6.4. Cemented carbide cutting teeth of external broaches:
a - broach with soldered cemented carbide inserts;
b - mechanical fastening of cemented carbide inserts with a wedge and pin;
c - mechanical fastening of knives with cemented carbide inserts

wear h_3 is much less than wear $h_{3,y}$ at junctions of main and minor cutting edges (Fig. 6.6).

Tool life of broaches is evaluated according to maximum permissible linear wear rate $h_{3\ max} = 0,4$ mm, regardless of cutting tooth and where blade wear reached this limit value. Limitation of maximum permissible wear of broach teeth is determined by permissible deviations of teeth transverse dimensions, which are very small, and also it is necessary to ensure two or three repeated resharpening to restore cutting properties of broach within specified accuracy of dimensions.

Broaches are only resharpened on rake face surfaces of teeth. For each resharpening from rake face surface of tooth a layer about 0,5 mm thick is ground.

Allowable teeth wear of external broaches. For prismatic broaches mounted on slab blocks, maximum wear by flank surface is allowed $h_{3\ max} = 0,6$ mm. Prismatic external broaches are resharpened on flank surfaces of blades and then polished on rake face surfaces. The initial dimensions of mounted broach block from resharpened broaches are provided by installing intermediate dimensional spacers under resharpened prismatic broaches.

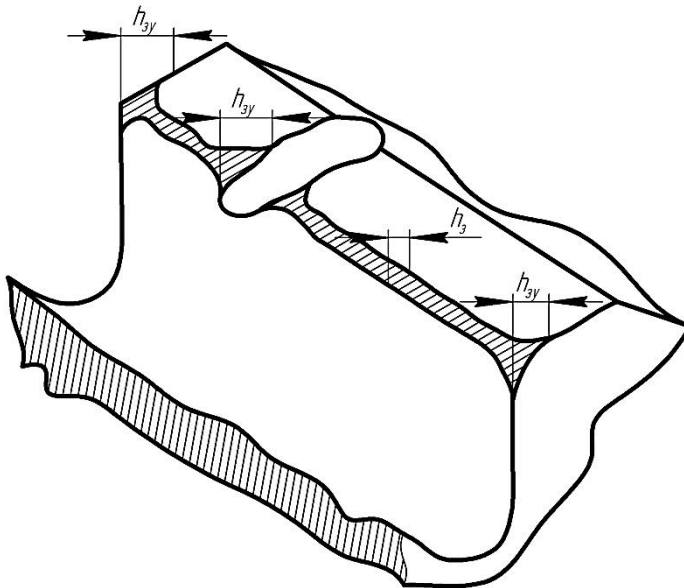


Fig. 6.6. Wear of broaches tooth blades

At low and medium cutting speeds, when diffusion processes due to low temperatures in the contact zone (up to 500 ° C) are unlikely, the cause of wear on the rake face and flank surfaces of the tool are integrally occurring processes of abrasive, adhesion and adhesion-fatigue types of wear. This is true for both teeth and deforming elements made from a wide range of tool materials, in particular, cemented carbide BK15 (Russian grade) and high – speed or alloy steels P6M5 and XBF (Russian grades), which are typical for combined broaches making. Stress distribution of normal stresses on the cutting part rake face surface and working cone of deforming part is highly gradient, i.e. value of contact pressure can differ 2 to 10 times along the diagram and reach a value of 4 GPa. This explains the different wear degree along contact area, which after a certain time of broach work takes form of surface described by second order curves such as of spiral, conchoid, involute, and cycloid. To reduce gradient of contact pressure diagram and to increase tool wear resistance, its working surfaces are given a curved – linear shape, which has a pressure diagram for a flat working surface. Significantly lower gradient of contact pressure diagram can also be achieved using the build – up.

In surface layer of parts broached at high cutting speeds of 25 ... 30 m/min, structural – phase transformations are not found and it is contain in 2 ... 2,5 times less particles of tool material that has collapsed during adhesion wear of broaches than at low speed processing 1,5 ... 2 m/min.

The brittle failure of cemented carbide broach teeth is caused by unfavorable conditions in cutting zone at moment when teeth exit from the work-part. Because of repeated increase of contact pressures on rake face and flank surfaces of broach tooth at time of exit from the work-part, contact adhesive welding of chip end with tooth cutting edge occurs both along the rake face and flank surfaces. In chip removal process, when chip is rotated, it breaks away together with tool material particles from rake face and flank surfaces, with destruction of cutting edge of broach tooth. To prevent brittle fracture of broach teeth, the method of supporting the outlet end of part with cast iron lining of optimum hardness was developed.

6.5. Durability of broaches

Brittle fracture of cemented carbide teeth cutting edges takes place when broaching in different cutting modes. The appearance of chipping on broaches cutting teeth leads to a sharp increase of feed rate at following behind crushed tooth and its destruction. Gradually there is an avalanche – like destruction of all subsequent cutting and finishing teeth of broaches, which causes a deterioration in roughness of the broaching surfaces of parts.

To minimize chipping of edges, it is necessary to change deformation conditions of material of work-part edge zone in such a way that in broach tooth not or arise minimal tensile stresses. To eliminate such problem use following methods: reducing value of contact loads on tooth working surfaces by reducing thickness of cut layer; change geometric shape of edge zone by creating chamfers at part end; installation of technological stops on part outlet end to prevent bending of edge zone. For example, without use of a technological stop from cast iron, it was possible to make no more than 40 cuts and broach teeth were chipped. The installation of a cast iron stop made it possible to make 800 cuts with one tooth, while uniform wear on back edge is observed.

6.6. Heat treatment of broaches

Heat treatment of long broaches is performed 3 times to reduce deformation: after preliminary machining by cutting, after final machining by cutting and after grinding.

When heat treating of broaches, the following conditions must be observed: for all operations, the broaches should be in a vertical position in a suspended state, final heating of short lengths should be carried out in a salt bath, and long ones in a shaft furnace (in the absence of such, they are heated in a horizontal oven at a sub rates); when cooling during quenching, the suspended broach should be moved up and down (flat broaches of small cross – sections to reduce deformation during cooling are clamped between cooled inserts or under press); correction after hardening and tempering must be carried out in hot condition; correction after cleaning should be carried out when heated with a welding torch to tempering temperature.

As strengthening technologies of broaching are used: impulse variable-gradient crystallization; pouring liquid metal into graphite chill, heated to 300 °C and then cooling it in liquid nitrogen; thermal cycling; the use of hardening coatings; vacuum heat treatment, treatment with a pulsed magnetic field, the use of powder tool steels. These technologies allow control macro and microstructure, strength and performance characteristics.

6.7. Non – firing grinding technology of broaches

Difficult – alloyed and hard – to – work high –speed steels are very sensitive to thermodynamic effects. When grinding them, there is always a high risk of burns on the treated surfaces and other structural and phase changes of cutting blades surface layer, which leads to a decrease of broaches tool life. This is also true for tools with hardening wear – resistant coatings.

A radical technological solution of the problem of high – performance and high – quality profile grinding of shaped tool is use of grinding wheels with increased cutting ability at optimum parameters of processing mode.

Broaches profiling. Mechanical machining of broaches from hardened high – speed steels with a hardness of 65 HRC and more, at the initial stage of work part shaping is made by profile grinding using grinding wheels based on traditional abrasives on a ceramic binder.

For defect – free profiling of broaches from high – speed steels, high-porosity grinding wheels from white electrocorundum of granularity 10 ... 16, hardness M1 ... M2 and with number of structure 12 are used, the characteristics of which depend on processing requirements.

However, the greatest effect when grinding high – speed steels of high – hardness can be obtained by using microcrystalline corundum wheels (sol-gel corundum – synter-corundum, azures, abral and other trademarks). Due to structure peculiarities grain of sol –gel corundum under such conditions provides higher cutting ability and dimensional stability of abrasive tool. According to its physico –mechanical properties, the grain of synter-corundum precedes white fused alumina and approaches to el'bor borazon material, and at a cost substantially – up to 3000 times cheaper than the latter.

The microcrystalline structure of grain with a crystal size of 0,2 – 0,5 microns, which is 20 –50 times smaller than that of fused alumina, provides synter-corundum up to 3 times greater strength and work in a mode of moderate self-sharpening by updating new cutting edges with minimal wear. Tool life of grinding wheel from synter-corundum can be 10 to 20 times higher than that of conventional aluminum oxide disk.

Example. Forming of profile by grinding wheels was carried out at a grinding speed of 30 m/s with a cutting depth per pass of 0,002 ... 0,005 mm and a longitudinal feed rate of 12 m/min. For grinding zone cooling an "Ukrinol" emulsion was used, supplied at a pressure of 6,5 bar at a flow rate up to 20 l/min. A sol –gel corundum wheel by accuracy and roughness of treated surface provides requirements of drawing and technology. The predetermined broach profile accuracy is ensured by accurate profiling of wheel working surface by special diamond roller and is maintained within permissible limits during entire grinding cycle due to increased dimensional stability of wheel on sol –gel corundum basis. Compared with white electrocorundum wheels tool from microcrystalline corundum is working in self – sharpening moderate mode, which allows reduce number of intermediate changes.

Highly porous wheels due to special volume –structural design contribute to provision of high –performance and non – burning treatment of the working part, which is the key to ensure required tool life of service life of cutting tool. But electrocorundum wheels when profile machining of long shaped tools, such

as broaches, are not always able to maintain required geometric accuracy along entire length of profile. Therefore, for final shaping of broaches, it is recommended to use grinding wheels from abrasive materials with higher wear resistant value, for example, from cubic boron nitride (elbor) on a ceramic binder.

6.8. Combined hardening of broaches

Complex ion – plasma treatment, including sequential application of two technological processes – ion nitriding and subsequent application of wear – resistant coatings. The choice of wear – resistant complex design depends on machined material. When broaching of high –temperature alloys such as ЭП609И (Russian grade), the most effective form of tool hardening from powder high – speed steel is application of a single – layer complex coating (NbTiAl)N. For treatment of high –temperature nickel alloys ЭП741ИП (Russian grade), it is expedient to use broaches with complex hardening, including ion nitriding and subsequent deposition of a complex – doped coating (NbTiAl)N. Nitrided layer has increased hardness in combination with high heat resistance and has a high resistance to microplastic deformations. All this contributes to inhibition of softening processes near back surface. An increase in nitrogen concentration in nitrogen/argon media up to 40% when nitriding somewhat reduces efficiency of complex hardening of broach tool when processing high – temperature nickel alloy ЭП741ИП (Russian grade). The increased nitrogen content, increasing hardness of broach cutting wedge, reduces its strength and creates "favorable" conditions for formation of brittle microspalls on tool cutting edge, which leads to its more intensive wear.

At the run –in stage there is no significant effect of hardening options on wear rate. The effect of hardening treatment is manifested at stabilization stage and, to a greater extent, at steady – state stage of broach operation.

The optimal mode for hardening treatment of broach tool from powder high –speed steel P12M3K5Φ2-МП (Russian grade) with speed broaching ($V_{br} = 10$ m/min) of turbine disks grooves made of heat – resistant steels type ЭИ517, ЭП609 (Russian grades) is: ion cleaning and tool heating to temperature 300 °C in a two – stage vacuum – arc discharge mode, applying a complex – doped coating (NbTiAl) N at a temperature of 450 – 480 °C for 70 min.

The optimal mode for hardening treatment of broach tool intended for work with high – temperature alloys of ЭП741ИП (Russian grade) type is: nitriding for 30 min at 480 °C with a argon/nitrogen ratio of 70/30 % in two – stage vacuum – arc discharge mode; ionic clearing in two – stage vacuum – arc

discharge mode 5 – 7 minutes; application of a complex – doped coating (NbTiAl)N at a temperature of 450 – 480 °C for 75 minutes.

The tool made of steel P12M3K5Φ2-МП (Russian grade) with ion – plasma hardening makes it possible to use high – speed broaching modes when processing of high –temperature steels ЭП609Ш (Russian grade) type. When broaching heat – resistant steels at speed of $V = 17,5$ m/min, wear resistance of hardened tool increases in comparison with initial ones (not strengthened) by more than 1,5 times. At broaching speed of 25 m/min when processing of heat – resistant steels, use of tool with ion – plasma hardening makes it possible to reduce amount of wear on flank surface up to 5 times in comparison with a non – strengthened tool.

When broaching heat – resistant nickel alloys of ЭП741НП (Russian grade) type at a speed $V_{br} = 1,5$ m/min the complex ion – plasma treatment of tool from high – speed steel makes it possible to increase tool life in comparison with unhardened tool up to 2 times.

A comprehensive approach to increasing wear resistance of profile – variable cutting scheme broaches made from steel P6M5 (Russian grade) used for broaching of discontinuous holes with joint planes includes a selection of structural geometry of tool cutting edge adapted to specific technological process; application of heat treatment with preliminary quenching and tempering of high – speed steels of moderate heat resistance, as well as the use of electric spark alloying for application of wear –resistant cemented carbide coating.

The application of coating by electrospark alloying of cemented carbide T15K6 (Russian grade) with a thickness of 0,020 ... 0,030 mm on flank surfaces of assembly round broaches calibrating teeth working by profile –variable cutting scheme when machining of discontinuous holes with joint planes increases surface hardness to HRC 89 ... 90 and in complex with other methods increases the wear resistance of tool in 1,35 ... 1,40 times.

Regular microrelief formed on tool surface before coating ensures its equal thickness along the entire length of surface and the smallest roughness. A certain form of regular microrelief provides the liquid friction mode in contact zone of tool with processed material. The presence of regular microrelief on the tool reduces surface roughness and increases degree of its hardening due to low – amplitude cyclic deformation.

The use of deforming and deforming – cutting broaches and piercings with wear –resistant coatings and regular microrelief applied to work surfaces in various combinations allows to improve quality of processing and also use high –speed and tool steels which could not previously be used because of catastrophic adhesive wear.

6.9. Application of cutting fluids when broaching

Cutting fluids during broaching have a great influence on broaching force, broach resistance, cleanliness and accuracy of processed surface. The choice of cutting fluid depends primarily on work-part material, specified cleanliness and size of treated surface. The average flow rate is 10 – 12 l/min.

When broaching cast iron workparts, use of water emulsions containing oil and oleic acid to irrigate cutting zone, in addition to reducing wear, improves the quality of treated surfaces and reduces contamination of shop area by fine-dispersed cast iron particles that spread in air during dry running.

Broaching of steel work-parts is always conducted with use of water – oil emulsions or oils for lubricating and cooling of broaches and processed work-parts. The best lubricating and cooling liquids for broaching of steel products are vegetable oils – linseed, hemp, sunflower, rape, etc.

It is necessary to use cutting fluid during *calibration of holes*.

For *high – speed broaching of hardened steel*, a special cutting fluid Cut-Max BR30 – free of chlorine, medium viscosity fluid, developed on basis of specially selected purified oils mixed with polar substances, anti – seize, anti-wear and lubricating additives was developed. A special additive complex provides a longer tool life in comparison with products containing chlorine at speeds up to 60 m/s. The use of cutting fluids for broaching of cast irons by HSS broaches is advisable only in case when requirements for treated surface quality are paramount.

The stability of deforming broaching process (absence of seizure between tool and processed material) is ensured by use of technological lubricants, which must be selected individually for each combination of tool and processed materials. The cemented carbide BK15 (Russian grade) has most favorable combination of mechanical and tribotechnical properties that ensure reliability of its use as a material of deforming broaches working elements. With deforming broaching of parts from structural carbon steels reliable operation of tool is ensured by use of liquid technological lubricants, traditionally used in processing of metals by pressure (sulfophrezol, lubricant MP type, based on industrial oil). However, their use in processing of parts from non – ferrous metals and alloys (including titanium alloys) is usually impossible due to grasping of processed material with tool. In these cases, solid lubricants with a high screening capacity can be used. For example, solid lubricants based on molybdenum disulphide are used for deforming broaching of work-parts from stainless steels, iodide cadmium for treatment of titanium alloys. A lubricant based on molybdenum disulphide in treatment of titanium alloys is not effective – it cannot provide treatment without grasping. The use of cadmium iodide is undesirable because of its toxicity. However, the use of solid lubricants significantly complicates

processing technology, because requires additional operations for their deposition and removal after stretching.

A technological lubricant based on polymeric composites (based on epoxidian resins) without filler allows to produce a multi – cycle deforming broaching of titanium parts at contact pressures up to 1,6 GPa. The introduction of filler in lubricants allowed to significantly increase its screening properties and produce a multi –cycle deforming broaching of parts from titanium alloys BT1-0 and BT 22 (Russian grades) at contact pressures up to 2,2 GPa and 3,1 GPa, respectively.

7. ASSURANCE OF GEAR CUTTING TOOL RELIABILITY

7.1. New technologies and equipment for cutting gears

The development of gear processing operations allows us to make the following conclusions:

- The traditional technological chain «milling with standard worm milling cutter – shaving» makes it possible to obtain toothed crowns of 7th degree of accuracy according to norm of smoothness and 6 degree of kinematic accuracy.

- Application of modern worm milling cutters of reduced diameter allows to increase accuracy of processing by norm by degree of smoothness.

- The technological chain « crown cutting with circular diagonal broaching – shaving» makes it possible to obtain toothed crowns of 6 degree of accuracy.

- The use of a fine calibration instead of a shaving produces a crown of 6 degrees of accuracy with a reduced roughness of tooth working surface.

Modern technologies for making of spur bevel gears is used CNC machine tools and tools that have high resistance and provide significant processing speeds. According to applicability of cutting fluids machine tools designed for work are distinguished: 1. with cutting fluids; 2. without cutting fluids, working by on so – called «dry» cutting technology; 3. in both modes.

High – speed dry processing with new gear milling tools became possible due to the use of thermal insulation coatings that divert heat to the chips and prevent it from penetrating into the tool material. At the same time powder high – speed steel allowed to remove a larger allowance in one pass. This significantly increased productivity of gear milling process.

Worm milling cutters from cemented carbide allow processing of hardened tooth crowns. For general – purpose gears, the technological process of teeth cutting can be tied to single machine tool with quick – change worm milling cutters.

High processing speeds and hard cutting with sufficient accuracy and quality are not possible on traditional machine tools. This is due to excessive loads and vibrations that affect not only the cutting tool and part, but also through them to drives and then to entire machine tool. To effectively use new materials, special machine tools are required (Liebherr, Gleason, Samputensili).

The combined tool – the shaver – roller is a shaver, conditionally divided into two parts: a part with vertical chip flutes on shaver teeth and a part with smooth teeth. A special machine tool is used, which uses power roll with crossed axis of tool and work-part. First, processed tooth crown being comes into engagement with shaver part of tool and its shaving takes place, then the crown moves into engagement with roller part and is subjected to plastic deformation for a few seconds.

Another modification of shaver –roller is tool that combines geometry of shaver and roller (Fig. 7.1). Cutting of chip thin layers is performed by shaver cutting edges and at the same time smoothing of teeth lateral surfaces of work-part is occur due to profile slip.

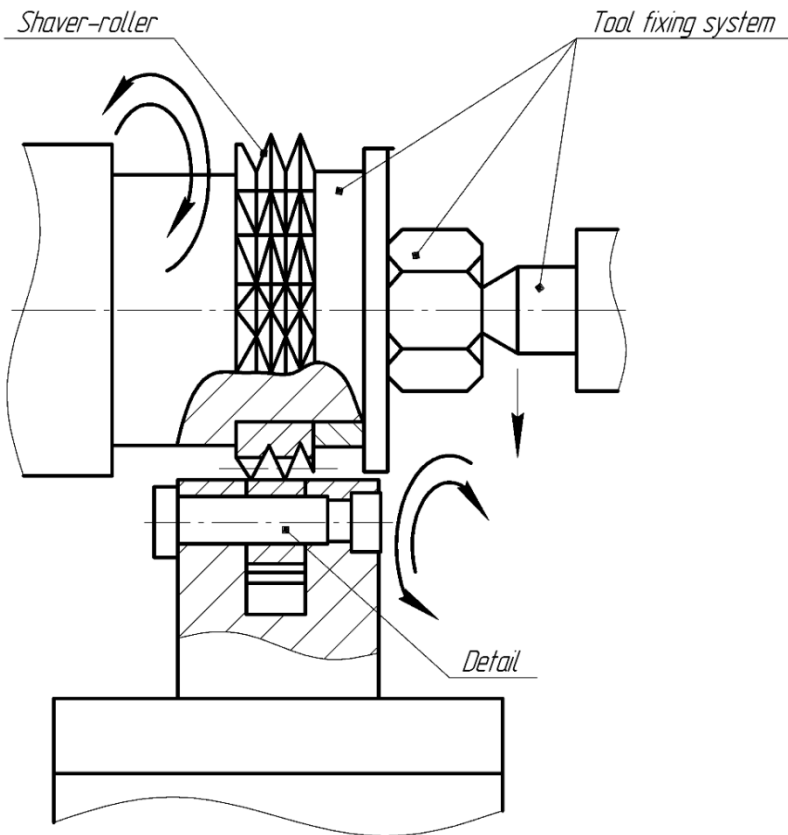


Fig. 7.1. Scheme of shaving by one shaver – roller

Due to compressive stresses generated during rolling, next gear heat treatment is not possible, since there is a possibility of peeling off the rolled and subsequently hardened layer due to excessive strengthening of the compressive stresses.

Combined with ultrasonic vibrations gear – milling of small –sized wheels provides a higher level of surface treatment, which has an increased load capacity (a decrease of roughness with simultaneous increase of accuracy).

7.2. Geometry and design features of main types of gear –cutting tools

Disc gear –cutting milling cutters are re – sharpened by rake face. The teeth of milling cutter, as a rule, are form-relieved, have not optimal geometry of cutting edges, which leads to a reduction of cutting modes and tool life.

The number of teeth in milling cutters with a form-relieved tooth due to need to have a large allowance for re – sharpening is small, which also adversely affects productivity and quality of treated surface. Therefore, this tools are used for cutting of the gears of the lowest (9th and 10th) degree of accuracy.

Back rake angle of standard milling cutters is equal to zero, which worsens cutting conditions, but simplifies the manufacture, re – sharpening and control of teeth profile.

To increasing the productivity for preliminary milling (roughing) of large modules gears are used milling cutters with inserted knives, often equipped with brazed cemented carbide inserts. In this case, the teeth profile can be taken as a simplified – straight or trapezoidal. Teeth are better to perform not form-relieved and sharp-pointed with sharpening by rake face and flank surfaces. This makes it possible to increase values of end relief angles to optimum values, to increase number of teeth, and, consequently, to increase tool life and productivity of cutters. Back rake angles are taken positive (up to $\gamma = 10 \dots 15^\circ$), which facilitates cutting process. For the same purpose use sets of 2 – 4 mills fitted on one mandrel.

In this case, each milling cutter removes a certain part of metal from the cavity between teeth of gear. After passing of cutters set the wheel turns on one tooth with help of a dividing device. Thus, the preliminary cutting of teeth is performed by the method of uncentroidal rounding with division of allowance between cutters in the set. Finally, cavity profile is formed by finishing milling cutter, allowance of which is reduced due to this cutting scheme. This increases accuracy of cut gears and tool life of cutters.

Essential disadvantages of *involute end mill* are low production and low precision of cut gears.

Worm gear – cutting milling cutters. The main directions of improving the design of milling cutters are:

- tool materials economy by using assembly structures and using more efficient cutters;
- change of cutting schemes and cutting edges profile;
- creation of milling cutters with unrelieved teeth, which at the same time have a favorable geometry of cutting edges.

Worm milling cutters are very difficult to manufacture and expensive, thus the use of new tool materials, such as high – speed steel with an increased content of cobalt and vanadium, cemented carbide and composites, has a significant economic effect due to increased cutting speed and tool life.

The standard milling cutters actively use 15 ... 20% of length of cutting edges along perimeter and the largest volume of cut metal falls on vertex cutting edges, especially those teeth that first come into cutting. These teeth wear out more quickly and have a decisive influence on the tool life. This disadvantage is sought to be changed by use of worm milling cutters with intake cone, as well as milling cutters with differentiated cutting schemes. Milling cutters with chamfer lead are more effective for diagonal milling, when slide assembly with milling cutter moves simultaneously in two directions: along milling cutter axis and along gear axis. In this case, the number of envelope cutters considerably increases and the roughness of treated teeth surfaces of gear decreases and, most importantly, teeth of milling cutter wear evenly along its entire length.

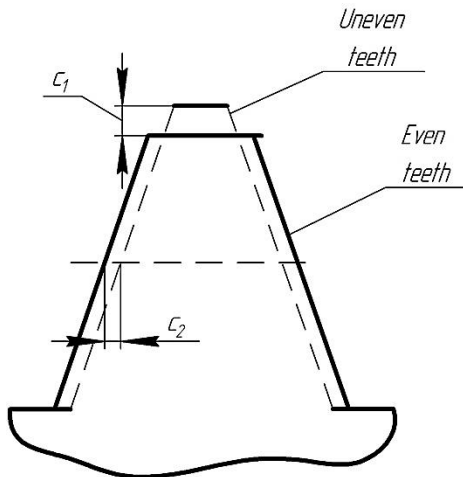


Fig. 7.2. Optimum cutting scheme for gear – cutting milling

With simultaneous operation of vertex and side cutting edges of milling cutter tooth, the cut layer has a complex shape, which leads to an increase of its deformation degree, cutting temperature and wear rate of tool. To create more favorable cutting conditions on all cutting edges, tooth sizes are changed in height and width through one tooth, as shown in Fig. 7.2. As a result, thicker and shorter chips are cut off separately by vertex and lateral cutting edges. Tool life of such milling cutters significantly increases.

Worm milling cutters with form-relieved teeth have a number of drawbacks that reduce their resistance: operation of relieving is complex and time-consuming, it requires preparation of special cams and tools, leaves traces of impact on cutting teeth; end relief angles on the side cutting edges are small, which reduces tool life of milling cutters.

Therefore, there appeared many variants of assembly milling cutters design in which relieving process replaced by grinding along circumference and along screw side surfaces.

In the mass production of large module gears various designs of milling cutters with a reduced profile angle up to 15° and with a 20° engagement angle are used, which provide higher productivity and durability due to the redistribution of load between cutting edges of milling cutter teeth and increase in the number of profiling cutting edges. As this reduces the surface roughness, they can be made multiturn.

Shavers are usually made of high – speed steels P6M5, P6M5K5, P18 (Russian grades). For processing of gears with a hardness of 35 ... 48 HRC and above, shavers are equipped with cemented carbide inserts. Sometimes cubic boron nitride coating of shaver teeth is used.

Tools for cutting conical gears with curved teeth. Gear-shaping cutter head are the most widespread in production. According to design, they are end face milling cutters, which, in addition to rotation make feed movement along their axis. Body of gear – cutting head is made of engineering steel, and then subjected to hardening and grinding. Cutters are made from high – speed steel.

For rough teeth cutting, double – sided and triple – sided cutting heads are used. This is the most time –consuming operation, as it proceeds under impact conditions, when large allowances are removed (up to 80% of material) and, accordingly, with high loads. Because of low wear resistance of cutters, the costs for shifting, re – sharpening and setting up of machine tools are increasing. Therefore, rough operations usually employ 2 – 3 times more machine tools than finishing operations.

The design of gear – cutting heads and methods of gear –cutting of conical gears are constantly improving in following directions: increasing of body rigidity and ways of cutters fastening in head and head fastening on machine tool; change of cutting scheme; use of machine tools for teeth cutting

with continuous rolling; increase tool life by replacing of form-relieved cutters on pointed; creation of heads with cutters equipped with a cemented carbide provides 2 ... 2,5 times increase in productivity, reduction of number of heads, their adjustments, cutters, linings, and other replacement parts; change of design and parameters of gears and gear – cutting tools.

The teeth of standard milling cutters work under severe conditions of not free cutting, cutting off the Γ or Π – shaped layers, teeth work under unfavorable conditions due to smallness of end relief angle on the lateral cutting edges, which is caused by considerations of retaining tooth profile with as many re – sharpening as possible. Therefore, a characteristic trend in improvement of worm milling cutters is the use of structures with cutting schemes that provide separate chip formation.

Maximum wear has the flank surfaces in corners of output cutting edge, which is associated with braking of free chip removal and the interaction of chips which are removed by vertex and two lateral edges.

Secondly, the low durability of worm milling cutters is due to fact that operation of cutting teeth side edges occur under unfavorable cutting conditions due to smallness of end relief angles. Increasing them is not possible for reasons of ensuring of conditions for repeated re – sharpening of worn out worm milling cutters, foreclosed along archimedean spiral.

When changing cutting scheme from standard to progressive one, the shrinkage stresses of chips, which are cut by the side edges, are reduced, direction of the chip removal changes, which leads to an increase of tool life by 2 – 3 times. At the same time, there are a number of disadvantages of progressive cutting scheme: first, it is an increased wear of high – pitch teeth; secondly, an increase of faceting of cut teeth due to a twofold reduction in the number of profiling teeth; thirdly, problems of end relief angle increasing on lateral cutting edges are not solved.

The problem of end relief angle increasing on side cutting edges can be solved using the designs of non re – sharpening milling cutters.

Worm – modular milling cutters, with all their advantages, have a significant disadvantage – low tool life and uneven wear of teeth both by turn and by profile. As a result, the most worn out are 1 – 2 teeth on the turn of milling cutter, which determine the degree of tool wear as whole. As a result, when re – sharpening of milling cutter, more than 80% of expensive tool material is wasted, since not only worn out teeth, but also all others, on which wear is barely scrutinized, are subjected to re – sharpening. One of the most promising ways to improve tool life and productivity in terms of application of modified cutting schemes is use of milling cutters with chip – dividing elements in form of overlapping facets.

The use of cemented carbide instead of high – speed steels makes it possible to increase processing capacity by 3 – 6 times at a cutting speed of 100 – 300 m/min.

Application of worm – modular milling cutters provides a significant increase of efficiency of gear – cutting operation of cylindrical gears due to use of assembly worm milling cutters with rotary toothed swiveling rack laths.

Application of multiple-thread hob. The practice of using of such milling cutters allows to reduce basic time of gear milling by 2 – 3 times and to increase tool life by 3,5 – 5 times.

A special group of *worm milling cutters with a special direction of flutes* are rough milling cutters with a steep rise of the flutes, milling cutters with double direction flutes and large angles of their ascent, two section milling cutters with flutes of left and right direction.

Ensuring of smoothness of gear milling is possible due to the use of mills that work by method of oblique cutting. General disadvantage in operation of these milling cutters is difference in conditions of chip formation on left and right lateral sides of the teeth, resulting to significant axial loads in spindle unit of machine tool. The use of axial flutes facilitates manufacture of milling cutter, increases uniformity of milling and accuracy of processing.

Increasing tool life can also be achieved by choosing optimal cutting geometry. A number of researchers suggest setting back rake angles to 15 °, and end relief angles – from 9 to 15°. As a result of this geometry, the cutting forces are reduced by 30 – 40%, and feed can be increased by 40 – 50%.

7.3. Materials for manufacture of gear-cutting tools

One of the most significant innovations in field of materials for gear processing is the creation and use of powder high – speed steel for the manufacture of tools, mainly worm milling cutters. Conventional high – speed steel has iron and carbon as a base, but is alloyed up to 30% with vanadium, tungsten, chromium, molybdenum, cobalt and some others added in a certain proportion. However, in the production of steel by traditional methods, structural defects arise, the main of which is the uneven distribution of alloying elements in the volume of steel, including their carbides. As a result, heterogeneity of metallurgical characteristics of steel occurs, excessive hardness and brittleness in individual zones, poor machinability, high level of deformation during heat treatment.

In powder high – speed steels carbides have a small size and they are very well distributed by all mass of material. In addition, with this method of production, it is easier to control the content of alloying substances and increase

content of some of them, improving the cutting ability of steel. Also powder high – speed steel has a fine – grained structure, no impurities and high uniformity throughout the volume of workpart.

Worm milling cutters made of cemented carbide have sufficient hardness to process already heat – treated workparts. However, in view of the fact that tool material is powder, it is possible for them to process work-parts only in «dry» mode without cutting fluid. This is due to fact that the cutting fluid lowers temperature of tool tooth after leaving the cutting zone. In connection with this, thermoshock occurs and there is a danger of microchipping of solid carbides and washing out cobalt from alloy. Also from the temperature drops, microchipping of powder high – speed steel is possible.

7.4. Coatings for gear – cutting tool

The most common wear resistant coating for worm milling cutters now is titanium nitride TiN. High hardness of the coating provides resistance, both to abrasion and to crater wear. As a result, it becomes possible to increase processing modes, while the wear of tool remains at the same level as that of uncoated tools. As a result of the coating by TiN, tool life of worm milling cutter can be increased by 2 – 12 times.

Since the working temperature of this coating does not exceed 600 °C, the cutting speed can be increased within certain limits. The limitation by operating temperature predetermines the use of tools with TiN coating only with use of cutting fluid.

The traditional coating with titanium carbonitride TiCN differs from the TiN coating with a higher hardness. High hardness (due to presence of carbon in the crystal lattice) in combination with a low coefficient of friction determines a wide field of application of this coating as a hard coating on the tool. When using tools with TiCN coating, cutting fluid is mandatory (due to low temperature resistance of coating). The coating is often applied in form of a multilayer or gradient with a gradual increase in the carbon content to the surface.

The proportion of coatings (Ti, Al)N in the total volume of wear – resistant coatings has been steadily increasing in recent years. The advantage of these coatings is high oxidation resistance at very high hardness and low thermal conductivity. The coating (Ti, Al)N creates a thermal barrier that practically isolates the tool material from heat generated during cutting. There is a redistribution of heat fluxes, and most of the heat goes to chips. In addition, unlike other types of coating, an increase of cutting temperature on surface of this coating produces an alumina film having a lower coefficient of friction. As a result, the processing effort is reduced. As a consequence, the application field of

tools with coating (Ti, Al)N is processing with large thermal loads on the tool. These operations include high – performance processing, when increasing the cutting conditions leads to an increase of temperature in the contact zone between the work-part and tool, and processing without the use of cutting fluid.

A non – titanium AlCrN coating has already found wide application, especially for worm milling cutters. The higher wear resistance of coating ensures an increase of tool life and a reduction of cost for tool. Compared with coating types discussed above, the AlCrN coating is characterized by oxidation resistance at temperatures up to 1100 °C, while maintaining high chemical stability at these temperatures. This coating can be applied to worm milling cutters from both powder high – speed steel and cemented carbide. Compared to TiAlN coatings, in this case, tool life is increasing (in some cases up to 2 times).

The nACro coating in chemical composition coincides with coating AlCrN coating, but it has a nanocomposite structure.

As a result, with a higher hardness, this coating is simultaneously more elastic, although usually these two parameters are mutually exclusive. Increasing of hardness and reducing of friction coefficient, nanocomposite coating favorably affects tool life.

Combinations of tool material and coatings for worm milling cutters are possible. As a rule, TiN, TiCN and TiAlN coatings are applied to conventional high – speed steel. TiN coating is used for processing various materials with cutting fluids at cutting speeds not exceeding 100 m/min. TiCN coating also requires obligatory use of cutting fluid and is used for processing of high hardness materials. Milling cutters from conventional high – speed steel are rarely used for dry processing. If this combination does occur, TiAlN coating is applied to the milling cutter. Cutting speeds in this case do not exceed 110 m/min, which is determined by properties of high – speed steel. On powdered high – speed steel all above types of wear – resistant coatings can be applied.

Any of these coatings can be used in the case of processing with use of cutting fluid. Cutting speeds in this case can be increased up to 130 m/min. Worm milling cutters with coatings containing aluminum are also used for dry processing (without cutting fluid). Cutting speeds in this case can be increased up to 180 m/min. It should be noted that a new coating must be applied to milling cutters for dry processing in process of re – sharpening and restoration of cutting properties to prevent crater wear occurrence. The decision by re – coating of worm milling cutters operating with cutting fluids is adopted depending on conditions of their operation. The choice of a coating for a cemented carbide also depends on whether use of cutting fluid is contemplated in this operation. The coating AlCrN can be applied in all cases. TiN coating is not applied. The coating TiCN is used only for processing with cutting fluid. The coating TiAlN on hard alloy is used as a single – layer coating for dry cutting.

The coating can be applied to new worm milling cutters and recovered after re – sharpening. Various in this case are the first, preparatory, operations. After the manufacture of a new worm milling cutter, it enters the preparation area before coating. The main operation at this stage is blasting with a specially selected abrasive. The purpose of this treatment is to remove the burrs formed on milling cutter edges after grinding of teeth along rake face surface and to clean flank surfaces of teeth for better adhesion of coating with tool material. The operation is performed on special automated jet devices. After blasting, worm milling cutters, as a rule, get directly onto the coating operation. In some cases, they can pass through a specialized washing stage, however, this is not required for normal blasting (this is the main difference between applying coatings on worm milling cutters from applying coatings to most other tools when washing is a mandatory stage). Worm milling cutters are loaded into coating chamber in an upright position on the turntable. After the coating cycle is completed, coating control is carried out. Since it is quite difficult to control milling cutter itself due to its complex shape, a small sample from same tool material as worm milling cutter is placed in coating chamber. The sample is coated with the same coating as the milling cutter and on it is controlled.

The technology of wear – resistant coating application in the process of restoring of tool cutting properties differs from coating technology of new milling cutters only by preparatory operations. First, it is necessary decide whether to restore the wear – resistant coating. In some cases, the coating is not reapplied, milling cutters are simply re – sharpened by rake face surface and burrs are removed from them. This is the case when the milling cutter operates at low cutting speeds and does not require presence of coating on the rake face surface for protection from crater wear. In this case, re – sharpening of milling cutter is carried out «over the coating», which reduces grinding wheels resistance. If it is necessary to restore the wear – resistant coating both on flank and rake face surfaces of tool, the first operation is removal of old coating. Coatings are removed chemically (dissolved) in specially selected solutions and conditions for coating removing very differs depending on type of coating and technology of its application. For example, an electrolytic process is required to remove the chrome coating. Remove coatings from hard alloy must be especially careful, because with improperly selected chemical composition of solution or non – observance of technology, cobalt is "washed away" from surface layer of hard alloy, which leads to a reduction of hard alloy viscosity. After coating removing worm milling cutters are blast cleaned and are re – sharpened. A sharpened worm milling cutter must necessarily undergo a blasting procedure to remove burrs and prepare surface for subsequent coating. From this moment, coating process of recovered milling cutters completely coincides with coating process of new milling cutters discussed above.

In addition to correct choice of wear – resistant coating the thickness of it is also very important. A coating thickness of more than 6 μm can lead to profile distortion. For finishing operations, it is better to apply a coating with a thickness of about 3 μm . A coating thickness of 6 μm on milling cutter with end relief angle of 3° allows a theoretical wear of the cutting edges of 0,14 mm. With increasing wear, coating breaks and substrate is visible.

7.5. Wear – resistance of gear – cutting tool

The causes of increased wear of high – rise teeth of worm milling cutter with a progressive cutting scheme are:

1. Profiling teeth work in better conditions than high – rise ones. In spite of fact that they remove Π – shaped layers (teeth of first two turns, the most loaded ones), chips along perimeter has almost the same thickness, or on the top edge chips are thinner. Thus, chips deviation towards exit edge is insignificant, teeth work at relatively low deformations of cut layers, in spite of fact that their lateral edges remove thicker layers in comparison with standard milling cutters.

2. The high – pitched teeth cut Γ – shaped layers, and chips on apical edge are much thicker than chips at input side edge. Consequently, the latter will have relatively large shear deformations and, possibly, crumbling, which leads to a greater wear than for profile teeth.

The correction values of teeth must be greater or equal to maximum thickness of corresponding shear layers. Therefore, it is necessary to take a more differentiated approach to designation of these quantities parameters, and thereby create more favorable cutting conditions, which will positively affect tool life of worm milling cutters.

Example. The average tool life of teeth with end relief angle at vertex edge of 15° was 850 minutes, which is 3,54 times higher than standard worm milling cutter between re – sharpening under same cutting conditions; tool life of tooth with end relief angle on at vertex edge of 18° - 930 minutes (3.86 times higher than the standard milling strength); with end relief angle on the vertex edge of 20° – 890 minutes (3,71 times higher than standard milling cutter).

When pinion-shaped cutter wears over 0,3 mm by vertexes of tooth flank surfaces the precision of gears with modules 0,75 ... 2 mm becomes below the 8th degree of accuracy (GOST 1643-56). Sometimes it is recommended that vertex of tooth be rounded to maximum permissible value. A rounding radius of 0,5 mm increases tool life by 30%. Tools working with reduced structural feed – stepped pinion-shaped cutters, most worn out the input cutting blade of rough step – the most loaded blade. In addition, as circular feed increases, wear of output cutting blade of finishing stage remains unchanged, while in rough stage it increases somewhat.

In the case of gear –cutting by classical scheme, type of U-shaped chip exit is most common (Fig. 7.3, *a*), in which the input 1 and vertex 2 cutting edges cut wider chips than the output cutting edge 3.

The occurrence of cutting edge local wear is due to extrusion of thin chips by wide chips into the gap between tool side and treated surface where they are wearing in butt area of vertex and output cutting edges. As a result, a crater of local wear on the rake face surface is formed.

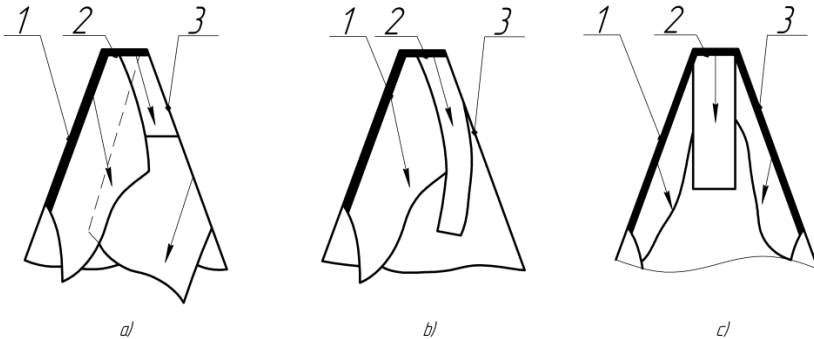


Fig. 7.3. Scheme of chips removal when gear planing

To reduce rate of local wear occurrence on output cutting edge, a number of techniques are used:

1. Change direction of rolling action movement before processing next part. In this case, local wear is formed symmetrically on input and output cutting edges. However, the intensity of its development slows down about 2 times;

2. Modification of the cutting scheme, which provides cutting of more simple L – shaped chips instead of U – shaped chips (Fig. 7.3, *b*). In this case, the L – shaped chips go unhindered and do not cause great deformations at the boundary between these edges;

3. Creation of cutting conditions, in which chip thickness cut by input and output cutting edges will be the same (Fig. 7.3, *c*). In this case chips having same thickness cause equal mutual deformation and come off at junction between vertex and side cutting edges under the same conditions. Due to mutual deformation, the rake face surface of cutting tool subjected to uniform force and heat load. The formation of localized wear zone is shifted in time and its redistribution occurs on both lateral cutting edges.

The wear of teeth – cutting tools along cutting blade perimeter is not the same. The flank surface of outlet edge of finishing stage has the greatest wear.

The tool life of cutters with a parallel cutting scheme increases in comparison with conventional cutters by 1,2 ... 1,5 times. Tool life with a

distributed cutting scheme is increased by 1,6 ... 2 times compared to conventional cutters. This is due to the fact that when cutter operates with differentiated schemes, favorable cutting conditions are created that affect finishing stage of cutter, which, with a parallel cutting scheme, has same thickness of cut metal layers along cutting blades, which is due to tool design. The deformation of cut layer decreases, and wear by side cutting blades is equalized. With a distributed cutting scheme, geometry of metal layers cut by the vertex blade of rough stage and lateral cutting blades of finishing stage is greatly simplified, which predetermines the increase of tool life in this case.

It is determined:

- gear planing productivity of spur – beam conical gears when using a tool with different cutting schemes is increased by 1,5 ... 1,8 times while maintaining accuracy parameters due to increase of feed and reduction of passes number;

- that use of cutters with differentiated cutting schemes of an open type makes it possible to increase the accuracy of gears by one degree while maintaining productivity due to decrease of cutting force amplitude and a more even distribution of load along tool steps. The closed type of cutters reduces the kinematic accuracy by 15% compared to open one.

Physical picture of gear – processing tool wear. Wear of gear – processing tool is described by interdependence of wear and machine time (curve *A* in Fig. 7.4), which is obtained with constant, unchanging cutting conditions. The initial intensive wear, corresponding to run – in period, is explained by formation of optimal geometry and state of cutting part surface layer of gear – cutting tool (rounding radius of cutting edge and vertexes of gear – cutting tool, roughness, microhardness and residual stresses of cutting part) characteristic for these processing conditions (processed material, tool material, cutting modes, stabilization forces of cutting, cutting fluid, rigidity of technological system). During this period, intensive molecular wear and tearing of roughness protrusions of working part of gear – cutting tool occurs at the areas of greatest pressure. This leads to change of geometry and microgeometry of cutting section of gear – cutting tool, which contributes to gradual equalization of working pressures in cutting zone and uniformity of wear of various parts of cutting wedge (Fig. 7.5).

The state of surface layer of vertices working sections, cutting edges, flank and rake face surfaces of gear – processing tool also undergoes a change, gradually acquiring the so-called «equilibrium state». All this leads to a gradual transition to normal wear of gear – cutting tool, which corresponds formed optimal geometry and state of surface layer of tool cutting part for these processing conditions. Moreover, this transition is smooth and it is often difficult to strictly delineate area of run – in and normal wear area. The gradual accumulation of fatigue in surface layer of cutting part leads to its destruction, i.e. to beginning of catastrophic wear.

However, this physical picture of wear periodicity is peculiar to a gear – processing tool that operates under constant, non – changing processing conditions (serial, large – scale production of rack gears).

In small – scale and individual production, the tool, as a rule, operates under varying processing conditions (processed material, cutting modes). This leads to fact that their working part must constantly adapt to new processing conditions. Dimensional wear of the gear –cutting tool for this case can be described by curve *B* in figure 7.4. And, depending on the number of parts, the wear of the gear – working tool may not leave the run – in period (Fig. 7.4, section 1, curve *B*), since changed processing conditions will lead to a new run – in period (Fig. 7.4, section 2, curve *B*).

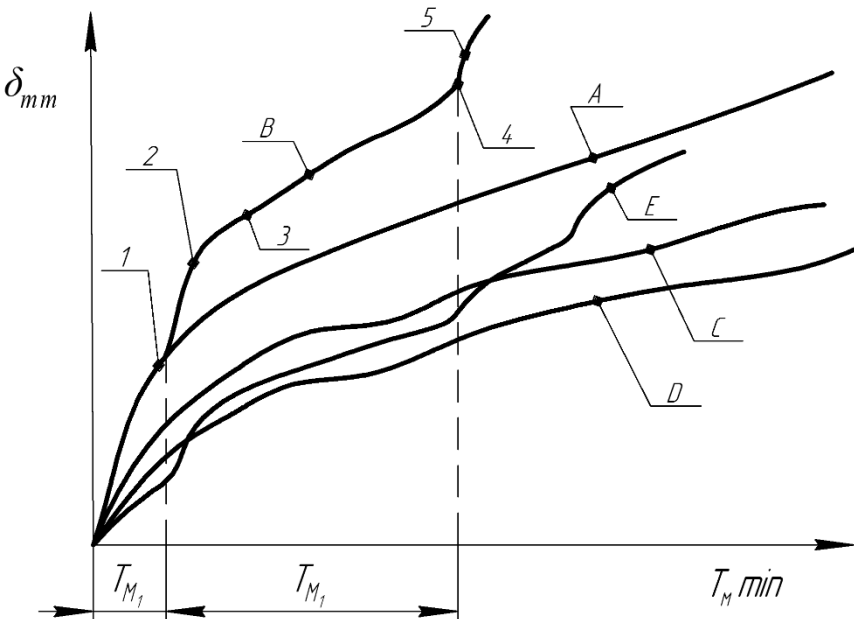


Fig. 7.4. Wear curves of cutting part of disc gear – cutting milling cutters on flank surfaces during counter milling:

A – for non – changing cutting conditions;

B – for conventional milling cutters with varying cutting conditions;

C – for non-changing cutting conditions with optimal geometry of milling cutters;

D – for constant operating conditions of milling cutters with optimal geometry and wear – resistant coating; *E* – for fast run – in mills with varying cutting conditions;

T_{M1} – run – in period; T_{M2} – period of normal wear

The mathematical description of gear – processing tool wear rate is calculated by formula

$$I_h = \frac{\chi}{n \cdot \lambda} \cdot \sqrt{\frac{h}{\rho}} \cdot \frac{A_r}{A},$$

where n is the number of exposure cycles, which leads to material destruction.

Surface residual stresses lead to a corresponding change in a given cycles number. This change is accounted for by a coefficient determined from equality

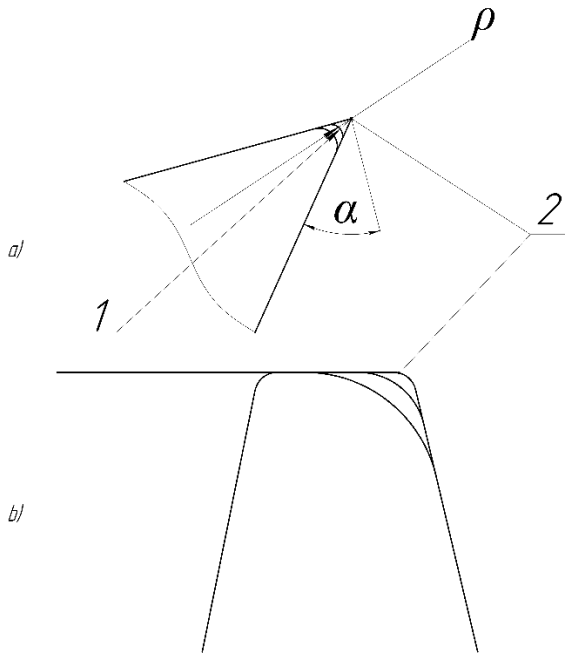


Fig. 7.5. Vertices wear of profile part of disk gear – cutting milling cutters;
a – formation of radius at vertex; *b* – formation of rounding t radius of cutting edge.
1 – run – in period; *2* – period of normal wear; ρ – rounding radius of tool cutting edge;
 α – end relief angle

Surface residual stresses lead to a corresponding change in a given cycles number. This change is accounted for by a coefficient determined from equality:

$$\lambda = \left(\frac{\sigma_b - \sigma_r}{\sigma_a} \right)^{t_y},$$

where σ_b – temporary resistance to tearing; σ_r – yield strength; σ_a – actual value of amplitude voltage in working layer; t_u – parameter of frictional fatigue of cutting part material in for elastic contact; χ is a parameter calculated by the formula:

$$\chi = \frac{1}{2(\nu + 1)} \cdot \sqrt{\frac{\nu}{2 \cdot \alpha_k}},$$

where α_k is a coefficient that takes into account difference of protrusions cross-section area at level ρ from actual contact area value at the same level. In accordance with contact interaction theory $\alpha_k = 1$; ν is parameter of supporting curve of profile of tool vertices roughness ($\nu = 2$).

Considering significant contact pressures during milling, it can be assumed that actual contact area of tool with workpart is equal to nominal area, i.e. $A_r = A$, and, consequently, $A_r/A = 1$. From the same considerations $h = R_z$. For calculation of wear intensity when milling rounding radius of cutting edge of gear – cutting tool as a local roughness protrusion ρ can be taken.

If the machining time for a new batch of parts is sufficiently large (T_{M2}), wear of gear – cutting tool will shift to the normal one (Fig. 7.4, section 3, curve B). However, changing processing conditions (manufacturing a new batch of parts) will lead to a new run – in period (Fig. 7.4, section 4, curve B), etc. Changing of working conditions lead to an acceleration of catastrophic wear (Fig. 7.4, section 5, curve B) and to a decrease of quality of treated surface.

For gear – processing tools operating under certain, unchanging conditions, at stage of their manufacture, it is necessary to ensure optimal geometry and condition of surface layer of its working part. Thus, the optimal values of the rounding radius of cutting edge from various materials, depending on the processed material of gear products, are given in Table. 7.1.

The optimum value of this radius is ensured by technology of gear-cutting tool sharpening and cutting edge finishing. The optimum condition of surface layer of working areas of the gear – cutting tool is determined by their material and is achieved by grinding and heat treatment technology.

Table 7.1

The optimum rounding radius of cutting edge ρ when processing different materials of gear rack and gears

Processed material (Russian grade)	Material of cutting blade of gear – processing tool (Russian grade)	Optimal rounding radius, ρ , μm
Steel 45	P6M5	10
Steel 40X	P6M5	8
Steel AI40X	P6M5	10
Steel 45	BK8	55
Steel 40X	BK8M	50
Steel AI40X	BK8	55
Cast iron	BK8	60

They also resort to applying various wear – resistant coatings for cemented carbide inserts and for tools made from high – speed steels by saturation with molybdenum disulphide by a thermo – diffusion method with following treatment in liquid nitrogen.

7.6. Application of dry electrostatic cooling on gear cutting

Dry cutting is an alternative to processing with use of cutting fluids due to its high environmental friendliness and cost – effectiveness. Cooling of cutting zone by ionized air is one of the most promising directions of metalworking technology without cutting fluid.

During gear shaping the high thermal and mechanical stresses act on cutting tool. The main mass of metal is cut off by top and entrance side of tooth profile, while tooth vertex removes the thickest sections. The maximum thickness of cut is taken off at the moment when edge vertex penetrate to the work-part. As a result, wear of tool cutting edges occurs. The wear mechanism depends on radial feed method. With stepped radial feed, the wear of the flank surface of cutting tool is predominant. For method with a spiral radial feed, formation of wear crater on rake face surface of pinion-shaped cutter is characteristic. It is during dry processing due to wear crater maximum manufacturing accuracy is achieved, as cutting edge remains stable until chamfer is broken before crater, and quality of the workpart remains constant.

Example. Processing of workparts from steel 12XH2 (Russian grade) with a width of 25 and 50 mm was carried out at a radial feed of 0,03 mm/double pass of a pinion-shaped cutter, cutting speed of 40 m/min, 52 teeth on work-part were cut on a 5A140 machine tool. The tool is a pinion-shaped cutter according to GOST 10059-80 from steel P6M5 (Russian grade). The criterion of tool blunting is wear by flank surface equals to 0,2 mm. The treatment was conducted by dry and using an ionized media.

When dry electrostatic cooling is used at gear shaping operations (Fig. 7.6), the nozzle – ionizer is fastened motionlessly from side of flank surface. The distance from the end of nozzle to the tool is 5 ... 10 mm. Operating mode of dry electrostatic cooling equipment: air pressure 0,4 MPa, nozzle diameter 4 mm, needle radius 0,8 mm.

The greatest increase of tool life (42%) is observed when machining workpart width of 25 mm. To a lesser extent (25%), the effect of dry electrostatic cooling is expressed when processing a workpart with a crown width of 50 mm. This is because the nozzle is further away from cutting zone and effect of electrostatic cooling is weakened. In addition to difference in values of tool life during dry processing and with dry electrostatic cooling, the wear character of a pinion-shaped cutter is different.

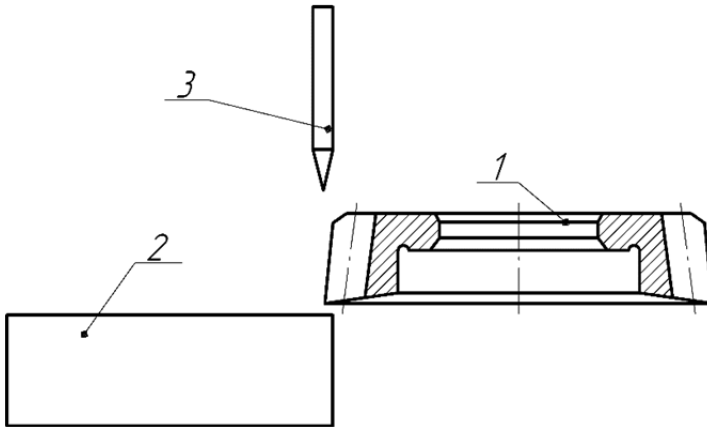


Fig. 7.6. Adjustment of dry electrostatic cooling when gear shaping:
1 – pinion-shaped cutter, 2 – work-part, 3 – nozzle

When processing without cooling, the largest amount of wear is observed on edges of the intersection of vertex and lateral flank surfaces. On the output lateral side, the maximum wear occurred near the tooth top, i.e., in cutting blade section, which removes slices, thickness of which approaches zero. Wear on the

rake face surface is expressed by the crater in immediate vicinity of cutting edge. When using dry electrostatic cooling, the wear crater on the rake face surface is smaller and is further away from cutting edge. Thus, the possibility of chamfer destruction before crater wear and cutting tool failure is reduced.

Explain the differences of tool wear during dry and dry electrostatic cooling treatment is possible when considering contact processes of pinion-shaped cutter and work-part cooperation. Areas of side edge of exit side, adjacent to tooth vertex, which are most worn out during dry processing, remove extremely thin slices and often occurs not cutting process but process of surface plastic deformation. Accordingly, a significant influence on tool wear has character of friction between the pinion-shaped cutter and the workpart. When using dry electrostatic cooling, weakening of softest material of friction pair occurs, in addition, application of dry electrostatic cooling, leads to the formation of oxide films on work-part and tool surfaces and as a consequence to reduction of friction coefficient and as a result to reduction of the cutting tool wear.

8. ASSURANCE OF RELIABILITY OF THREAD – CUTTING TOOL

8.1. Wear criteria of thread – cutting tool

The main «normal» wear is wear on the flank surface, characterized by the worn site width h_B and extending on teeth corners (h_c). Permissible wear value is determined by suitability of cutting thread. Usually it is allowed tool wear only up to a certain, optimal value, at which the maximum tool life is ensured taking into account repeated sharpening. In addition to «normal» wear, «catastrophic» wear can occur when cutting teeth are microchipping and tool breaks (sudden failure). In addition to wear, the cause of thread – cutting tool failure can be sticking of processed material on rake face surface or between cutting teeth.

The main reason of thread – rolling tool wear is microchipping of turn of thread due to metal fatigue failure of tools in area of variable forces that occur during rolling. Sometimes wear is accompanied by deformation (crushing) of turns. Wear begins and increases during operation from microchipping at the turn top, thereby the profile height is reducing. This increases surface roughness of thread and changes its diameter.

The wear of turns of free – chipped taps initially discover itself in appearance and increase of rounding radius at vertex and profile sides, which subsequently leads to a decrease of outer diameter d and loss of a given size.

8.2. Application of cutting fluids of thread cutting

When thread cutting, oil lubricating – cooling liquids, aqueous emulsions, synthetic coolant and sometimes plastic lubricants are used. Oily liquids are more effective as a lubricant because they reduce amount of heat produced during cutting of metal, and aqueous emulsions better divert already formed heat and act mainly as cooling agents. When rolling the outer and inner threads, oil fluids are preferable.

The use of cutting fluids improves tool life of the thread – forming tool and improves thread quality. For automatic lines, aggregate machine tools and

other multi – tool equipment, as a rule, universal cutting fluids with properties that satisfy operating conditions of most tools and are not always optimal for thread – cutting tools are used. In such cases, if possible, for thread cutting operations an autonomous supply of cutting fluid is provided.

When thread cutting, the cutting fluid is most often supplied by flowing into the cutting zone by free falling jets. In some cases, for example, when cutting in hard – to – work materials, the cutting fluid is supplied under pressure through channels in tool (tap), which improves lubrication conditions, provides heat removal, chip removal, and increases tool life. When tapping it is recommended, that pressure of pressure jet is 1,0 – 1,5MPa, cutting fluid supply rate is 5 – 10 l/min. For supply of coolant cutting fluid to rotary tools, special cartridges or couplings are used. The tap has channels that lead cutting fluid either into butt or into flutes.

On automatic lines, aggregate machine tools, CNC machine tools, the cutting fluid is sometimes delivered by spraying in form of air – liquid aerosols. This requires exhaust ventilation, which limits the scope of this method.

Plastic lubricants used for rolling of internal threads are applied periodically with brushes or tampons, after processing of certain number of work-parts.

Cutting of external and internal threads in work-parts made from grey cast iron, bronze, brass and rolling on work-parts from non – ferrous alloys is possible without use of cutting fluids.

8.3. Thread – cutting tool protective coatings

When thread cutting, jamming and curing of tool lead to appearance of an almost incorrigible defect – thread defects (scoring, large roughness, microchipping, burrs). Coatings for a thread – cutting tool should have sufficient strength of adhesion with base material and increased anti – friction properties (low friction coefficient, minimum duration of running-in, minimum heat release during friction). The following types of coatings are used: nano – coatings; with a multiphase structure of various types; composition with variable thickness; compositions with layered structure; compositions with hard-composition hardening; with an amorphous –crystalline or amorphous structure.

Coatings on tool contact areas are facilitates plastic deformation process when thread cutting and reduces proportion of deformation and force loads due to «uneasiness» of cutting process. The average contact loads are monotonously reduced from first pass of thread cutter to latter by an average of 10 – 20% during generator and by 20 – 30% during profile cutting schemes, which is

associated with an increase of cut layer area with an increase of number of tool passes.

Both as the thermo-physical properties of coating and as change of contact interaction conditions on tool rake face surface can lead to a redistribution of heat fluxes between work-part, tool and chips. The heat fraction entering the cutter will be decreasing, and in the chips it will increasing.

The top layer of the *multilayer coating* should promote maximum stresses reduction in cutting wedge to increase its form stability and have high residual compressive stresses to provide high normal compressive stresses in coating during cutting that reduce the cracking process intensity and lower layer should provide high adhesion strength of coating with base.

As top layer of multilayer coating, three – element nitride coatings TiAlCrN, TiCrAlN and TiCrZrN are recommended. These coatings have a high level of compressive residual stresses, which promote formation of high normal compressive stresses during cutting, and provide the best thermal and stressed state of tool cutting wedge. As lower layer of the multilayer coating, two – element TiAlN and TiCrN coatings are recommended, which provide a higher adhesion strength (have the lowest delamination coefficient K_d), compared to three – element coatings.

The architecture of multilayer coatings for turning and thread cutting cutters are shown in Figure 8.1. As such coatings, the following systems are used: TiCrN-TiCrZrN, TiCrN-TiCrAlN, and TiZrN-TiZrAlN.

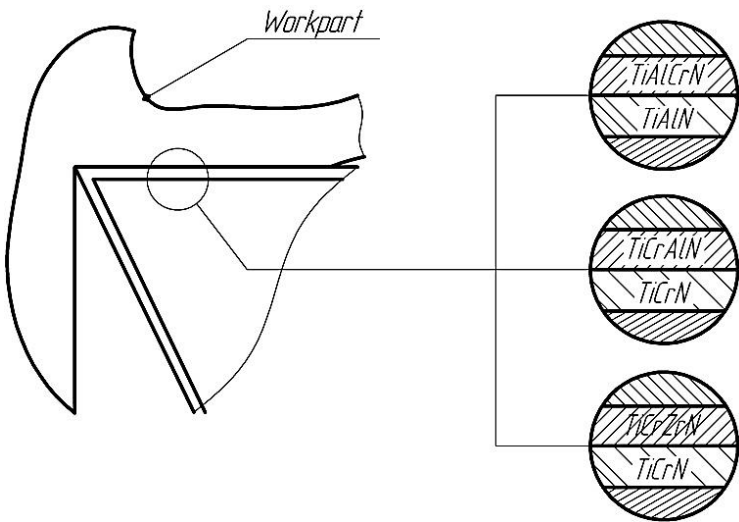


Fig. 8.1. Multilayer coatings architecture of turning and thread cutters

Thread cutters wear rate is affected by top layer thickness TiCrZrN. The wear rate change of thread cutter from top layer thickness has extreme character (Fig. 8.2 and 8.3). With an increase of layer thickness TiCrZrN wear rate decreases, reaching a minimum, and with increasing of upper layer thickness wear rate increases. The minimum wear rate of cutting tool is provided by a multilayer coating with a total thickness of 7 μm and an upper layer thickness of 50 – 65% of its total thickness.

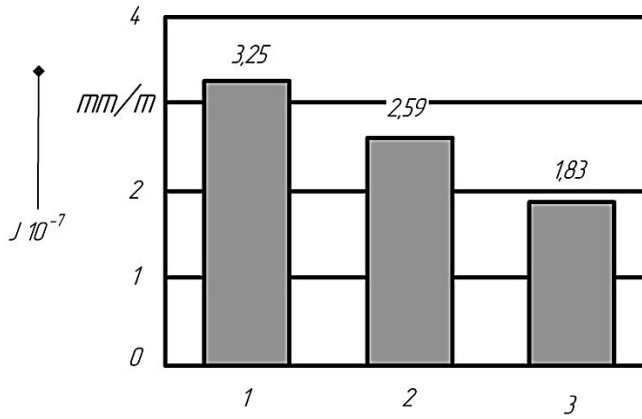


Fig. 8.2. Influence of total thickness of multilayer coating TiCrN-TiCrZrN on thread cutter wear rate: total coating thickness is 5 μm (1), 6 μm (2), 7 μm (3)

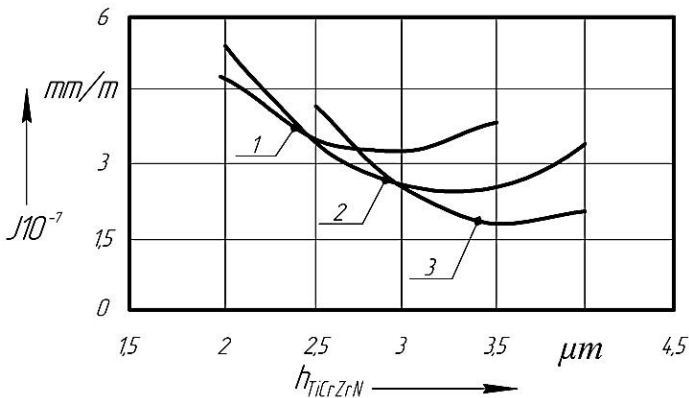


Fig. 8.3. Influence of coating structure on wear intensity of threaded cutters when thread cutting of work-parts from steel 38XГН: total coating thickness is 5 μm (1), 6 μm (2), 7 μm (3)

When thread cutting (Fig. 8.4) occurs on work-parts from steel 38XГH (Russian grade), the use of multilayer coating TiCrN-TiCrAlN increases tool life, depending on the cutting regime, by 2,4 – 3,8 times, and multilayer coating TiCrN-TiCrZrN by 3,7 – 4,6 times in comparison with a thread cutter without a coating, and in comparison with cutters with coating TiN by 2,5 – 3,0 times.

When thread cutting occurs on work-parts from steel 12X18H10T (Russian grade), the effectiveness of multilayer coatings is lower. The use of multi – layer coatings TiCrN-TiCrAlN and TiCrN-TiCrZrN increases the tool life of thread cutters by 1,8 – 2,0 times in comparison with uncoated tool and by 1,3 – 1,5 times in comparison with coating TiN. As in the case of work-parts processing from steel 38XГH (Russian grade), the most effective coating is TiCrN-TiCrZrN. During thread cutting the use of multilayer coatings increased tool life of thread cutters by 1,67 – 1,74 times compared with cutters coated by coating TiN and by 3,5 – 4,0 times, as compared to a thread cutters without coating.

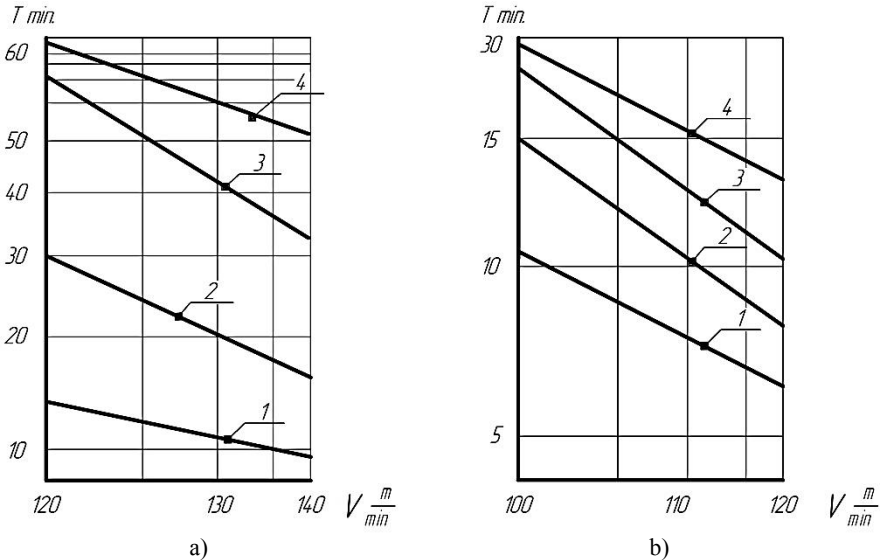


Fig. 8.4. The influence of cutting speed V on tool life period T of inserts H13A when thread cutting on workparts from steel 38XГH (a) and 12X18H10T (b):
 1 – without coating; 2 – TiN; 3 – TiCrN-TiCrAlN; 4 – TiCrN-TiCrZrN

Finishing plasma hardening produces nanocomposite multilayer coatings with an amorphous – crystalline heterogeneous structure of system Si-O-C-N with thickness of 1 μm , which have minimum friction coefficient that is more

than 5 times smaller than friction coefficient of coating Ti-Al-N and base material. Depending on work-part material tool life of taps made from steel P6M5 (Russian grade) is increased by 2,2 ... 10 times.

8.4. Assurance of operability of thread cutters and thread chasers

8.4.1. Influence of geometry and design features of single-point threading tools

The characteristics of main thread cutting methods by *single-point threading tools* are given in Table 8.1.

Table 8.1

Characteristics of thread cutting methods by single-point threading tools

Radial penetration	Penetration along one side of thread profile	Penetration along one side of thread profile with lateral displacement	Penetration with alternate lateral displacement
Advantages			
<ul style="list-style-type: none"> – Easy to use. (Standard cycle for thread cutting). – Wide application. (Easy change of cutting modes). – Even wear of right and left sides of cutting edge. 	<ul style="list-style-type: none"> – Relatively easy using. (Semi-standard cycle for thread cutting). – Cutting force decreases. – Suitable for thread cutting of large step or easy processed materials. – Good chip removal. 	<ul style="list-style-type: none"> – Prevents side wear on right side of cutting edge. – Cutting force decreases. – Suitable for thread cutting of large step or easy processed materials. – Good chip removal. 	<ul style="list-style-type: none"> – Even side wear of right and left sides of cutting edge. – Cutting force decreases. – Suitable for thread cutting of large step or easy processed materials.
Disadvantages			
<ul style="list-style-type: none"> – Difficult chip-forming. – Vibration susceptibility on last stages of cutting. – Inefficient for thread cutting of large steps. – A large load on radius at vertex. 	<ul style="list-style-type: none"> – Significant lateral wear of right side of cutting edge. – Relatively difficult change of cutting depth (Complicated programming). 	<ul style="list-style-type: none"> – Complicated processing programming. – Difficult change of cutting depth. (Complicated programming) 	<ul style="list-style-type: none"> – Complicated processing programming. – Difficult change of cutting depth. (Complicated programming) – Difficult chip-forming.

To increase tool life and to avoid damage of radius at vertex, it is recommended to use method of corrected lateral penetration. To obtain uniform lateral wear on both sides of cutting edge, the method of radial penetration is recommended. For prevention of hole wear, a lateral penetration method is recommended.

In some designs of *thread chaser* through-hole for cutting fluid supply and chip-breakers direct cutting fluid at high pressure (up to 210 bar) precisely to cutting edges, optimizing chip formation and chip removal efficiency and increasing tool life.

8.4.2. Application of inserts for thread cutting

When thread cutting on hardened work-patrs, it is recommended to use cemented carbide inserts with hardening coating. Replaceable polyhedral non – re –sharpening inserts are manufactured for cutting of various types of threads with complete and incomplete profile.

Ceramic inserts have much greater red hardness and firmness (hardness) than cemented carbide, but they have less plasticity and bending resistance, i.e. they are more fragile. The increase of normative lifetime of insert can be achieved by iterative use of inserts in other operations that allow a larger amount of wear, for example, semi – finishing, or when processing more rigid parts, etc.

The second direction involves re – sharpening of blunted inserts by rake face surface even if they have wear – resistant coatings on them. The validity of such a decision is justified by the fact that, in the case of finishing, the flank surface is subjected to preferential wear. With such re – sharpening on rake face surface it is necessary to form a ledge that will perform functions of remote chip – forming elements of insert.

Instead of 2 cutterss, it is possible to use one combined cutter with 2 vertices. This will reduce auxiliary time associated with replacing of rough cutter to finishing cutter, which is very important at low speeds of idle strokes.

8.4.3. Surfacing of thread cutters

Error of locating and not dense adherence of inserts to body during soldering lead to insufficient strength of connection and decrease of durability and premature failure of tool. Insufficient strength of connection allows to use about 50% of insert length during re – sharpening. Application of soldered cutting part, strength connection of which is higher, makes it possible to re – sharpen tool along entire length of cutting part. The cutter after soldering is subjected to single tempering at $t = 560$ °C during one hour. According to margin

of technological strength steel 30XГСА (Russian grade) is recommended for body manufacture.

Cooling forming inserts, made from copper, provide high quality of soldered metal surface and have a long service life (up to thousand of soldering cycles). After surfacing and machining, the work-parts were hardened by impact surface plastic deformation in cooling process during tempering operation. Manufacturing of cutter with use of soldering technology allow to reduce consumption of high – speed steel by more than three times. The durability of soldered tool is higher than normative by 25 ... 30%.

8.5. Assurance of taps operability

8.5.1. Influence of geometry and design features of taps

Tapping cutting conditions are very heavy due to non –free cutting, large cutting and friction forces, as well as difficult chip removal. In addition, taps have a reduced strength due to a weakened cross – section. This is especially negative when thread cutting of viscous materials with small diameter of taps, which often fail because of breakages caused by chip packing.

Advantages of taps are: simplicity and technological design, possibility of thread cutting by self – feeding, high accuracy of thread, determined by manufacturing accuracy of taps.

Tap cutting part determines thread accuracy and its durability. Tap cutting part tap performs main cutting work and should be as short as possible, since this reduces machine time, specific cutting force and tool load decreasing due to increase thickness of cut, friction force and chip entrapment, as well as risk of failure, torque is reduced.

Tap calibration part is used for thread surfaces cleaning, giving it correct geometric shape and final dimensions, as well as for tap directing during formation of thread by intake part. To reduce breakdown and friction between tap and hole, thread of the calibrating part has a reverse taper (0,05 ... 0,10 mm per 100 mm of working part length). The breakdown will be the smaller, the shorter the calibrating part, the smaller feathers width and their number.

The geometrical parameters of teeth of tap cutting part are shown in Figure 8.5. The front angle γ of tap teeth is the angle between tangent to front surface and radius drawn to point of cutting edge through which main plane passes.

According to difficult working conditions of tap, back rake angle, as a rule, is taken positive. For processing of medium hardness steels, it is

recommended to take angle $\gamma = 12 \dots 15^\circ$, for brittle materials (cast iron, bronze, brass), and for solid steel $\gamma = 0 \dots 5^\circ$, for non – ferrous metals and alloys $\gamma = 16 \dots 25^\circ$.

The end relief angle α_e at the main vertex edges is angle between cutting speed vector through which passes cutting plane and tangent to flank surface. It is created by relieving of vertex cutting edges of teeth along Archimedian spiral. It is recommended to take $\alpha_e = 6 \dots 12^\circ$ (a smaller value is taken for hand taps). On the lateral cutting edges with generator cutting scheme, there are no rear angles, since thicknesses of cut layers are small.

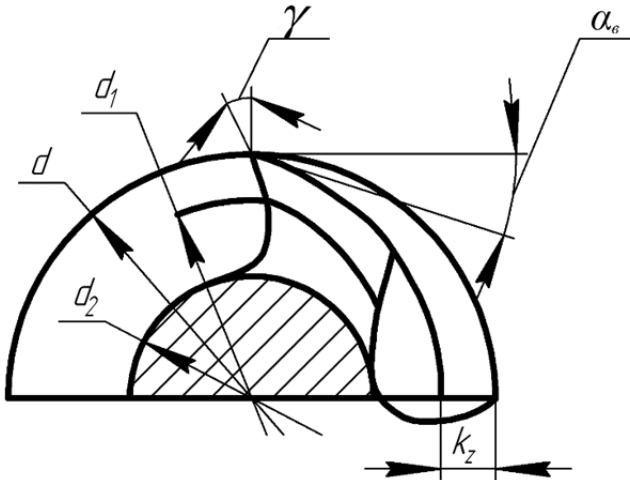


Fig. 8.5. Geometric parameters of cutting teeth of tap

The shape of flutes and the feathers of tap has a great influence on its operability. The flute volume should be sufficient to accommodate chips, especially during thread cutting in blind holes. The shape of flute should facilitate better formation and removal of chips from cutting area. Despite the simplicity of taps designs various variants of their implementation applied to solution of specific production problems have found wide application in practice (Figure 8.6).

During thread cutting in viscous steels and hard – to – work materials, conventional taps often fail and do not provide clean thread. The cutting process is accompanied by large frictional forces between the tool turns and part, chips pressing and tap pinching in hole. Taps with a chess arrangement of teeth are recommended for thread cutting in such materials, since they exclude jamming

of tool turns during cutting due to friction forces reduction. In this case, cutting of tap teeth is usually carried out only on its calibration part. During processing of low – strength viscous materials, teeth are cut as by 1/3 of intake part length and over its entire length. The effect of frictional forces reducing is the higher, as the larger the thread pitch.

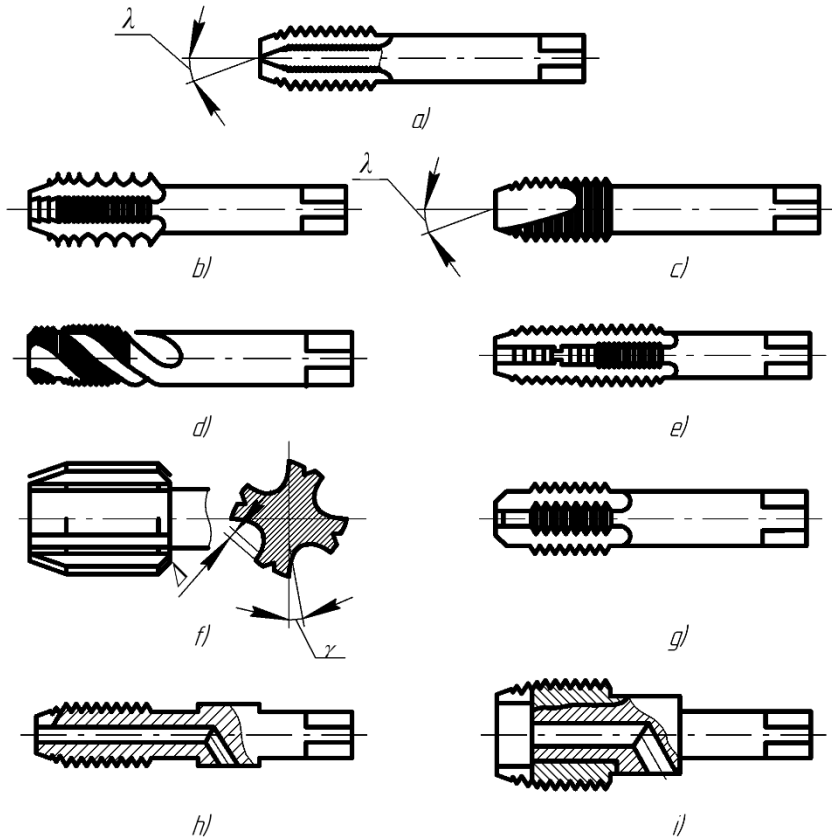


Fig. 8.6. The designs of taps:

- a* – metalworker (manual); *b* – with chess arrangement of teeth; *c* – without flute;
- d* – with screw flutes; *e* – stepped; *f* – with cutting – smoothing teeth; *g* – with guide part;
- h* – with internal supply of cutting fluid; *i* – bell type

Taps without flutes have great strength, provide a better thread quality, facilitate cutting conditions and chip removal in forward direction, more

complete use of material due to multiple flute elongation after fluted land grinding off across the width. The preferred application field of taps without flutes is processing of light alloys, non – ferrous metals, viscous steel, stainless steel and cast iron. Taps have short flutes of variable depth with an inclination angle of flute bottom to the axis $\psi = 5 \dots 10^\circ$ and an axial angle $\lambda = 9 \dots 12^\circ$. In comparison with conventional taps, these taps are more durable because of larger cross – section. The flutes length is approximately equal to twice length of intake cone. In order to avoid an increased friction torque, due to absence of flutes over larger length of unrelieved gauge part, a larger inverse conicity by outer diameter is made (up to 0,2 mm per 100 mm of length). Such taps are recommended to use for thread cutting of threads with diameters up to 10 mm in through holes. They also provide high accuracy and low surface roughness of thread.

Screw flute taps are used for processing of high – strength and viscous materials. This design provides better chip removal when cutting of cylindrical threads in holes with a discontinuous surface, in long blind holes. Screw flutes reduce axial forces, provide better access of cutting fluid and increasing actual back rake angles without increasing strength.

Stepped taps have a double cutting part and allow to realize any combination of cutting schemes in single tap. For example, the first part, which has an underestimation along profile, can process thread according to generator scheme, and the second part can process thread according to profile scheme. In this case, it is possible to cut high – precision threads. This design is also convenient for such combined schemes, in which one part performs cutting, and the second – smoothing of thread.

Taps with cutting – smoothing teeth have feathers with cutting and driving areas. The flutes separating the cutting and driving parts of tap serve to supply cutting fluid and abrasive wheel outlet when thread profile grinding.

Taps with guiding parts are used for processing of parts with exact mutual arrangement of surfaces of several holes. In taps for through holes, the guide part is located in front of cutting part, and for the blind ones – after calibration part. The guide part located after calibration part has an enlarged diameter and requires use of conductor sleeve.

Taps with internal supply of cutting fluid have a resistance of 3 ... 4 times higher due to better cooling, lubrication and chip removal conditions, but require special devices for supplying of cutting fluid.

Taps of bell type are used in heavy engineering for thread cutting of through holes with large diameters $d = 50 \dots 400$ mm. They are either integral or composite. In latter case, tap working part is shell, consisting from cutting and calibrating parts. The internal cavity of tap provides supply of cutting fluid and has a large space for chip placement. The number of feathers in these taps reaches 16.

Broach tap (Fig. 8.7) allows to cut thread of any profile and length in through holes, with any number of passes. Broach tap compared with conventional tap and thread cutters provides increased productivity in several times with high accuracy and low roughness of thread.

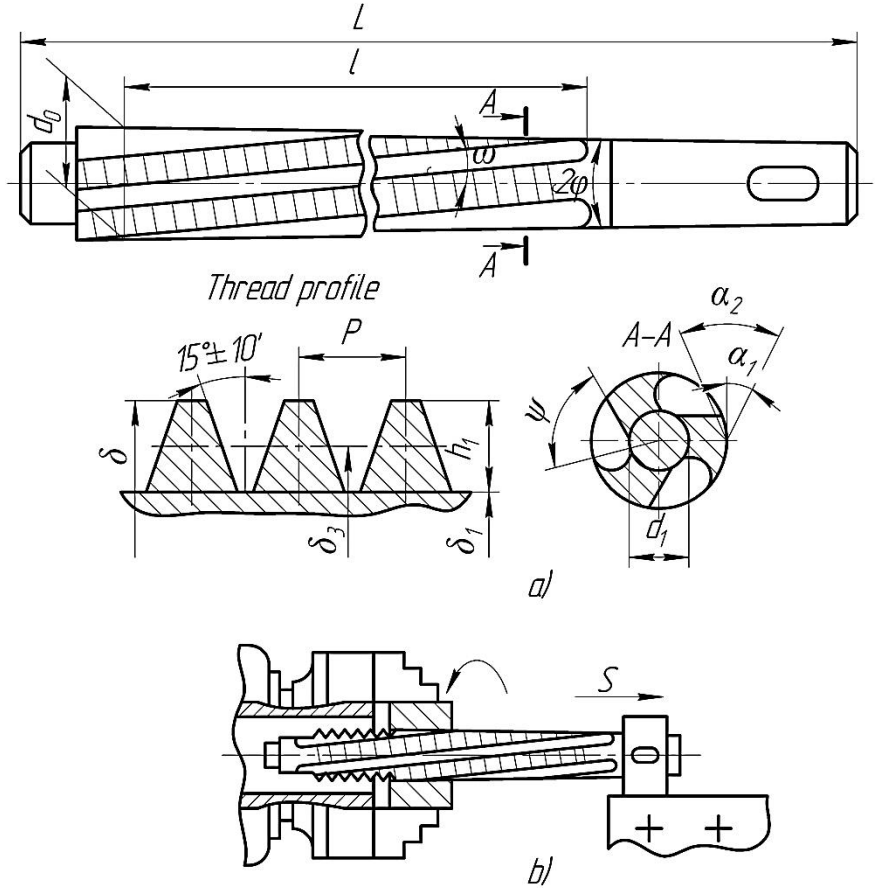


Fig. 8.7. Broach tap:
a – design; *b* – internal thread broaching scheme

The effective dimensions of tap are determined by taking into account hole breakdown δ_{pr} and margin for wear δ_{wear} , as well as achievable production accuracy δ_{pr} and ensuring of nut dimensions.

The wear margin by average thread diameter of finishing tap depends on thread pitch and is selected according to formula

$$\delta_{2wear} = \frac{16\sqrt{p}}{1000}$$

where p is thread pitch.

The wear margin δ_{wear} by outer diameter of finishing tap is assigned more than by average diameter, because at this diameter, cutting speed is maximum, and strength of tooth top is reduced. For all types of taps, the wear margin is assumed to be the same and equal to allowance $IT9$:

$$\delta_{wear} = 0,086 - IT9$$

Taps with internal chip placement have a number of advantages over conventional taps, in particular a reduction of tool failure number, better centering and direction of hole in work-part, which results to a more stable index of thread accuracy.

The main constructive difference between these taps (Fig. 8.8) from standard ones is the presence of an internal cylindrical cavity for placing chips and supplying of cutting fluid to cutting zone with diameter d_0 and length l_0 , whose axis coincides with tool axis. This allows to make guide part in form of a continuous cylindrical thread surface. On tail part there is a cylindrical section with diameter d_4 for placing of clutch for supply of cutting fluid and a channel along tool axis for its supply inside the working part. Taps re – sharpening can be performed both by rake face surface of tooth and by flank surface. Taps for blind holes are usually sharpened by rake face surface.

Cemented carbide taps allow to increase productivity of thread cutting in cast – iron and steel (hardened) parts by 2 ... 5 times and to increase resistance to hardened and high – strength steels by 5 ... 10 times. According to design, cemented carbide taps can be: solid-carbide tool (monolithic), with a solid carbide working part, with soldered cemented carbide inserts, shell tap with soldered cemented carbide inserts and assembled with a solid cemented carbide working part.

Monolithic cemented carbide taps M8 ... M10 from plasticized blanks are expedient to use in especially severe conditions of thread cutting with a large heat release, when the use of soldered taps with cemented carbide inserts is inexpedient. Taps M8 ... M12 with a monolithic working part that soldered to steel shank, it is advisable to use for processing of cast iron, high – strength steels and materials with increased physical and mechanical properties.

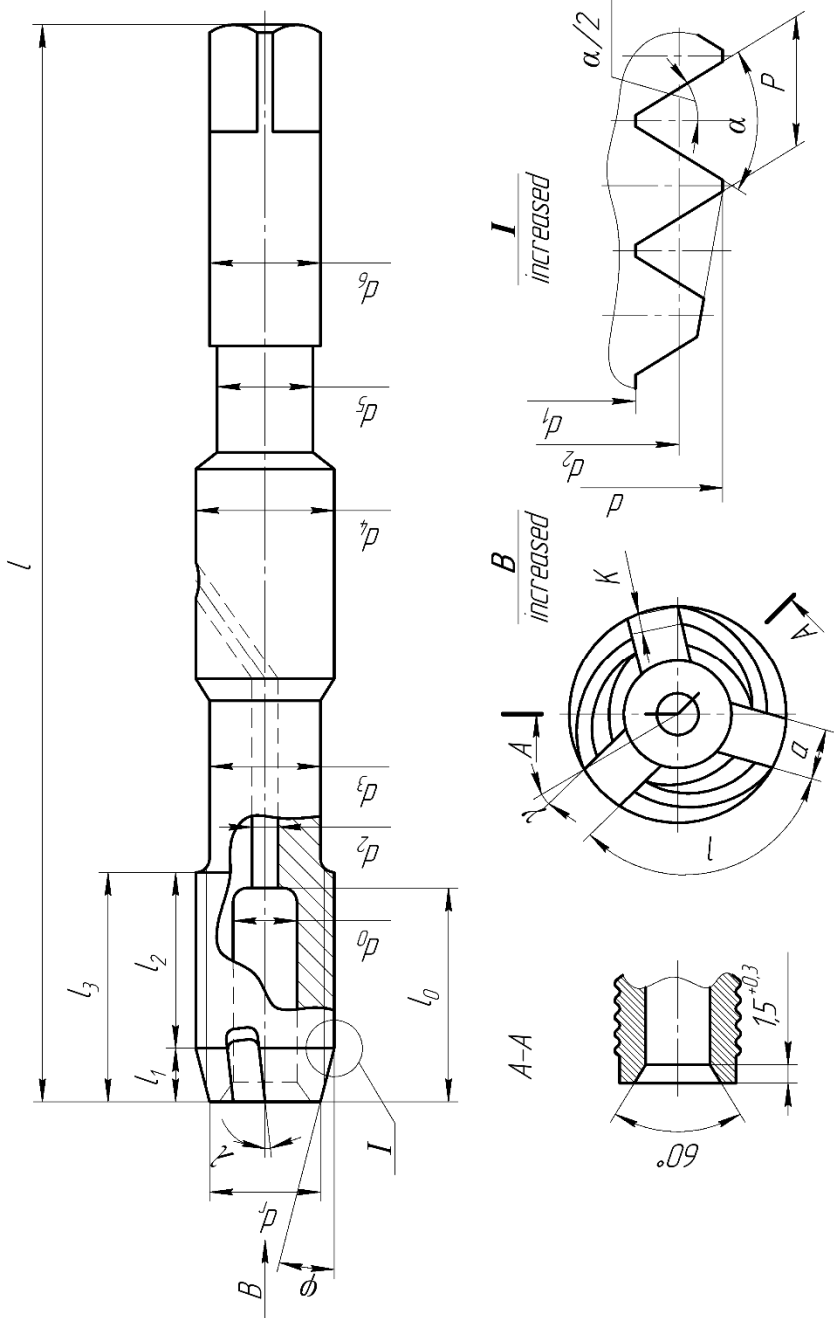


Fig. 8.8. Tap with internal chip placement

TaeguTec company has developed taps with straight flutes and screw sharpening for high – efficiency through – hole machining. Lead-in chamfer of such taps has 4 – 5 threads. The use of such geometry of taps facilitates thread cutting process of internal thread due to free ejection of chips in feed direction. For thread cutting of blind holes, special designs of taps with right – hand spiral flutes at an angle of 40° and lead-in chamfer part with 2 – 3 threads are developed, which makes it possible to expose chips upwards, not allowing it to be packaged at the hole bottom and cutting edges damaging.

Flat sharpening of flank surfaces is the most simple, allows to relieve taps with pinched centers and does not require special machine tools and devices. Taps with a double flat flank surface showed increased resistance during thread cutting in a titanium alloy BT-3 (Russian grade).

Combined sharpening is used for taps for thread cutting in relatively viscous steels, when one of the main reasons for premature tool failure is the teeth microchipping on chamfer lead.

Information by relative strength and rational application of various types taps is given in Table 8.2.

In this case, it is possible to obtain the following accuracy degrees of thread that cut by taps: with increased accuracy and without chips – 2 – 6th, stepped with screw flutes and cutting – smooth teeth – 4 – 6th, the rest – 6 – 7th. The approximate number of repeated sharpening is indicated in Table 8.3.

As well as tool life, there are geometric parameters and design elements of tool, optimal by processing accuracy. And on the accuracy of processing they do not affect themselves, but through phenomena that accompany the cutting process, mainly through specific pressures (pressures per length unit of cutting edge or per area unit of tool support surfaces) from forces acting on tool and part during cutting. These forces violate screw motion law of tap. So, for example, increasing back rake angle of tap reduces cutting forces, including the axial ones, which are the main cause of thread breaking.

If the axial forces are perceived by thread (thread cutting by method of tap self – sharpening), then end relief angle of tap, provided by tap relieving along thread profile, have strongest effect on thread breaking. The larger the relieving (larger auxiliary end relief angles), the more thread breaking.

The side cutting edge angle of tap affects thread dimensions through the difference of radial forces on its feathers. The greater this difference, the greater the breakdown.

The angle of flute inclination affects value of sum vector of axial forces. The average value of optimal flute inclination angle is 30° .

Since the main reason for low accuracy of thread is violation of helical motion law of tap from effects of axial and radial forces, to increase the accuracy, it is necessary to reduce these forces or limit them, and possibly neutralize, their impact. Neutralize effect of axial forces can be due to profile or combined cutting schemes, but the best solution is to ensure tap by forced axial feed through threaded copier.

Table 8.2

The influence of taps design on their tool life

Taps	Diameter of tap d , mm	Relative tool life	Рациональная область применения метчиков Rational area of application
1	2	3	4
With straight flutes of accuracy: normal increased	1 – 52 1 – 52	1,0 0,8	For normal processing materials
With axial inclination angle of cutting edge	5 – 52	1,3 – 2,0	By chips transportation before the tap
With chess arrangement of teeth	4 – 52	1,3 – 2,5	For processing of low – carbon, corrosion – resistant and heat – resistant steels, light alloys
Reinforced: – with strengthened core; – without flutes.	5 – 12 2 – 6	1,3 – 3,0 1,3 – 2,5	For processing of hard – to – process materials
With screw flutes	3 – 52	1,3 – 2,5	To remove continuous chip from blind holes
Stepped: – cutting – cutting – rolling	10 – 20 16 – 36	1,3 – 1,6 1,3 – 1,6	For processing of precise holes that have no restrictions by thread runout
With cutting – smooth teeth: – barrel – shaped – blocked	6 – 12 12 – 72	1 1	To obtain an accurate thread in viscous materials
Chipless	1 – 36	2 – 10	For processing of color alloys and low – carbon steels, mainly for taps with diameter of 1 – 8 mm
Cemented carbide: – monolithic – with brazed inserts	5 – 12 14 – 72	3 – 10 3 – 10	For processing of hard – to – process materials and cast irons
With guide part: – front – rear	6 – 30 16 – 52	1 1	At small allowances of surfaces mutual arrangement
With internal channels for supply of cutting fluid	10 – 52	1,5 – 3	For processing of steels with increased strength and hardness
Bell type: – monolithic – pocketed insert	20 – 52 60 – 400	2 – 6 2 – 6	For large thread manufacturing in heavy engineering

* Tool life of tap with straight flutes of accuracy degree H3 when processing of normal processing materials is adopted as a unit.

Table 8.3

Number of re – sharpening of taps and round thread chasers

Thread diameter, mm	Number of re – sharpening	
	Machine taps	Round thread chasers
3 – 5	1 – 2	–
6 – 10	2 – 4	40 – 60
12 – 18	3 – 5	60 – 80
20 – 36	4 – 6	50 – 80
40 – 52	8 – 10	40 – 70

Limitation of axial forces influence is possible due to tap parameters: base barrel elements on lateral sides of its thread profile; reduced up to zero amount of relieving by profile; relieving by profile not entire width of pen; limiting of cutting ability of lateral base cutting edges by their blunting with an abrasive bar.

If necessary, it is possible to reduce forces by choosing proper cutting scheme and geometric parameters of tap. The most effective of them is the group cutting scheme, which is possible when cutting of large pitch threads, and the 30° inclination angle of helical flutes – right for right thread and left for the left.

Reduction of sum vector of radial forces is achieved by reducing the radial runout of main cutting edges and by choosing optimum angle in plan, which aligns the cutting edges lengths on tap feathers, and by reducing the radial runout of machine tool spindle, increasing the accuracy of tap setting, and using bellows – type cartridges.

Partial neutralization of radial forces is possible by limiting tap radial vibrations due to exact direction along conductor sleeve or by cutting hole. It is possible to use hump – like elements, made by relieved surfaces of tap intake part and perceiving radial force.

The deformation of tap, which affects breaking, is its twisting under the action of torque. As a result, the tap feathers, if they were parallel to axis, warp and become slightly inclined or screwed. Positive results are achieved by multipass cutting or other methods of reducing torque. In mass production, it is possible to cut thread on special machine tools with taps rotated by two tails: a normal rear and an additional front. The probability of taps breakage in such cases also decreases.

The change in transverse shape of blades edges can bring additional positive effects. Rounding the edges of these blades leads to their hardening and increase tool life of tap. Applying magnetic – abrasive machining of taps, it is possible to create on blades a hardening rounding of cutting edges.

8.5.2. Materials and coatings for taps manufacturing

The grade of high – speed steel for manufacturing of tap working part is selected depending on properties of processed material, surface layer state of the work-part hole and technological requirements for thread cutting operation (surface roughness, accuracy, etc.). For thread cutting of normal quality carbon steels, structural carbon quality steels, low – alloy steels, non – ferrous metals, alloys and plastics, recommend to use HSS P6M5 (Russian grade). For thread cutting of high – alloy, hard – to – process, heat – resistant, corrosion – resistant steels and alloys, high – speed steel P6M5K5 (main) and also steels P9M4KB, P9K1C (Russian grades) are recommended. Machine – hand taps with a diameter of 1 to 2,5 mm are allowed to be made from carbon steel Y11A and Y12A (Russian grades).

Cemented carbide taps have high hardness, wear – resistance, red – resistance, heat – resistance, are capable of operating at maximum cutting speeds and with high productivity, but sometimes they lack strength (the higher the hardness, the lower the strength), in these cases use taps from powder high – speed steel, such taps have high strength and practically the same characteristics as for a hard alloy.

Leading world companies develop and use new tool materials and coatings. Table 8.4 shows characteristics of materials and coatings for taps used by WIDIA Products Group.

Table 8.4

Characteristics of tool materials and coatings for taps manufactured by WIDIA Products Group

Grade	Characteristics of tool materials
1	2
WN38MG	The basis of high – speed steel HSS-E, coated with a black oxide coating. It is recommended for processing of various materials, including steel, stainless steel and malleable cast iron. Not recommended for processing of non – ferrous metals.
WS32MG	High – speed steel HSS-E-PM with coating. The base of HSS fast – cutting powder steel, enriched by vanadium and cobalt, with a heat and wear – resistant PVD coating including high – strength bottom layer of TiCN. It is recommended for thread cutting of parts from heat – treated steel with a hardness of 44 – 55 HRC and heat – resistant alloys based on cobalt or nickel.
WU40EG	The basis of high – speed steel HSS-E without coating, with a polished surface. Universal alloy for easy processing materials

Table 8.4 (continued)

1	2
WU41EG	The basis of high-speed steel HSS-E with PVD coating TiN. It is recommended for many operations, including machining of parts made from steel, stainless steel, malleable cast iron and aluminum casting.
GM6515	High-speed steel HSS-E-PM with coating. The basis of HSS fast – cutting powder steel, enriched by vanadium and cobalt, with a heat and wear – resistant PVD coating. The coating includes antifriction layer CrC/C and wear – resistant layer TiN. It is recommended for thread cutting of stainless steel and non – ferrous metals.
GN1515	Cemented carbide with coating. A two – layer coating PVD is applied on a fine-grained cemented carbide basis. The coating includes antifriction layer CrC/C and wear – resistant layer TiN. The layer CrC/C prevents sticking of non –ferrous metals on tap during processing. The alloy provides excellent performance when thread cutting of parts from aluminum castings and other non – ferrous metals.
GP4535	Hard alloy with coating. The multi – layer PVD coating TiAlN and TiN is applied to a high – strength carbide base, specially developed for thread cutting operations. The use of this alloy for processing of steel with a hardness of up to 32 HRC and cast iron allows up to four times the cutting speed compared to taps from high – speed steel HSS-E-PM.
GP6520	High – speed steel HSS-E-PM with coating. The basis of high – speed powder steel HSS, enriched by vanadium and cobalt, with a heat and wear – resistant PVD coating with a base layer TiCN. It is recommended for processing of steel, cast iron and aluminum casting containing silicon.
WH16PG	Cemented carbide with coating. A two – layer PVD coating comprising a high – temperature backing layer TiAlN and antifriction top layer MoS ₂ is applied to carbide base. The alloy is recommended for processing of hardened steel with a hardness of 55 – 63 HRC.
WN35MG	High – speed steel HSS-E-PM. The basis of HSS-E high – speed steel with a two – layer PVD coating. The lower layer TiN and top layer DLC, which prevents sticking of non – ferrous metals on tap. It is recommended for thread cutting of parts from titanium. It is not recommended to use for viscous steels processing.
WN38MG	High – speed steel HSS-E-PM with coating. The basis of high – speed powder steel HSS-E coated with DLC (diamond – like carbon coating), deposited by PVD. It is recommended for thread cutting of aluminum parts. It is not recommended to use for processing of steel.

Table 8.4 (continued)

1	2
WN48EG	High – speed steel HSS-E with coating. The basis of high – speed steel HSS-E with a low content of vanadium and coating DLC, deposited by PVD method. It is recommended for thread cutting of parts from non – ferrous metals with low cutting temperatures, for example, a deformable aluminum alloy. It is not recommended to use for processing of steel.
WP31MG	High – speed steel HSS-E-PM with coating. A basis of high speed powder steel HSS-E with PVD coating TiN. It is recommended for thread cutting of steel with hardness up to 32 – 44 HRC and thread cutting of parts from steel with hardness up to 32 HRC.
WP42EG	The basis of high – speed steel HSS-E with PVD coating TiCN. It is recommended for many operations, including processing of parts from steel, stainless steel, malleable cast iron and aluminum casting. Alloy WP42EG has a higher abrasion resistance than WU41EG.

TaeguTec employs blackening to ensure high resistance of taps at medium and high cutting modes. The resulting oxide coating provides ideal conditions for chip removal, and also reduces build – up on cutting edges. Blackening when cutting thread $M6 \times 1$ at a speed of 25 m/min in parts from steel 40 (Russian grade) ensures tool life of taps during processing of 1300 holes. Coating TiAlN-PVD has the highest wear resistance of cutting edges. It provides increased resistance and stability of thread cutting process of various materials. When thread cutting of parts from high – strength cast iron BЧ40 (Russian grade) at a cutting speed of 25 m/min it ensures tool life of taps during processing of 3,500 holes. A diamond – like coating for thread cutting of $M8 \times 1,25$ of parts from an alloy Al provides 8000 holes.

To save tool steel, it is recommended to manufacture assembly tap: the working part from high – speed steel P6M5 (Russian grade), the tailpiece from cheaper steels 45, 40X (Russian grade). The displacement of welded ends, lack of fusion, micro-cracks, and the formation of a brittle zone of decarburized layer lead to decrease of strength and tool life. Apply taps from bimetals, performance of which during cutting of metric thread in hole of steel part on average by 13% exceeds performance for standard taps $M12 \times 1,25$ from steel P6M5 (Russian grade).

8.5.3. The occurrence of taps failures

The increase of rounding radius of cutting edges has a significant effect on the value of cutting force and initiates shear fracture, microchipping of cutting blades, which is especially pronounced at small thicknesses of cut layer.

The reason for uneven wear of taps cutting profiles are differences in force and heat loads attributable to individual profiles due to their location on the cutting part of tap, as well as the differences in the conditions of chip formation during their operation.

The wear process of taps cutting profiles by flank surface is accompanied by a slow – running wear process of guide profiles along the outer diameter. After a few re – sharpening, a parametric failure occurs, the tool goes to the limit state and becomes unrecoverable.

The minimum wear rate of taps with internal placement of chips is observed in cutting speed range from 9 to 12 m/min. When processing of blind holes without cutting fluids, taps with internal placement of chips provide an increase of durability by 25 ... 35%, and for processing of through holes with cutting fluids by 40 ... 50%.

When working with cutting speed $V \approx 10$ m/min, an increase of taps diameter leads to a gradual increase of their tool life. This is due to improved heat removal from cutting zone into the tool body and improved of chip placement in inner hole.

An increase of taps pitch leads to a gradual decrease of their resistance. Increasing of pitch at a constant value of cutting part angle φ leads to an increase of cut layer thickness. Tool life of taps decrease from re – sharpening. Decrease of tool life from re – sharpening can be changed by 1,2 or more times. This is explained by the gradual accumulation of irreparable defects on the working surfaces of tool during cutting, which include: changing of cutting profiles shape and support surfaces roughness, accumulation of fatigue stresses, micro-adherence on contact surfaces. When thread cutting of blind holes, conditions of chip removal are difficult: during reverse chip particles get under working surfaces of tap, sometimes its large fragments that lead to micro – scratches and cleavages micro-chipping of tool blades.

8.5.4. Strengthening of taps

Unlike drills, taps may not have a high hardness over entire section. With a viscous core, the risk of taps breakage during work is reduced. For hardening small diameters taps with small thread pitch, they are heated to lower limit of process temperatures.

Various methods of taps hardening surface including coating are applied. Magnetic – pulse treatment provides an increase of tool life of taps from high –

speed steel P18 (Russian grade) by 30%. Magnetic – abrasive treatment of taps allows increase tool life by 2 – 3 times. The tool life is increased due to reduction of run – in time, increase of micro-hardness of tool working surface, reduction of friction coefficient and structural changes of material.

Modification of taps M12 × 1,25 mm from steel P6M5 (Russian grade) by action of low – temperature combined – discharge plasma provided processing of 400 parts from steel 42XMΦA (Russian grade), hardness according to HB 246 ... 286, with a standard amount of 300 parts.

Increase of modifying efficiency and subsequent use of taps is possible by implementation of following recommendations:

- selection of cutting tool material most appropriate to existing cutting conditions;

- provision of cutting part geometry regulated by standards: when thread cutting on the pass accept the length of cutting part equals to 6 thread pitches, when thread cutting of blind thread accept the length of cutting part equals to 2 thread pitches (short cutting part provides a reduction of specific cutting force (due to removal of chips with larger cross – section), torque, frictional forces and chips pinching, buckling of tap during heat treatment);

- reduction of flutes number (for taps M8 ... M14 – up to three), since otherwise a bad chip removal is provided due to reduction of flutes volume and tap core weakening;

- uniform disposition of cutting edges along circle in order to avoid breaking;

- performing of re – sharpening by intake part cone in order to eliminate effect of cutting turns weakening as a result of improper sharpening with large back rake angles;

- avoiding of burns formation while thread profile grinding and relieving of all turns of calibrating part to eliminate «sealing» effect of tool due to adhesion of processed material (especially viscous) to rear and calibrating surfaces. Application of high – temperature gas extrusion process for production of taps from high – speed steels makes it possible to increase their tool life from 2 to 5,5 times.

Use of effective combination of high – speed steels heat treatment to hardness of HRC 53 – 57 and subsequent liquid carbonitriding, allow to increase tool life of taps by an average of 75%.

The cyanidation of high – speed steels in a carbonitride salt bath is very effective for increasing of tool life, while difference in tool life of taps made of steel P18 and cheaper steels P6M5 and P6M3 (Russian grades) is minimized as a result of cyanidation. From an economic point of view, use of cyanated tungsten – molybdenum steels P5M5 and P6M3 (Russian grades) instead of much more expensive high – speed steel P18 (Russian grade) becomes more profitable.

8.5.5. Application of cutting fluids for improvement of taps efficiency

From 20 to 70% of taps fail due to breakage. The greatest number of microchipping and breakages of taps occurs with reverse (more than 75% of cases) by 90 – 120° of tap first turn unscrewing. The main factors of reducing of taps overall performance are: cutting edges microchipping and jamming, especially during reverse process. When tap is reversed, torque has a maximum value due to jamming of tool teeth by cut chips. Under these conditions, considerable plastic deformation, cold working, build – up and intensive adhesion processes occur, which leads to cutting tool wear, rupture of threads, deterioration of thread surface quality and its profile accuracy.

These problems can be minimized by using modified compositions of cutting fluids. The latter would help reduce frictional forces between rubbing pair «tool – part» and improve mechanical properties of treated surface.

With use of sunflower and mineral oils, the torque is the highest, but when emulsion and pork fat supply to the treatment zone, there is a noticeable reduction of torque, both for forward and reverse movement of tool.

Influence of mineral and sunflower oils on wear and tool life of tap, in comparison with the full – jet irrigation of 10% concentration emulsion showed an insignificant effect of wear reduction (about 20 – 40%). The greatest effect of wear reduction (more than 200%) is use of tap in a medium of pork fat.

8.6. Assurance of operability of thread–rolling tool

8.6.1. General information

To increase static and fatigue strength of thread joints, as well as tool life of nuts in screw pairs, burnishers and combined taps are used, which made it possible to improve accuracy and quality of thread surface.

Rolling taps are tools for non – chips manufacturing of internal thread, in which the material undergoes cold deformation without interrupting the so – called «fiber direction». In contrast to thread cutting, the metal from work-part is not cut out, but thread forming is done by extrusion. Thread spiral of rolling tap with a uniform thread pitch is «screwed» into the pre – drilled work-part. The cross – section of rolling tap has form of a polygon, which ensures a gradual penetration of thread part into material of work-part. The material is radially displaced, «floats» along thread profile into the free area of tooth base and thus forms internal diameter of nut thread.

Advantages of thread rolling: no chips; threads in through and blind holes can be made by same tool; variety of materials can be processed; thread trimming is excluded; errors of thread pitch and angle at profile vertex that occur when thread cutting are excluded; rolled internal thread because of the so – called «continuous fiber direction» and hardening, especially in base side surface of tooth profile, has a higher strength; thread has a better surface; chipless taps can operate at an increased cutting speed, since plastic deformation of many materials increases with rolling speed. There is no adverse effect on tool life in this case; tool practically does not break due to its solid construction.

When rolling threads, cutting fluid prevents material sticking and reduces load that occurs when thread forming, it is recommended to use an oily cutting fluid containing graphite.

The LMT Tools company has developed a roller with an internal axial supply of cutting fluid. It has a cushioning («soft») steel body, a much greater torsion stiffness compared to carbide – tipped rollers. The intake part has a rigid and wear – resistant fine – grained base with a coating, which guarantees a long operating life of tool. This cooling method is most effective when treating of blind holes (especially in horizontal direction) and deep threads, since cutting fluid is supplied directly to working area. Tools with internal cooling for through holes (IKR, radial outlet) and for blind holes (IKZ, axial output) are produced. Tool life of new tools in comparison with former increased by 400%, and cycle time was reduced by 70%.

The diameter of workpart affects not only the accuracy and quality of rolled thread surface, but also the tool life of thread – rolling tool. For threads with a pitch of up to 1 mm, radial runout should not exceed 0,01 mm. For the threads of a larger pitch, radial runout in range 0,01 ... 0,04 mm is most rational, since it is difficult to achieve radial runout less than 0.01 mm, and radial runout of more than 0,04 mm causes considerable uneven loading, which leads to a significant decrease of tool life.

To expand the application of thread – rolling, it is possible with help of combined cutting – deforming treatment (thread rolling by previously cut profile) (Fig. 8.9). Cutting part of allowance allows to reduce deformation degree during subsequent rolling. Threads with a large pitch and threads on parts with hardness greater than HRC 50 are expediently obtained by cutting (for example, whirling treatment) with subsequent hardening by surface plastic deformation.

Tool life of the cutting – deforming taps is 6 ... 8 times higher than cutting taps and 1,8 ... 2 times than deforming taps when processing of aluminum alloys characterized by a high degree of adhesion; torque during operation of cutting – deforming tap is lower by 12% than deforming taps. When operating cutting – deforming taps, it is recommended to select the cutting speed up to $V = 0,09$ m/s.

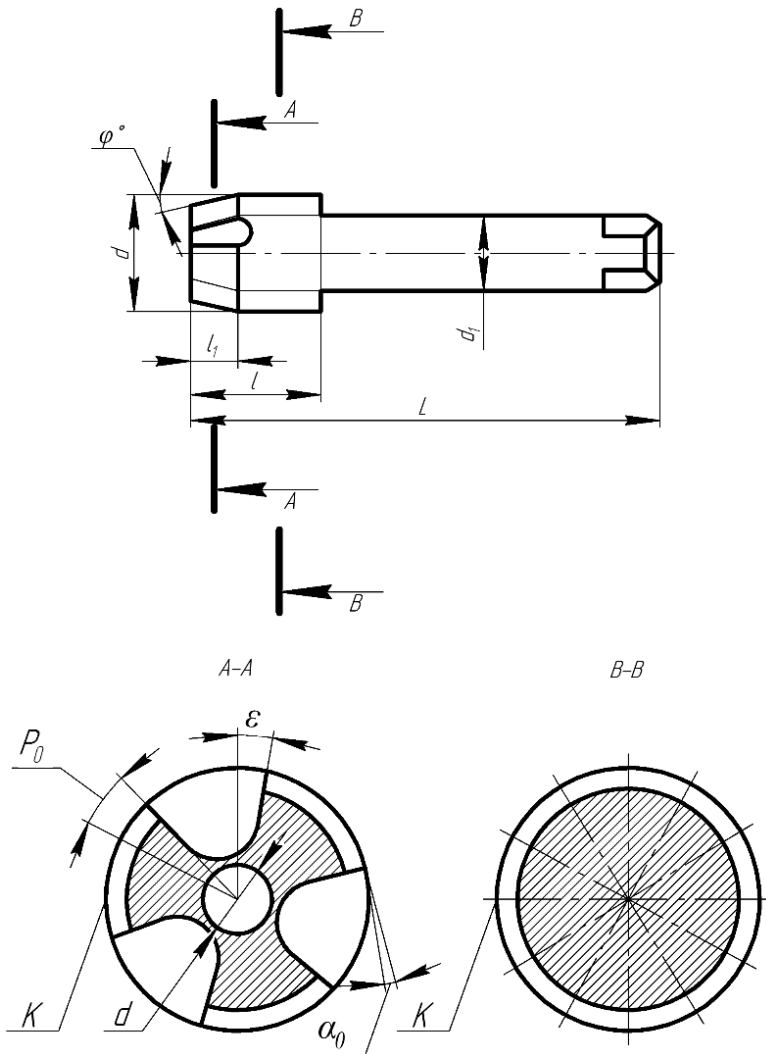


Fig. 8.9. Combined tap (cutting – deforming)

8.6.2. Increasing tool life of thread – rolling tool

The durability of a thread – rolling tool can be greatly increased by design improvements, use of wear – resistant coatings and by chemical – thermal and hardening treatment of various types.

One way to increase tool life is to increase number of working sides up to two for rollers and segments and up to four for flat dies. However, use of this method is limited by length of rolling thread and capabilities of thread – rolling equipment.

Increase of tool life is also achieved by using jet abrasive treatment. This treatment is hardening and provides removal of residual stresses, as well as partial removal of defective layer (micro – cracks, directed traces of processing, decarburized layer) after thread grinding, creates an optimal microgeometry of surface, due to that cutting fluid is better retained.

The greatest tool life is achieved by improving technological process of tools manufacture, consisting in a special heat treatment, which allows obtaining an increased content of residual austenite (up to 20 – 30% instead of the usual 10%), grinding thread surface and other surfaces with el'bor borazon material wheels, and also low temperature tempering to remove residual stresses. This method is recommended for tools from steels X12M, X12Φ1 (Russian grades). In tools manufactured by usual technology, carbides are arranged in layers – in form of parallel lines, and by advanced technology – they are evenly distributed throughout the volume. Such a structure is achieved by repeated forging or electro – slag remelting with subsequent special heat treatment. In this case, hardness is higher by 2 – 3 units of HRC in compare with normal, i.e. HRC 61 ... 62. Tool life in this case increases several times, as austenite increases plasticity, which, with a high surface hardness, reduces microchipping of thread fiber. In addition, increased content of austenite promotes self – hardening of tool metal during thread rolling.

Below are given coefficients of tool life increasing from the use of various ways to increase working capacity of thread – rolling tool. It is possible to use several methods simultaneously:

Method of tool life increasing	Coefficient of tool life increasing
Jet abrasive blasting	1,2 – 1,3
Increased number of working sides: rollers and segments flat dies	2,0 2,0; 4,0
Increased content of residual austenite up to 20 – 30%	2,5 – 3,0

Tool life of grinding and rolling tools, when all other things equal, has ratios from 1: 0,75 to 1: 0,85. Tool life of grinding and milling tools has a ratio of 1: 0,5 to 1: 0,7. On average, the following ratio of tool life of grinding, rolling and milling tools are adopted: 1: 0,8: 0,6.

Very tangible results by tool life can be achieved by application of a complex of design and technological measures. For example, when double rolling of thread $M30 \times 1.5 - 6g$ on work-part from steel 40X (Russian grade), tool life was increased by 6 ... 8 times due to increase of rollers diameter from 150 to 180 mm and width to 60 mm (instead of 50) – what made it possible to create them two – sided, that rollers were made from steel X12M (Russian grade) and with application of jet abrasive treatment.

The use of steel blanks obtained by electroslag remelting, refining metal from undesirable impurities and improving its microstructure, making it more uniform throughout the volume, makes it possible to increase tool life by 1,5 – 2 times. Carbochroming and boriding can increase the tool life by 3 – 4 times due to presence of hard wear – resistant diffusion coating in surface layer. However, area of their application is limited due to deformations occurring at high temperatures (1000 °C), characteristic for these processes.

The operating capacity of thread – rolling tool is also strongly influenced by accuracy of relative position of its working surface to base end and error of pitch between its thread – forming fibers. The greatest value they take with carbochroming and the smallest – with heat treatment for an increased content of austenite. The step error (mm) for these types of additional treatment for tools with rigidity $K_r = 3 \dots 7$: for carbochroming 0,058 ... 0,038 mm; at borating 0,038 ... 0,035; when heat treated to austenite 0,027 ... 0,024. Deviations from perpendicularity (mm) of working part to base end; at carbochroming 0,068 ... 0,05 mm; at borating 0,049 ... 0,048; when heat treated to austenite 0,035 ... 0,032. Thus, deformation during borating up to 1,5 times, and when heat treatment on austenite is up to 2 times less than in carbochroming.

The use of cemented carbides instead of tool steels as working parts material of provides a reduction of wear value by 1,5 – 1,7 times. New design of rolling dies has been developed, in which insert from high – strength wear – resistant material is installed in special slot at the end of intake and beginning of calibration part. When a certain degree of working part wear of insert is reached, it is possible to adjust its position in flute with help of screws, which increases tool life of dies.

The reason for unsatisfactory low stability of rollers when rolling large-profile threads (with pitch of more than 6 mm) are unacceptably large values of contact stresses. The increase of passes number leads to reduction of work-part hardening and contact pressure and, as a consequence, to high tool life of thread rollers.

For threads with a pitch of up to 1 mm, the radial runout should not exceed 0,01 mm. For threads of a larger pitch, radial runout in range of 0,01 ... 0,04 mm is the most rational, since radial runout is less than 0,01 mm is difficult to achieve, and radial runout of more than 0,04 mm causes considerable uneven loading, which leads to a significant decrease of tool life.

To improve productivity and tool life, and to reduce the load on tool, the working part of assembly roller is made from material based on nanostructured cubic boron nitride CBN – nano of such brands as Nanocompact cBN-wBN, Nanocomposite Diamond-20SiC, Nanocompact BN or Nanocomposite BN - 30AlN.

Inserts from nanocomposite BN -30AlN are soldered into pre – prepared nests in cassette discs of roller. The subsequent processing of working part profile of roller is made on a 5 – coordinate grinding – sharp center with diamond circles on a metal bond of type AC2 (Russian grade).

Compared with other rollers with working part from high – speed steel or cemented carbide for planetary shaping of internal threads the roller from nanocomposite BN -30AlN provides a processing speed up to 2 – 6 times higher, and the roughness of treated surface is 2 – 4 times lower.

8.7. Assurance of threading dies and thread cutting heads operability

Dies with a large back rake angle are used for processing of materials that give drain chips. The use of dies with a small angle is advisable for materials that produce segmental chips. Dies used on automatic machine tools, equipped with a screw sharpening for direct chip removal. Screw sharpening reduces cutting force, increases tool life of dies and overall quality of work.

Heat treatment of dies. The dies must have an increased viscosity. In order to prevent micro-chipping of cutting part, they are heated for quenching to lower limit of temperature interval with a minimum holding time.

To reduce warpage flat dies are cooled under a press between plates, by water.

Thread cutting heads. The main disadvantages of round dies are low quality of cutting surfaces, small resource associated with an insignificant period of tool life and rarely used re – sharpening after blunting, lack of thread diameters adjustment, etc. – leads to the need to develop an alternative design of a thread cutting tool, which is devoid of, or at least minimizing, these disadvantages. Designs of thread cutting heads have been developed, the cutting elements of which are rack-type tools – they are relieving in one technological

position over helical surface to obtain necessary end relief angles, and then installed in another, working position, in which occurs thread cutting of work parts.

Tool life of dies that cutting threads in work-parts from hard – to – work materials increases with number of turns on intake cone. Increasing of work-part diameter for rolling reduces tool life of dies due to increase of pressure. The taper and ellipticity of work-part cause uneven wear of dies.

Sulfidation significantly increases tool life. For example, tool life of dies when cutting bolts M10, M12 and M16 increases by an average of 3 – 5 times, and tool life of reamers and counter-bores from steel grades Y8 and XBF (Russian grades) by 1,5 – 2 times.

8.8. Assurance of thread milling cutters operability

The use of milling instead of turning when cutting external and internal threads provides a significant increase of productivity due to: 1) use of multi-tooth tool with a large sum of active length of cutting edges that simultaneously remove chips (multiple row milling cutters); 2) increasing of cut thickness to one tooth (disc milling cutters); 3) increasing of cutting speed due to equipment of cutters by cemented carbides (heads for whirling thread cutting). Cemented carbide thread milling cutters provide ability to mill materials with hardness up to 63 HRC and high thread quality.

The following grades of hard alloys are used for manufacture of WIDIA-GTD™ thread cutters.

Grade	Description of hard alloy grade
WU12PV	Fine – grained cemented carbide base with hard PVD coating TiCN. Universal alloy for thread cutting in a wide range of materials.
WU13PV	Cemented carbide base with high – temperature PVD coating TiAlN. Universal alloy for thread cutting in a wide range of materials.
WU16PV	Cemented carbide base with a two – layer PVD coating, which includes a heat – resistant lower layer from TiAlN and an antifriction top layer from MoS ₂ . It is recommended for thread cutting in various materials, including materials with increased hardness.

The use interchangeable polyhedral inserts significantly improves the efficiency of threading cutting process due to multiple use of bodies, repeated use of inserts, good chip breaking by form rake face of insets, high strength of blade due to absence of internal stresses arising from soldering of inserts of soldered cutting edges, high reliability due to high hardness of base surface below cutting insert, which is not constructively applicable in soldered cutters.

REFERENCES

1. Бернштейн М.Л., Пустовойт В.Н. Термическая обработка стальных изделий в магнитном поле. М.: Машиностроение, 1987. - 251 с.
2. Васин С.А., Хлудов С.Я. Проектирование сменных многогранных пластин. Методологические принципы. – М.: Машиностроение, 2006. – 352 с.
3. Верещака А.С. Резание материалов: учебник/А.С. Верещака, В.С. Кушнер. – М.: Высш. шк., 2009. – 535 с.
4. Воробьева Г.А., Усков В.Н. Аэротермоакустическая обработка сталей и сплавов: учеб. пособие.- СПб.: Изд.-во БГТУ. «ВОЕНМЕХ», 2012. - 130 с.
5. Грановский Г. И., Грановский В. Г. Резание металлов: Учебник для машиностр. и приборостр. спец. вузов. – М.: Высш. шк., 1985. – 304 с.
6. Евдокимов В.Д., Клименко Л.П., Евдокимова А.Н. Технология упрочнения машиностроительных материалов: Учебное пособие-справочник / Под редакцией д.т.н., проф. В.Д. Евдокимова. – Одесса Николаев: Изд-во НГТУ им. Петра Могилы, 2005. – 352 с.
7. Инструментальные материалы: учебн. пособие / Г.А. Воробьева, Е.Е. Складнова, А.Ф. Леонов, В.К. Ерофеев. – СПб.: Политехника, 2005. – 268 с.
8. Кушнер В.С. Изнашивание режущих инструментов и рациональные режимы резания: Учеб. пособие. - Омск: Изд-во ОмГТУ, 1998.
9. Лоладзе Т. Н. Прочность и износостойкость режущего инструмента. – М.: Машиностроение, 1982. – 320 с.
10. Маслов А.Р. Инструментальные системы машиностроительных производств: учебник. - М.: Машиностроение, 2006. - 336 с.
11. Петрушин С.И., Грубый С.В. Обработка чугунов и сталей сборными резами со сменными многогранными пластинами. - Томск: Изд. ТПУ, 2000. - 156 с
12. Петрушин С.И., Даниленко Б.Д., Ретюнский О.Ю. Оптимизация свойств материала в композиционной режущей части лезвийных инструментов: Учебное пособие. - Томск: Изд. ТПУ, 1999. - 99 с.
13. Режущий инструмент: учебник для вузов / Д.В. Кожевников, В.А. Гречишников, С.В. Кирсанов, В.И. Кокарев, А.Г. Схиртладзе / Под ред. С.В. Кирсанова. – 3-е изд. М.: Машиностроение, 2007. – 528 с.
14. Режущий инструмент: учебное пособие / А.А. Рьжкин, К.Г. Шучев, А.Г. Схиртладзе, А.И. Боков, М.М. Алиев – Ростов н/Д: Феникс, 2009. – 405 с.
15. Сверхтвердые материалы. Получение и применение: в 6 т. / под общ.ред. Н.В. Новикова. – Т.5: Обработка материалов лезвийным инструментом / под ред. С.А. Клименко. – К.: ИСМ им. В.Н. Бакуля, ИПЦ «АЛКОН» НАНУ, 2006. – 316 с.

16. Смазочно-охлаждающие технические средства и их применение при обработке резанием: справочник / Л.В. Худобин [и др.]; под общ.ред. Л.В. Худобина. М.: Машиностроение, 2006.
17. Табаков В. П., Сагитов Д.И. Работоспособность режущего инструмента с износостойкими покрытиями в условиях стесненного резания – Ульяновск: УлГТУ, 2015. – 179 с.
18. Табаков В. П., Смирнов М.Ю., Циркин А. В. Работоспособность торцовых фрез с многослойными износостойкими покрытиями. - Ульяновск: УлГТУ, 2005. – 152 с.
19. Табаков В.П., Чихранов А.В. Износостойкие покрытия режущего инструмента, работающего в условиях непрерывного резания /. Ульяновск: УлГТУ, 2007. – 255 с.
20. Фельдштейн Е.Э., Корниевич М.А. Режущий инструмент. Эксплуатация: учеб.пособие – Минск: Новое знание; М.: ИНФРА-М, 2012. – 256 с.
21. Шагун В.И. Режущий инструмент: Проектирование. Производство. Эксплуатация: Учеб.пособие. – Мн.: НПООО «ПИОН», 2002. – 496 с.
22. Якухик В. Г., Ставров В. А. Изготовление резьбы: Справочник. – М.: Машиностроение, 1989.– 192 с.
23. Coatings tribology: contact mechanisms, deposition techniques and application. – 2nd ed. – (Tribology and interface engineering series; v. 56). By Kenneth Holmberg, Allan Matthews. Elsevier, 2009. – 560 p.
24. Cutting-Tool-Application. By George Schneider. ASM International, 2002. –243 p.
25. Fundamentals of Modern Manufacturing: Materials, Processes, and Systems. Third ed. By Mikell P. Groover. – John Wiley & Sons, Inc., - 2007. – 1022 p.
26. Krol O. Engineering Forecasting of Machine Tools for Designers: monograph / Krol O. – Sofia: Prof. Marin Drinov Academic Publishing House of Bulgarian Academy of Sciences, 2019. – 114 p. DOI: <https://doi.org/10.7546/EFMTD.2019>
27. Krol O.S., Porkuian O.V., Sokolov V.I., Tsankov P.G. Vibration Stability of Spindle Nodes in the Zone of Tool Equipment Optimal Parameters / Comptes rendus de l'Academie bulgare des Sciences. – Sofia: “Prof. Marin Drinov“ Publishing House of Bulgarian Academy of Sciences, 2019. – Vol. 72, No. 11. – pp. 1546–1556. DOI: <https://doi.org/10.7546/CRABS.2019.11.12>
28. Krol O, Shevchenko S, Sokolov V. Design machine tools in environment APM WinMachine. – Lugansk: V. Dahl EUNU, 2011. – 388 p.
29. Krol O., Shumakova T., Sokolov V. Design metal cutting instruments by dint of system of KOMPAS. – Lugansk: V. Dahl EUNU, 2013. – 144 p.
30. Krol, O., Sokolov, V.: 3D modelling of angular spindle’s head for machining centre. Journal of Physics: Conference Series 1278, 012002 (2019). DOI: <https://doi.org/10.1088/1742-6596/1278/1/012002>
31. Krol O. Sokolov V. 3D Modeling of machine tools for designers: monograph. – Sofia: Prof. Marin Drinov Academic Publishing House of Bulgarian Academy of Sciences, 2018. – 140 p. DOI: https://doi.org/10.7546/3d_momftd.2018
32. Krol, O., Sokolov, V.: Development of models and research into tooling for machining centers. Eastern-European Journal of Enterprise Technologies 13(1(93)), 12–22 (2018). DOI: <https://doi.org/10.15587/1729-4061.2018.131778>.

33. Krol, O., Sokolov, V.: Modeling Carrier System Dynamics for Metal-Cutting Machines. 2018 International Russian Automation Conference (RusAutoCon). IEEE (2018). DOI: <https://doi.org/10.1109/RUSAUTOCON.2018.8501799>
34. Krol, O., Sokolov, V.: Modelling of spindle nodes for machining centers. Journal of Physics: Conference Series 1084, 012007 (2018). DOI: <https://doi.org/10.1088/1742-6596/1084/1/012007>
35. Krol O., Sokolov V.: Parametric Modeling of Gear Cutting Tools. In: Advances in Manufacturing II. Lecture Notes in Mechanical Engineering, vol. 4, 3–11. Springer, Cham (2019). DOI: https://doi.org/10.1007/978-3-030-16943-5_1
36. Krol O., Sokolov V. Parametric modeling of machine tools for designers: monograph. – Sofia: Prof. Marin Drinov Academic Publishing House of Bulgarian Academy of Sciences, 2018. – 112 p. DOI: <https://doi.org/10.7546/pmmtd.2018>
37. Krol O., Sokolov V.: Parametric Modeling of Transverse Layout for Machine Tool Gearboxes. In: Advances in Manufacturing II. Lecture Notes in Mechanical Engineering, vol. 4, 122–130. Springer, Cham (2019). DOI: https://doi.org/10.1007/978-3-030-16943-5_11
38. Krol O., Sokolov V. Rational Choice of Machine Tools for Designers. Sofia: Prof. Marin Drinov Academy Publishing House of Bulgarian Academy of Sciences, 2019. – 114 p. DOI: <https://doi.org/10.7546/RCMTD.2019>
39. Kunderák, J., Mitsyk, A., Fedorovich, V., Morgan, M., Markopoulos, A.: The Use of the Kinetic Theory of Gases to Simulate the Physical Situations on the Surface of Autonomously Moving Parts During Multi-Energy Vibration Processing. Materials, 12(19), 3054 (2019). DOI: <https://doi.org/10.3390/ma12193054>
40. Shevchenko, S., Mukhovaty, A., Krol, O.: Geometric Aspects of Modifications of Tapered Roller Bearings. Procedia Engineering 150, 1107–1112 (2016). DOI: <https://doi.org/10.1016/j.proeng.2016.07.221>
41. Shevchenko S., Mukhovaty A., Krol O. Gear Clutch with Modified Tooth Profiles. Procedia Engineering 206, 979–984 (2017). DOI: <https://doi.org/10.1016/j.proeng.2017.10.581>.
42. Schevchenko S., Mukhovaty A., Krol O.: Gear transission with conic axoid on parallel axes. In: Proceedings of the 5th International Conference on Industrial Engineering (ICIE 2019). ICIE 2019. LNME, vol. 1, pp. 1–10. Springer, Cham (2020). DOI: https://doi.org/10.1007/978-3-030-22041-9_1
43. Sokolov, V.: Diffusion of Circular Source in the Channels of Ventilation Systems. In: Advances in Engineering Research and Application. ICERA 2018. Lecture Notes in Networks and Systems, vol. 63, 278–283. Springer, Cham (2019). DOI: https://doi.org/10.1007/978-3-030-04792-4_37
44. Sokolov, V.: Transfer functions for shearing stress in nonstationary fluid friction. In: Proceedings of the 5th International Conference on Industrial Engineering (ICIE 2019). ICIE 2019. LNME, vol. 1, pp. 707–715. Springer, Cham (2020). DOI: https://doi.org/10.1007/978-3-030-22041-9_76
45. Sokolov, V., Krol, O.: Determination of Transfer Functions for Electrohydraulic Servo Drive of Technological Equipment. In: Advances in Design, Simulation and

- Manufacturing. DSMIE 2018. Lecture Notes in Mechanical Engineering, pp. 364–373. Springer, Cham (2019). DOI: https://doi.org/10.1007/978-3-319-93587-4_38
46. Sokolov, V., Krol, O.: Installations criterion of deceleration device in volumetric hydraulic drive. *Procedia Engineering* 206, 936–943 (2017). DOI: <https://doi.org/10.1016/j.proeng.2017.10.575>
 47. Sokolov, V., Krol, O., Baturin, Y.: Dynamics Research and Automatic Control of Technological Equipment with Electrohydraulic Drive. 2019 International Russian Automation Conference (RusAutoCon). IEEE (2019). DOI: <https://doi.org/10.1109/RUSAUTOCON.2019.8867652>
 48. Sokolov, V., Krol, O., Stepanova, O.: Automatic Control System for Electrohydraulic Drive of Production Equipment. 2018 International Russian Automation Conference (RusAutoCon). IEEE (2018). DOI: <https://doi.org/10.1109/RUSAUTOCON.2018.8501609>
 49. Sokolov, V., Krol O., Stepanova O.: Choice of Correcting Link for Electrohydraulic Servo Drive of Technological Equipment. In: *Advances in Design, Simulation and Manufacturing II*. DSMIE 2019. Lecture Notes in Mechanical Engineering, pp. 702–710. Springer, Cham (2020). DOI: https://doi.org/10.1007/978-3-030-22365-6_70
 50. Sokolov, V., Krol, O., Stepanova, O.: Nonlinear simulation of electrohydraulic drive for technological equipment. *Journal of Physics: Conference Series* 1278, 012003 (2019). DOI: <https://doi.org/10.1088/1742-6596/1278/1/012003>
 51. Sokolov, V., Rasskazova, Y.: Automation of control processes of technological equipment with rotary hydraulic drive. *Eastern-European Journal of Enterprise Technologies* 2(2(80)), 44–50 (2016). DOI: <https://doi.org/10.15587/1729-4061.2016.63711>

CONTENTS

INTRODUCTION	3
1. FAILURE OF CUTTING TOOL.....	5
1.1. Classification of failures	5
1.2. Gradual wear failure	6
1.3. Low tool life	10
1.4. Microchipping of cutting edges and tool breakage.....	11
1.5. Vibrations	14
1.6. Adhesion wear	14
2. TRENDS OF ASSURANCE OF CUTTING TOOL RELIABILITY	16
2.1. General information.....	16
2.2. Improvement of the cutting tool designs	17
2.3. Improvement of cutting tool materials.....	21
2.4. Increasing of rigidity and vibration resistance of technological cutting system.....	24
2.5. Influence of edge condition on the running ability of cutting tools.....	25
2.6. Application of cooling and lubrication media (CLM)	27
2.7. Optimization of cutting tool shape and rough cutting conditions	28
2.8. Optimization of cutting conditions for finishing operations	33
2.9. Assurance of tool serviceability for high-speed cutting.....	35
3. ASSURANCE OF SINGLE-POINT TOOLS RELIABILITY	37
3.1. Optimal periods of single-point tool life.....	37
3.2. Criteria of cutting tool selection	39
3.3. Application of replaceable polyhedral inserts.....	41
3.3.1. <i>Wear features of replaceable polyhedral inserts</i>	41
3.3.2. <i>Assurance of even wear of replaceable polyhedral inserts</i>	42
3.3.3. <i>Replaced cutting inserts with high thermal conductivity</i>	44
3.3.4. <i>Temperature compatibility and stresses intensity in cutting insert</i> ...	46
3.3.5. <i>Assurance of strength of replaceable inserts</i>	48
3.4. Modification of contact areas of cutters	51
3.5. Coatings on contact areas of cutters	53
3.6. Combined methods of hardening of cutters	54
3.7. Increasing of reliability of cutting and grooving cutters.....	55

4. ASSURANCE OF RELIABILITY OF HOLE MAKING TOOLS	59
4.1. Influence of geometry and design features of hole making tools	59
4.1.1. <i>Geometry and design features of drills</i>	59
4.1.1.1. Drills with improved operational properties	61
4.1.1.2. Sharpening of twist drills.....	65
4.1.2. <i>Geometry and design features of counterbores</i>	67
4.1.3. <i>Geometry and design features of reamers</i>	69
4.2. Influence of cutting conditions	74
4.3. Increasing of tool life of the cutting tool by electric insulation method .	77
4.4. Hole making tools wear and ways of its reduction	77
4.5. Modification of the surfaces of the hole making tools.....	78
4.6. Hole making tools hardening by pulsed magnetic treatment.	81
4.7. Application of coatings on hole making tools	82
4.8. Application of combined methods of hole making tools sharpening.....	83
4.9. Minimizing of hole making tools failures.....	84
4.10. Application features of cutting fluids for drilling and related operations	87
4.11. Increasing efficiency of making of holes by vibration cutting.....	91
 5. RELIABILITY OF MILLING CUTTERS	 93
5.1. Operating conditions of milling cutters	93
5.2. Influence of geometry and design features of milling cutters on their reliability	96
5.3. Wear of milling cutters	105
5.4. Strength of milling cutters	108
5.5. Features of application of cutting fluids for milling	110
5.6. Thermal treatment of milling cutters	112
5.7. Surface hardening of milling cutters.....	113
5.8. Coating application on milling cutters.....	113
5.9. Application of combined methods of hardening of milling cutters.....	117
 6. RELIABILITY ASSURANCE OF BROACHES.....	 118
6.1. New means of broaching	118
6.2. New materials and protective coatings of broaches.....	120
6.3. The influence of cutting wedge geometry and design features of broaches.....	122
6.4. Wear of broaches	125
6.5. Durability of broaches	127
6.6. Heat treatment of broaches	128
6.7. Non – firing grinding technology of broaches.....	128
6.8. Combined hardening of broaches	130
6.9. Application of cutting fluids when broaching.....	132

7. ASSURANCE OF GEAR CUTTING TOOL RELIABILITY	134
7.1. New technologies and equipment for cutting gears	134
7.2. Geometry and design features of main types of gear –cutting tools	136
7.3. Materials for manufacture of gear-cutting tools	140
7.4. Coatings for gear – cutting tool	141
7.5. Wear – resistance of gear – cutting tool.....	144
7.6. Application of dry electrostatic cooling on gear cutting.....	150
8. ASSURANCE OF RELIABILITY OF	
THREAD – CUTTING TOOL.....	153
8.1. Wear criteria of thread – cutting tool.....	153
8.2. Application of cutting fluids of thread cutting.....	153
8.3. Thread – cutting tool protective coatings.....	154
8.4. Assurance of operability of thread cutters and thread chasers.....	158
8.4.1. <i>Influence of geometry and design features</i>	
<i>of single-point threading tools</i>	<i>158</i>
8.4.2. <i>Application of inserts for thread cutting.....</i>	<i>159</i>
8.4.3. <i>Surfacing of thread cutters</i>	<i>159</i>
8.5. Assurance of taps operability.....	160
8.5.1. <i>Influence of geometry and design features of taps.....</i>	<i>160</i>
8.5.2. <i>Materials and coatings for taps manufacturing.....</i>	<i>170</i>
8.5.3. <i>The occurrence of taps failures</i>	<i>173</i>
8.5.4. <i>Strengthening of taps</i>	<i>173</i>
8.5.5. <i>Application of cutting fluids for improvement of taps efficiency</i>	<i>175</i>
8.6. Assurance of operability of thread–rolling tool	175
8.6.1. <i>General information</i>	<i>175</i>
8.6.2. <i>Increasing tool life of thread – rolling tool</i>	<i>178</i>
8.7. Assurance of threading dies and thread cutting heads operability	180
8.8. Assurance of thread milling cutters operability	181
REFERENCES	183

Scientific Publication

KHARLAMOV Yu.O.,
SOKOLOV V.I.,
KROL O.S.,
ROMANCHENKO O.V.,
MITSYK A.V.

ASSURANCE OF CUTTING TOOLS
RELIABILITY

Monograph

English version

Authorized for printing 07.05.2020.
Print format 60x84 ¹/₁₆. Printing paper. Times Font.
Offset printing. Printer's sheet 11.04. Publisher's sheet 12.2.
Run of 50 copies. Issue No. 3273. Order No. __. Contracted price.

The V.Dahl East Ukrainian National University Press

Registration certificate: Series DK No. 1620 of 18.12.2003.

Address of the University: prosp.Tsentralnyi 59-a
Severodonetsk, 93400 Ukraine
e-mail: vidavnictvoSNU.ua@gmail.com.

Printed: