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Analysis of Rotary Cutter Structure

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Abstract—Possible structures of rotary cutters are analyzed and classified. A special lathe cutter is proposed: the benefit of this design is the absence of a cutting tip, which is the weakest component of the cutting edge and is highly susceptible to wear. Constant renewal of the cutting edge as a result of rotation permits uniform distribution of the wear, temperature, and unit load. That considerably increases the tool's working life.

Keywords: machining, turning, rotary tools, cutting tip, tool wear, load distribution

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INTRODUCTION

Very diverse methods are used in machining materials. The selection of a particular approach depends on the requirements regarding the accuracy and surface roughness and also on the shape and size of the surfaces being machined [1–7].

In mechanical engineering, turning is the most common machining method with chip removal. In fact, this method has remained basically unchanged since it was first proposed: the primary motion is workpiece rotation; and the supply motion is the cutter's linear progress along, perpendicular to, or at an angle to the axis of rotation. Its simplicity explains the wide adoption of this method.

However, the cutter, which is fundamental to the process, complicates this process, because its standard design includes a cutting tip. That results in roughness of the machined surface. To decrease the roughness, the supply must be decreased, with consequent loss of productivity. In addition, the cutting tip is a weak spot of the tool. A large heat flux passes through its small cross section, resulting in high temperatures and wear of the cutting tip.

Because it is the point of intersection of the primary and secondary cutting edges, the cutting tip is the source of increased wear. The increased thermal stress around the cutting tip is associated with considerable temperature rise and more intense wear. That shortens tool life, increases the frequency of sharpening, impairs the productivity, increases tool consumption, and so increases the machining costs.

The benefits of tools with no cutting tip in turning were outlined in [8]. Existing designs with no cutting tip were reviewed and a new design was proposed. This design permits regulation of the cutting edge's inclination, so as to ensure the optimal machining conditions in terms of productivity and machining quality. In this case, there is no need to change the design of the other components in the tool.

A pass-through cutter intended primarily for semifinishing and finishing stages of turning was proposed in [9, 10]. Its universality permits the installation of cutting inserts with different rake and rear cutting angles. By that means, materials with different physicomechanical properties may be machined.

Some methods of improving lathe cutters [11–13] and other metal-cutting tools [14, 15] are of broad applicability, despite the diversity of the tools themselves. Operational requirements for tools in specific cutting conditions have also been outlined.

One method of high-speed finishing on lathes is to use tools with no cutting tip, in which the cutting edge in the cutting plane is inclined at an angle λ to the workpiece axis and at an angle φ in the transverse plane; usually $\varphi = 0$. Rather than a cutting tip, a section of the cutting edge is in contact with the workpiece. Consequently, the turning conditions resemble free cutting [16].

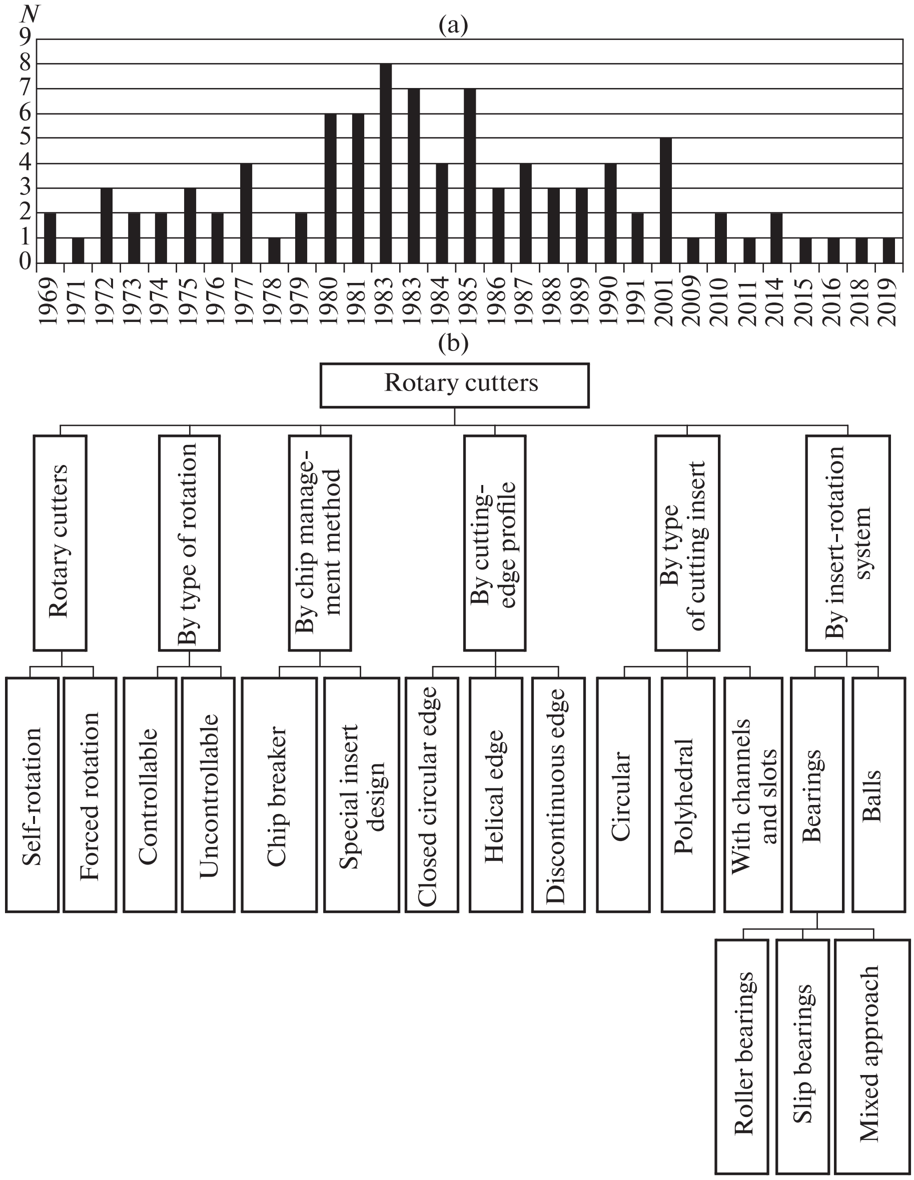

Fig. 1. The number of patents by year of application according to a Yandex.Patents search with the keyword *rotary cutter* (a); and a classification of rotary cutters (b).

A promising method is turning by means of rotary cutters: tool rotation is added to the standard turning setup [17–21].

STRUCTURE OF ROTARY TOOLS

When finishing the external surfaces of solids of revolution on a lathe, a rotary tool is more efficient than a traditional pass-through cutter. In the rotary tool, the constant renewal of the cutting edge greatly extends tool life, improves the quality of the machined surface, and lowers the temperature and unit load in the cutting zone.

However, this is a relatively new design, and its refinement is still underway. For example, a Yandex.Patents search with the keyword *rotary cutter* provides extensive information regarding pending patent applications [22]. The number of applications per year is shown in Fig. 1a. (Patents for drilling systems, stone cutters, and other irrelevant tools are omitted from Fig. 1a.) Analysis of the patent applications yields the classification of tool designs in Fig. 1b, from which it is evident how profoundly the design of rotary tools has been studied.

A distinctive feature of the self-rotating cutter in Fig. 2a is that the rotation of the cutting inserts depends on balls rather than bearings [23]. The balls sit in conical grooves at both ends of the shaft, at the lower end of the U-shaped yoke in the cutter housing, and at the end of the screw mounted at the top of the

Table 1. Comparison of rotary tools

Rotary tool	Basis of rotation	Inclination of cutting insert	Chip breaker
From [23]	Balls	Fixed	No
From [24]	Bearings	Fixed	Yes
From [25]	Bearings	Adjustable	No
Proposed design	Bearings	Adjustable	Yes

yoke. Holes pass through the screw and the shaft, while channels pass through the conical grooves. The screw thread permits attachment of a pipeline for liquid lubricant applied to the contacting ball surfaces. Deficiencies of this cutter include the lack of a chip-management element and the inability to adjust the cutting edge's inclination [23].

A distinctive feature of the self-rotating cutter in Fig. 2b is the inclusion of a continuous holder and assembly components within the tool head [24]. This cutter differs somewhat from other current designs in that a chip breaker is present and three bearings are used for rotation. The presence of three bearings may increase cutter safety if one or two bearings are damaged, but also increases the cost of the design and introduces additional vibration. The self-rotation of the cutter is facilitated by the inclination of the cutting edge. However, that angle is fixed, which limits the machining options.

A distinctive feature of the self-rotating cutter in Fig. 2c is that the inclination of the cutting edge may be regulated [25]. Another is the presence of a torsional spring in the holder to permit stricter control of the rotation. Deficiencies include the lack of a chip breaker and the presence of very many bearings both in the head for rotation of the cutting insert and in the holder for rotation of the head. That complicates tool operation and increases repair costs.

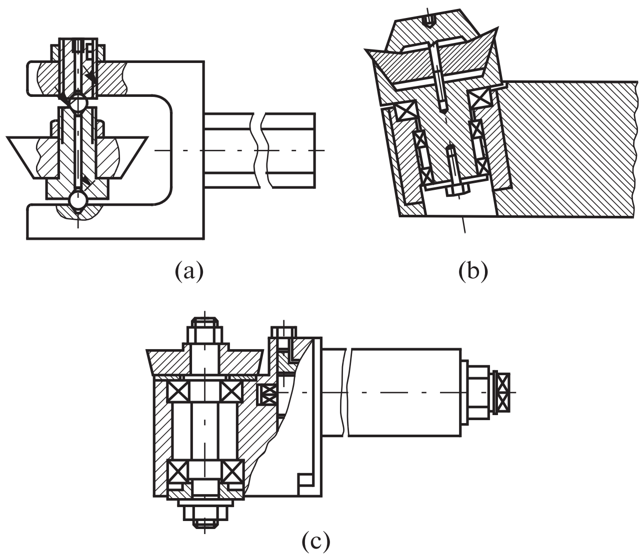

Fig. 2. Rotary cutters from [23] (a), [24] (b), and [25] (c).

Our analysis of existing rotary tool designs and investigation of metal cutting processes has led to the development of a new tool: a rotary lathe cutter with no cutting tip but with a chip breaker [26].

A benefit of this tool is the absence of a cutting tip, which is the weakest component of the cutting edge and is highly susceptible to wear. In addition, the constant renewal of the cutting edge as a result of rotation permits uniform distribution of the wear, temperature, and unit load. That considerably increases the tool's working life.

In the proposed tool, the cutting edge may be rotated around its axis. That increases the range of materials that may be machined and also the range of possible cutting configurations. Table 1 compares the competing tool designs. All of the tools considered are self-rotating.

The proposed cutter consists of a housing, a base, a head, a round hard-alloy insert, and various standard components. The tool may rotate around its axis, with change in the plate inclination and also in the rotation conditions. The chip breaker permits control of chip expulsion in contact with the cutting edge and prevents the appearance of continuous chip.

CONCLUSIONS

The proposed cutter is characterized by decreased wear in machining an increased life. That improves the roughness of the machined surface, which is especially important in finishing.

The absence of a cutting tip increases the tool strength and decreases the mechanical and thermal stress at the cutting edge. In the center of the cutter–workpiece cutting zone, conditions are good for smoothing of the machined surface by the straight cutting edge.

A benefit of the proposed tool is the rotation of the cutting edge, which permits uniform distribution of all the thermal and mechanical strain and markedly slows wear. However, continuous machining may impair chip formation, and so the design must make special provision to address that problem.

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