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METHODS OF IMPROVEMENT OF HARDNESS AND/OR EFFICIENCY OF CUTTERS WITH CHANGEABLE CUTTING SPEEDS ALONG THE CUTTING TOOTH EDGE LENGTH

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Abstract. The article shows that one of the drawbacks of most cutters is uneven cutting speeds along the cutting tooth edge length resulting from the peculiarities of their construction and operation. Due to uneven cutting speeds cutting teeth edges of the cutters are worn irregularly which generally reduces operating parameters of cutters. This article provides data on improvement of hardness and/or efficiency of using cutters with changeable cutting speeds along the cutting tooth edge length which are based on the provision of changeable parameters of the cutting edge properties depending on the current operational functions. For proposed cutters with changeable properties along the length of the cutting teeth edge length there have been developed principles of improvement of hardness and/or efficiency on the grounds of function-oriented approach. There was made analysis of peculiarities of improvement of hardness and efficiency of cutters` work on the basis of these principles and there were given general recommendations on the operation of the proposed cutters.
Keywords: uneven cutting speed, cutting tooth edge, cutter, function-oriented approach, efficiency.

1. Introduction

One of the drawbacks of the operation of most cutters [1,2,3] is uneven cutting speeds along the cutting tooth edge length [4] resulting from the peculiarities of their construction. Because of the uneven speeds along the cutting teeth length they are worn irregularly, usually limiting wear of the cutting edges occurs in zones with a maximum speed of cutting, and namely in zones located in the most distant points of the cutting edges from the axis of rotation of the cutters [4]. The irregular wear of the cutting edges of the cutter`s teeth results in the following:

- decreasing of the hardness and efficiency of work of cutters having uneven cutting speeds along the cutting teeth edge length;
- usage of not complete, but only partial work potential of cutting teeth edges, and accordingly of all cutters in whole.

On the basis of the made analysis of the peculiarities of the operation of cutters with changeable cutting speeds along cutting tooth edge length [4], to ensure uniform wear of the cutting edges of the teeth of the cutter, to increase of hardness and efficiency of the cutter`s work cutters and to use the full potential of the work of the cutting teeth edges it is necessary to ensure the changing properties of the cutting edge along its length depending on the specific effects of the operational functions. These specific effects, and namely changeable features of the cutting teeth edges of the cutter can be realized on the basis of application of the function-oriented approach in the cutters processing or the application of the principle of functional orientation of properties of the cutting edge depending on action of the operational functions and realization of given the changing local technological influences on the cutting edge [5].

The use of function-oriented approach in the cutters processing have changeable cutting speed along the cutting tooth edge length provides uniform wear of the cutting edge, improvement of the hardness and efficiency of the cutters and use of full potential of the

work of the cutting edge of the tooth and the cutter in whole.

The aim of this work is to improve hardness and/or efficiency of the work of the cutter by ensuring uniform wear of the cutting edge along its length and using the full potential of its work by the way of ensuring the properties of the cutting tooth edge along its length depending on the peculiarities of operation and operating functions.

In accordance with the stated aim the following tasks are defined in the work: to offer functional orientation of properties of the cutting edge of the tooth depending on the peculiarities of its operation and operating functions; to develop principles for improvement of hardness and/or efficiency of the work of the cutter under terms of changeable cutting speed along the cutting tooth edge length: to propose variants of ensuring the changeable properties along the cutting tooth edge length; to perform analysis of peculiarities of operation of the proposed cutters.

2. Methods of ensuring of changeable properties along the cutting tooth edge length of the cutter

The process of ensuring of changeable properties along the cutting tooth edge length of the cutter in this work is planned to be made on the basis of function-oriented approach [5]. To decide this question it is reasonably to use two principles of function-oriented technologies, and namely [5]:

1. Functional conformity of peculiarities of the action of elementary function in each functional element of the product, characteristics of the realization of technological effects and parameters of providing the necessary properties in this functional element of the product at each depth level of technology.

2. Topological compliance of geometrical parameters of the functional element of the product, in which an elementary function acts by the operation, with geometric parameters of the zonal element of realization of technological effects of flows of matter, energy and information on the product and the geometric parameters of the zonal element of providing the necessary properties at each depth level of technology.

The first principle of orientation of technological influences and the product properties in accordance with acting function can be mathematically represented the following three mappings (transformations) [5]:

$$\left.\begin{array}{l}\varphi_{11}: F \to TB;\\ \varphi_{12}: TB \to C;\\ \varphi_{13}: C \to F,\end{array}\right\} \qquad (1)$$

where *φ11* – is a mapping (transformation) of operational function F of the product in technological effect TB;

φ12 – is a mapping (transformation) of technological effects TB in properties C of the product;

φ13 – is a mapping (transformation) of properties C in technological effects TB.

It should be borne in mind that abovementioned system of mappings (1) has closed form, so the solution of these equations can be made on the basis of iterative methods of successive approximation using many recurrent cycles.

At that, the second principle of orientation can be described by the following three mappings (transformations):

$$\left.\begin{array}{l}\varphi_{21}: G(F) \to G(TB);\\ \varphi_{22}: G(TB) \to G(C);\\ \varphi_{23}: G(C) \to G(F),\end{array}\right\} \qquad (2)$$

where *φ21* – is a mapping (transformation) of the geometric parameters of action zone of the operational function G(F) of the product in the geometrical parameters of the zone of realization of the technological effects G(TB) ;

φ22 – is a mapping (transformation) of the geometrical parameters of the zone of realization of the technological effects G(TB) in the geometrical parameters of the zone of securing of properties G(C) of product;

φ23 – is a mapping (transformation) of the geometrical parameters of the zone of securing of properties G(C) in the geometric parameters of action zone of the operational function G(F) of the product.

It can be noted that securing of changeable properties of the cutting edges of cutter can be made by various methods. Let's consider some variants of creating the changing properties of the cutting edges of the cutter.

Fig. 1. Presents schemes of securing of changeable properties of cutting edge of a tooth of the cutter depending on the following parameters: Fig. 1, a – changeable properties of the work piece material from the center to the periphery; Fig. 1,b – changeable properties of the work piece material along the height; Fig. 1,c - changeable properties of the work piece material from the center to the periphery and along the height; Fig. 1,d – securing of local changeable technological effects on the cutting tooth edge length. Shown here are: 1 – Work piece (shown schematically), 2 – cutter, 3 –tooth of the cutter.

Here it can be pointed out that by means of the first three schemes realization of the changeable properties of the cutting edge is made by securing variable properties of the work piece material (Fig. 1, a, b, c). Through the presence of changeable properties on the volume of work piece material in during process of cutter manufacturing, changeable properties of the cutting edges of the teeth of the cutter along their length are formed automatically. In these schemes the changing properties of the work piece material are of three types, and namely Fig. 1, a - properties of the work piece are changed from the longitudinal axis to its periphery. Such properties of the work piece can be obtained with use of special technologies. The properties of the work piece according to Fig. 1,b are changed along the height of work piece. They can be obtained, for example, by the manufacturing of the work piece using method of electroslag melting with adding

of changeable quantity of alloying elements according to the axial movement of the crystallizer. The third scheme (Fig. 1, c) is a combination of the methods of the first two schemes.

In the fourth scheme (Fig. 1,d) securing of changeable properties of cutting edge of a tooth of the cutter is made due to technological methods, and namely the combination of abrasive processing and surface plastic deformation of the surface coating of the cutting edges of the teeth of the cutter. By virtue of uneven technological effects on the cutting edge length of the cutter by air-abrasive processing of the cutting edge variable geometric parameters of the cutting wedge on the edge tooth length of the cutter are provided. Here it is much more change of the radius of the cutting wedge on the cutting tooth edge length of the cutter.

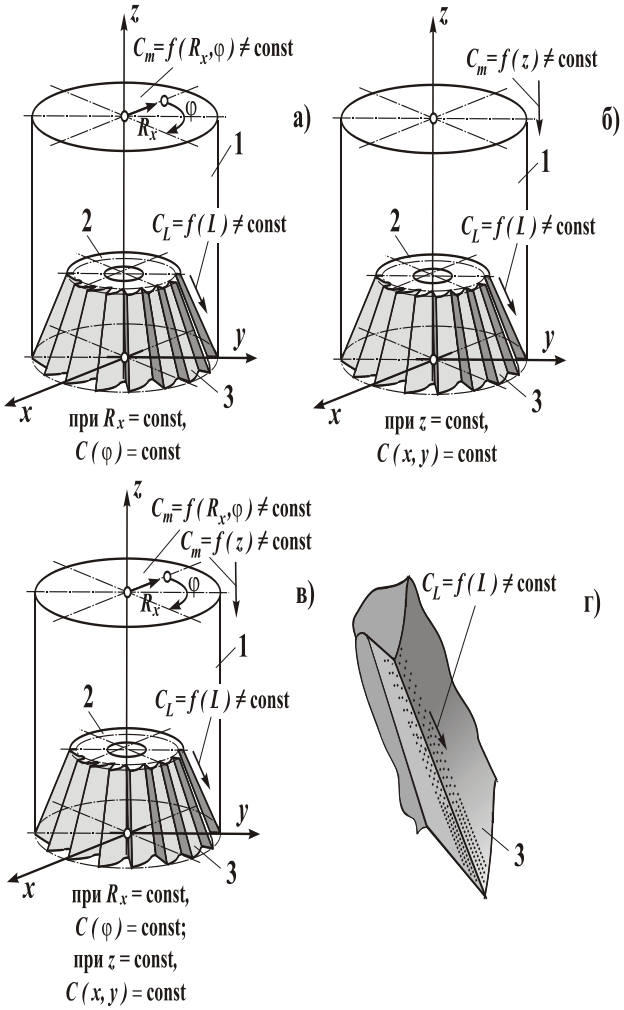

Fig. 1. Schemes of securing of changeable properties of cutting edge of a tooth of the cutter depending on the following parameters: **a** – changeable properties of the work piece material from the center to the periphery; **b** – changeable properties of the work piece material along the height; **c** - changeable properties of the work piece material from the center to the periphery and along the height; **d** – securing of local changeable technological effects on the cutting tooth edge length

And also due to these uneven technological effects there have been secured changeable material properties by varying degree of the surface plastic deformation of the material of the cutting teeth edges of the cutter.

Thus, abovementioned schemes allow securing the changeable properties of the cutting tooth edge of the cutter, depending on operational peculiarities of operation of the functions along the cutting edge length. And it creates an opportunity to decide questions of increasing of the hardness and/or efficiency of cutters having changeable cutting speeds along the cutting teeth edge length.

It can be noted that the realization of changeable properties along the length of the cutting tooth edge of the cutter creates non-conventional peculiarities of operation of such cutters, as well as the conditions of appointment of parameters of their hardness and efficiency. Let`s consider these peculiarities in more detail.

3. Peculiarities of operation of cutters with changeable properties of cutting edges

It can be noted that cutters with changeable properties of the cutting teeth edges have certain peculiarities of operation. Among the main peculiarities are the following.

First of all, the main thing in operation of cutters having changeable cutting speeds along the cutting edge teeth length with changeable properties of the cutting edges depending on acting operational functions is that there occurs the possibility to improve the efficiency and hardness of cutters owing to the following features:

- owing to straightening of the wear of the cutting edges along their length at changeable cutting speeds along the cutting edge teeth length of the cutter;
- owing to the full usage of the cutting potential of the cutting teeth edges along their length;
- owing to reducing of the wear of the cutting edges in general and increasing their hardness.

Here it should be pointed out that for standard cutters because of uneven cutting speeds along the cutting edge length there usually occurs partial wear of the cutting edge in the zone with the maximum cutting speed. This is due to the fact that the abrasive and oxidative wear of the material of cutting teeth edge of the cutter prevails. If this occurs the adhesive wear of the surface layer adjacent to the cutting edge in zones with a lower cutting speed for offered cutters is reduced owing to special technological decisions, and namely combined processing with securing of special microwave polished surfaces.

It can be marked that for cutters having changeable properties along the cutting teeth edge length improvement of efficiency and hardness of the cutter can be made on the basis of the following principles (Fig.2):

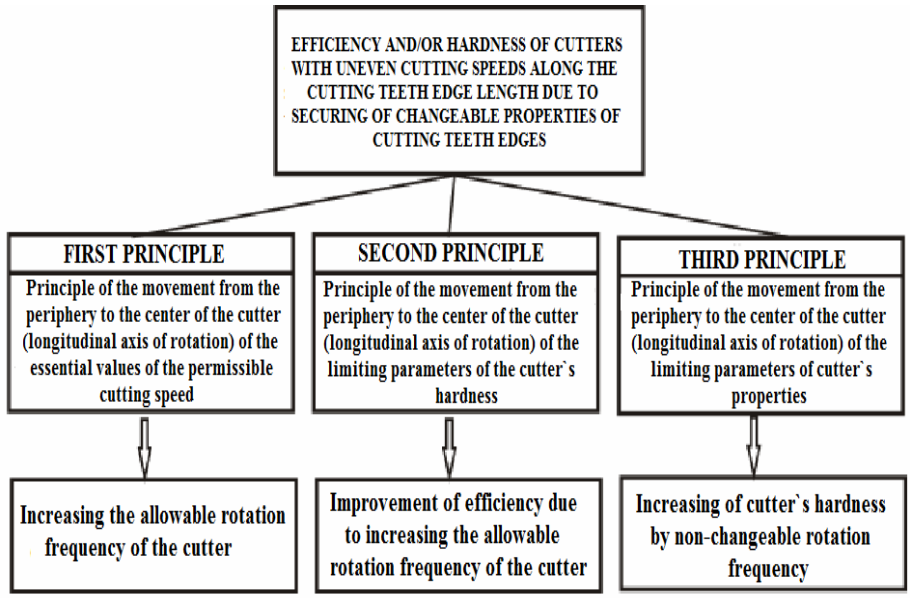

Fig. 2. Main principles of increasing of efficiency and/or hardness of cutters with uneven cutting speeds along the cutting teeth edge length

- the first principle is the principle of the movement from the periphery to the center of the cutter (longitudinal axis of rotation) of the essential values of the permissible cutting speed;

- the second principle is the principle of the movement from the periphery to the center of the cutter (longitudinal axis of rotation) of the limiting parameters of the cutter`s hardness;

- the third principle is the principle of the movement from the periphery to the center of the cutter (longitudinal axis of rotation) of the limiting parameters of cutter`s properties.

Let us remark that the realization of these principles is possible only with the use of cutters having changeable properties of the cutting edges from the periphery to the center depending on operating changeable cutting speed at the cutting edge.

The possibility of increasing the allowable rotation frequency of the cutter is secured on the basis of the first principle. This is caused by the fact that for standard cutters limiting rotation frequency is determined by the maximum cutting speed of the cutter occurring on the periphery of the cutter. For the proposed cutters having changeable properties of the cutting edge depending on the cutting speed it becomes possible to ensure the same cutting speed as of the standard cutters, but with orientation point not to the periphery of the limiting parameters of cutting speed, but closer to the center, which gives the opportunity to increase the rotation frequency of the cutter. So here is a kind of "shifting motion" of the essential values of the permissible cutting speed.

The possibility of increasing the efficiency of processing by the cutters with the changing properties of the cutting teeth edges is realized due to the second principle. In this case, the properties of the cutting edge should be secured in dependence of changeable cutting speed along its length. That`s why the increase in the efficiency of such cutters` work are made by means of increasing the allowable rotation frequency of the cutter, and namely by means of movement from the periphery to the center of the cutter of the limiting parameters of the cutter`s hardness.

The possibility of increasing of cutter`s hardness when their rotation frequency is similar to the value of the rotation frequency of the standard cutters is secured on the grounds of third principle. In this case, the increasing of cutters` hardness is made due to the easing of cutting modes of the cutters with new properties of the cutting teeth edges. This is carried out owing to movement from the periphery to the center of the cutter of the limiting parameters of properties of the cutting tooth edge of the cutter.

Table 1 represents the operational peculiarities of cutters with the changeable properties of the cutting teeth edges. Changeable properties are considered here with the following parameters:

- changeable geometry of the cutting edge along its length depending on peculiarities of changing of cutting speed along the cutting edge length;

- changeable properties of the cutting edge material along its length depending on peculiarities of changing of cutting speed along the cutting edge length.

The process of securing of changeable properties of the cutting teeth edges is provided to be made using technological methods with the help of the following operations:

- by means of the air-jet abrasive cutting with change in the duration of processing along the cutting edge length;

- by means of the air-jet work hardening of the surface layer with change in the duration of processing along the cutting edge length.

It can be also noted that to improve the quality of cutters` work a range of different technological operations [4] is to be made. In particular, it is very important to preserve changing geometry of the cutting edge along its length. This is because of the fact that in

the process of cutting the proposed geometry of the cutting edge is changed, which leads to reduction of cutters` hardness. Decision of this problems in this paper was carried out with the help of vacuum ion-plasma coatings, such as TiN, TiAlN, (Ti,Cr) N and other ultra-hard coatings.

Table 1
Operational peculiarities of cutters with the changeable properties of the cutting teeth edges

№	Securing	Process	Principles	Possibilities	Results
1	Changeable geometry of the cutting edge along its length depending on peculiarities of changing of cutting speed along the cutting edge length	By means of the air-jet abrasive cutting with change in the duration of processing along the cutting edge length	First principle	Increasing the allowable rotation frequency of the cutter	1. Securing of uniform wear of cutting edge along the cutter`s tooth length. 2.Achievement of full potential of usage of cutting edges along their length. 3. Decreasing of wear of cutting teeth edges of the cutter
			Second principle	Improvement of processing`s efficiency	
2	Changeable properties of the cutting edge material along its length depending on peculiarities of changing of cutting speed along the cutting edge length	By means of the air-jet work hardening of the surface layer with change in the duration of processing along the cutting edge length	Third principle	Increasing of cutter`s hardness by non-changeable rotation frequency	

4. Conclusion

Therefore, this paper introduces to increase the hardness and/or efficiency of cutters having changeable cutting speeds along the cutting teeth edge length due to the functional orientation of the cutting properties of cutting teeth edges depending on the peculiarities of their operation and operating functions.

For proposed cutters with changeable properties of the cutting teeth edges there have been developed principles of increasing the hardness and/or efficiency of their work in terms of changeable cutting speed along the cutting teeth edge length. Also the paper describes technological methods of ensuring the changeable properties of the cutting teeth edges of the cutter.

The paper also considers some variants of securing of changeable properties along the cutting teeth edge length of the cutter and there was made an analysis of peculiarities of work of the proposed cutters.

In the whole made investigations allow creating cutters with non-traditional properties which secure increasing of efficiency and/or hardness of the tool with changeable cutting speeds along the cutting edge length.

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