Computer Simulation of Replaceable Many Sider Plates (RMSP) with Enhanced Chip-Breaking Characteristics

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Abstract. Out of all common chip curling methods, a special tool face form has become the most widespread which is developed either by means of grinding or by means of profile pressing in the production process of RMSP. Currently, over 15 large tool manufacturers produce tools using instrument materials of over 500 brands. To this, we must add a large variety of tool face geometries, which purpose includes the control over form and dimensions of the chip. Taking into account all the many processed materials, specific tasks of the process planner, requirements to the quality of manufactured products, all this makes the choice of a proper tool which can perform the processing in the most effective way significantly harder. Over recent years, the nomenclature of RMSP for lathe tools with mechanical mounting has been considerably broadened by means of diversification of their faces

1. Introduction.

The analysis of literature data [1,3] showed that the most efficient chip in the automated manufacture is of the kind "flat spiral" or "cylindrical spiral", and for this, it is necessary that it wraps in the sectional flow plane. Previously [2,3,5], the conditions of circular chip wrapping have been formulated, and a calculation method of dynamic canting angle of the cutting edge has been suggested for the achievement of those conditions. It was established that, for a certain cutting edge form and one combination of depth and feed rate, there is only one angle λ_d which creates the condition of circular wrapping. However, when cutting with varying duty, which is mostly spread in the manufactures, there is a need of such face form of RMSP that can provide with the conditions of circular wrapping for all possible cross-sections of the cut layer within a specified range. It can be achieved by means of changing the canting angle of the cutting edge.

We suggest to split the development process of new RMSP constructions with chip formation elements into three stages. In the first stage, on the basis of theoretical provisions or empirical dependences, we determine the initial data for RMSP designing; in the second stage, we design chip formation elements on working areas of the RMSP face by means of geometric computer simulation; in the third stage, we elaborate the final appearance of the construction of special and specialized RMSP taking into account their spatial orientation.

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Methods of simulation of replaceable many-sided plates

The initial data for the choice or constructing of cutting tools include the information about the material and the form of a blank part and a component part, on the basis of which they choose the geometry of tool cutting edge as well as cutting modes. Following parameters must be set:

φ, φ_1 – the main and the auxiliary angle on the plan;
λ – canting angle of the cutting edge;
γ – rake;
r – tip radius, mm;
i – number of profile points of the cutting edge (maximum 255);
l – length limit of the main cutting edge, $l \approx 1{,}2$ t;
S – feed rate, mm/rev;
t – cutting depth, mm;
ω_f – angle of emergency of flow lines onto the face;
β_1 – canting angle of the conventional shear plane.

Main angle φ and auxiliary angle φ_1 in the plan depend on the form of work surface; rake γ is designated according to the mechanical characteristics of work material as well as to the processing type [1]; in the process of finishing, tip radius of the cutting edge r depends on the required surface undulation of the component part according to the drawing; cutting depth and feed rate are determined on the basis of allowance, mechanical characteristics of the material, as well as the features of work surface.

General methods of simulation of replaceable many-sided plates were implemented in the computer program, the calculation results of which are the flow angle for determined cutting conditions, the coordinates of gravity centers of chip cross-section and contact mark as well as files including the coordinates of points which describe the profile of cutting edge, chip cross-section, and chip contact mark with the flat face. Additionally, the program visualizes the section of the cut layer, chip cross-section in the direction of its flow, and contact mark.

The condition of circular wrapping can be used in order to solve two tasks: first, to pick cutting modes (S, t) for a certain cutting edge geometry (φ, $\varphi 1$, λ, r); second, to pick a λ_d for a certain section form of the cut layer (φ, φ_1, r S, t). In the first case, the geometric parameters of a tool are determined in accordance with cutting modes; in the second case, they receive the necessary data for face form computer simulation.

Using the computer program, they calculate the dependences of the flow angle and the dynamic canting angle of the cutting edge on cutting modes with varying geometric parameters of the plate. In order to observe the condition of circular wrapping, they change angle λ_d up to the moment of gravity centers equality of chip cross-section and contact mark with the face within the accuracy of 0.001 mm.

As long as the dependences of λ_d on the feed rate and the cutting depth are directly-proportional [1,5], we can design the form of chip formation area of the RMSP face as a ruled surface.

In the cutting process, for varying parameters of section of the cut layer, the developed program helps project RMSP analogous to the case of varying cutting depth, varying feed rate as well as their constant ratio S/t.

2. Results and Discussion.

2.1. Designing of a chip formation geometry on the RMSP face with varying cutting depth.

When processing with CNC metal-turning lathes, they mostly perform cutting with varying depth and constant feed rate. This case is present when turning blank parts with varying allowance.

The designing of the RMSP face for such processing type is characterized by the fact that all variants of sections of the cut layer have one mutual point C (figure 1) on the main cutting blade the position of which is determined by the feed rate. The starting phase of projecting a chip formation area of the face is the determination of coordinates of nodal points on the main cutting edge which depend on the change interval of cutting depth. In fig. 1, index 1 corresponds with tmin, n with tmax, and i with the current value of cutting depth t. The origin of coordinates is put onto the corner of the cutting blade. From this point, the value of the half feed rate is plotted on axis X to the right, and the coordinate of the nodal point C on axis Y is found. In order to determine the coordinates (x, y) of nodal points of the section on the main cutting blade, they transfer the distances in the direction of axis Y which equal to the cutting depths within the projecting range of the plate. Thus, points B_i are found.

In order to accomplish this, we draw connecting lines through the nodal points and the origin of coordinates, register the mutual nodal point determined by feed rate, lay off angle λ_d (fig. 1), and, on the crossing with connecting lines, we find Z-coordinates of the nodal points for the maximum cutting depth. Then, we determine Z-coordinates of the nodal points for the minimum cutting depth. Through a point on the auxiliary cutting edge corresponding with the half feed rate as well as through the nodal points of the minimal and the maximal cutting depth, we can draw a plane. When this plane crosses the surface that limits the plate in the top area, a transitional curved surface is formed.

For the purpose of following the condition of circular wrapping, it is necessary that angle λ_d is constant along the whole chip-tool contact area. Preliminarily, a full contact mark is built on the tool face. For each section variant of the cut layer, through a reference point on the tool face corresponding with the condition of matching gravity center of the contact mark and cross-section of the chip, we lay off distances in the flow direction from the cutting edge which equal a full contact length.

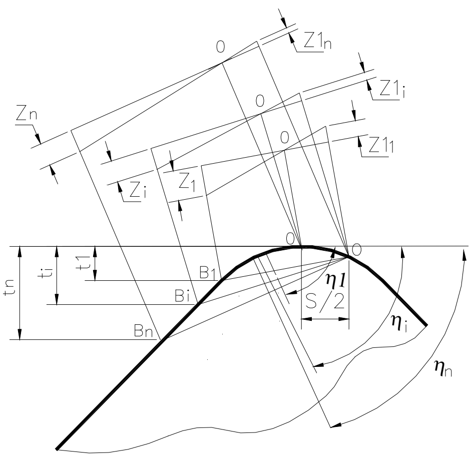


Figure 1. Scheme to the determination of coordinates of chip formation surface for the condition of constant feed rate

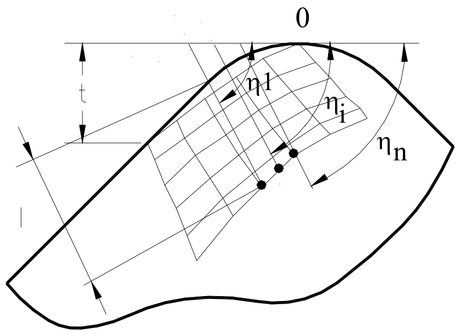
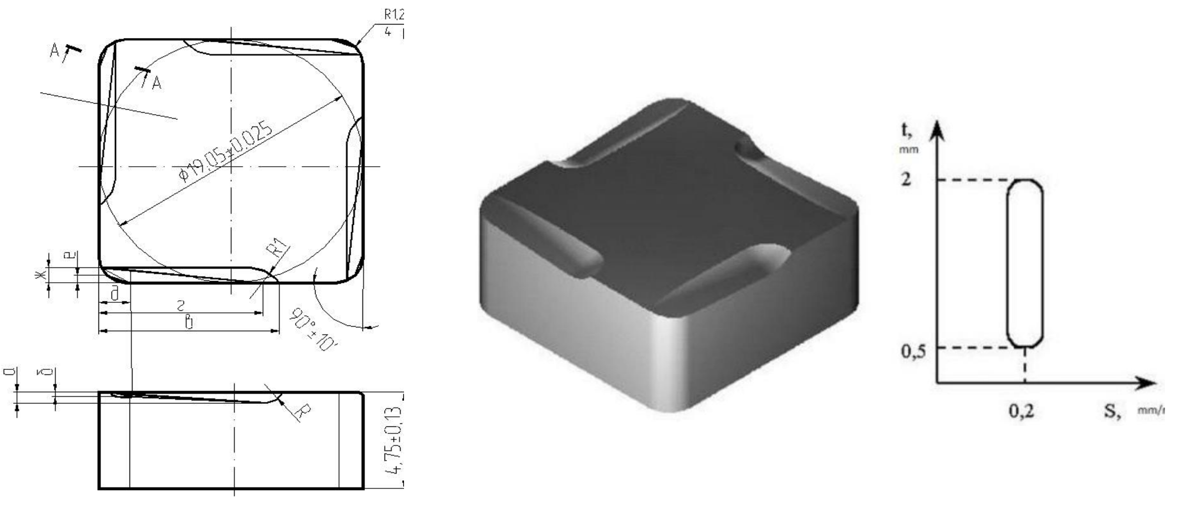


Figure 2. Simulation of the contact mark with varying cutting depth

Connecting the ends of this distances, we create the curve of contact end of the chip with the tool face (fig. 2). A line drawn through the nodal points of this mark must be bent to the basic plane with the same angle λ_d as the cutting edge.

The built area of the tool face will be the main chip formation element; and it is characterized by the fact that reference contact lengths shall be equal — it is only the points on the main cutting blade from which they are laid off that shall be different.

In fig. 3 and 4, there are sketches of a square and a triangular RMSP represented, as well as solid models and project diagrams of chip breaking with varying cutting depth. These plates designated for external linear turning have been formed into 20G cutters with RMSP of hard alloy T15K6 with feed rate S = 0.2 mm/rev and the cutting depth variation range t = 0.5–2 mm. The square plate is designed for the mounting into the cutter body with the entering angle $\varphi = 45^o$, the triangular — $\varphi = 90^o$.



a b c

Fig. 3: Example of a square RMSP construction which follows the condition of circular chip wrapping with varying cutting depth:
a) sketch drawing; b) solid model; c) designed diagram of chip breaking

2.2. Designing of a chip formation geometry on the RMSP face with varying feed rate

A possible case of processing with CNC metal-turning lathes is cutting with varying feed rate and a constant cutting depth. It is especially characteristic for the lathes with adaptive control systems of processing accuracy when the feed rate is considered as a control parameter.

Here, all section variants of the cut layer have one mutual point B on the main cutting blade (fig. 5) the position of which is indicated by constant cutting depth. The form of contact mark (fig. 6) is conditioned by the fact that when changing the feed rate, there is a proportional change of the full contact length.

In fig. 7, there is an example of a triangular RMSP for the processing with t = 1 mm and S = 0.05–0.5 mm/rev (steel 20G — T15K6).

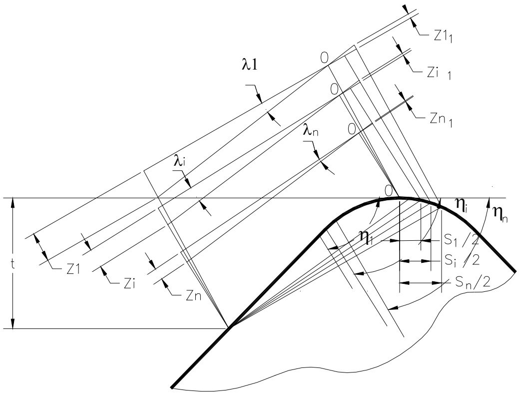


Fig. 5: Scheme to the determination of coordinates of chip formation surface for the condition of constant cutting depth

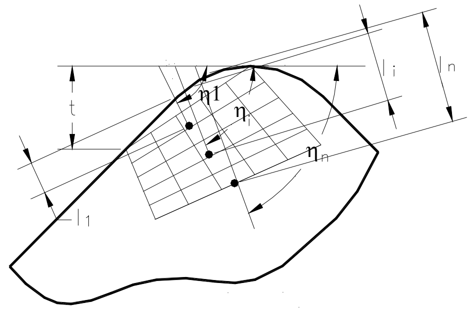


Fig. 6: Simulation of the contact mark with varying feed rate

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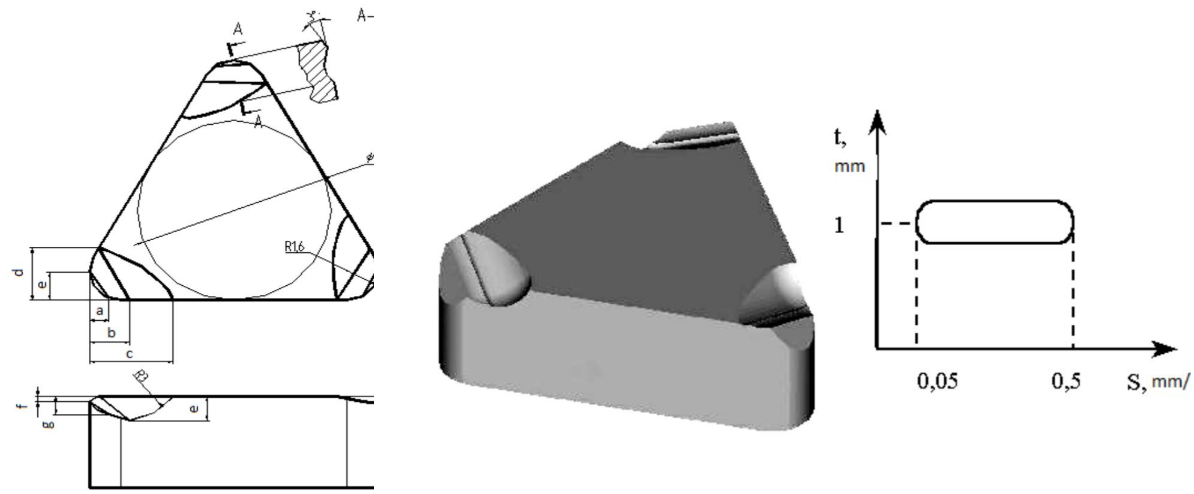

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Fig. 7: Example of a triangular RMSP construction which follows the condition of circular chip wrapping with varying feed rate: a) sketch drawing; b) solid model; c) designed diagram of chip breaking

2.3. Designing of a chip formation geometry on the RMSP face with constant ratio of feed rate and cutting depth

The case of simultaneous change of cutting depth and feed rate is approximate with the variant when value S/t is constant. Besides, it was established [1,2,3] that the centers of chip breaking diagrams of most RMSP for lathe turning are positioned within the range S/t = 0.08...0.1 which corresponds with the area of accurate breaking.

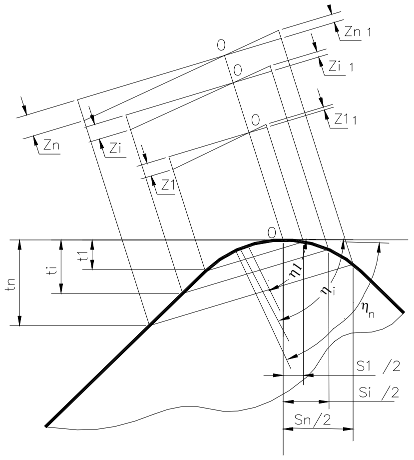
A plate is designed analogous to the above described variants. The scheme of finding the coordinates of chip formation surface is presented in fig. 8. As seen from it, in the process of a proportional change of cutting depth and feed rate, there are no mutual points characterizing the section of the cut layer.

In fig. 9, there are RMSP models represented with improved chip formation features for the following conditions: work material is Steel 20G; RMSP material is T15K6; t = 0.5–2 mm; S = 0.05–0.2 mm/rev.

In order to create a spontaneous variation range of the section of the cut layer, the simulation of the chip formation area of the tool face must be conducted by means of overlapping of a variety of specific solutions. This results in a not ruled form of this surface and demands the improvement of software.

2.4. Designing of additional constructional parts on the RMSP face

The methods of computer simulation of a chip-formation area on the RMSP face elaborated in the previous chapters help to exactly describe the form of this area based on the initial data. At the same time, the RMSP construction is determined by other constructional parts: plate form, thickness, availability or lack of holes, accuracy, and other constructive parameters [2,3]. At this, they consider the stability of the plate [6,7], its wear-resistance as well as the methods of its fixation and orientation in the tool body [5].



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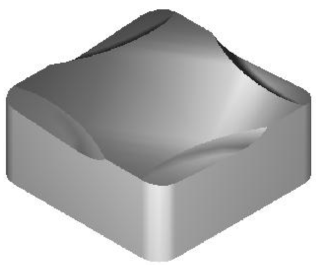

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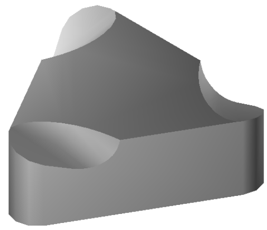

c

Fig. 8: Scheme to the determination of coordinates of chip formation surface for the condition of constant ratio of feed rate and cutting depth

Fig. 9: Examples of solid RMSP models following the condition of circular wrapping when the ratio of cutting depth and feed rate is S/t = 0.1: a) square $\varphi = 45^o$; b) triangular $\varphi = 90^o$

For the ratio S/t > 0.1, the received face form is enough for its secure breaking. At the same time, the observance of the condition of circular wrapping of smooth chip does not guarantee its breaking. In this case, it is necessary to create chip lead grooves and ledges on the face which work according to the principle of forced chip wrapping with its subsequent stop at the cutting surface. We can suppose that it is most rational to put the starting point of chip wrapping radius into the point of contact end of the chip with the face [4,8].

Based on the analysis of RMSP manufactured by Sandvik Coromant, Hertel and Moscow combine of hard alloys (MCHA), we have unveiled that an average distance from the main cutting edge to the step-type chip breaker depends on the feed rate and the cutting depth as follows:

$$l_{av}=4.2\, S^{0.1}$$

$$l_{av}=1.2\, t^{0.5}$$

In general, the recommended designing order of a new RMSP form with improved chip-breaking characteristics consists in the following:

1. Creation of a solid plate model in the rectangular coordinates system established taking into account the orientation angles of the plate in the body (AutoCAD usage is possible).
2. Determination of conditions of circular chip wrapping.
3. Simulation of a chip formation area on the RMSP face.
4. Designing of additional constructional parts on the face.
5. Combination of a solid model of the oriented plate and the modeled face object in order to create a complex topography on the plate face.
6. Positioning of the plate into the rectangular coordinates system for the purpose of realization of its final construction.

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3. Conclusion

The suggested method of computer simulation of RMSP with improved chip breaking characteristics helps to design a face area providing the circular wrapping of flow chips.

The face area of a metal-cutting tool indicated to the circular chip wrapping is a complex ruled surface which can be replaced by a plane.

There were RMSP constructions created for a varying cutting depth, varying feed rate, and a constant ratio of feed rate and cutting depth. The elaboration of a RMSP for a general case of changing the section of the cut layer demands a switch from AutoCAD-based software to the software of the type Mechanical Desk Top or ProEngineering.

Apart from the considered approach to RMSP designing according to the chip breaking condition, a full RMSP construction must simultaneously meet the conditions of stability, firmness, and other requirements. It is recommended to put the corresponding constructional parts beside the limits of the full contact length with the face.

Created solid RMSP models can be realized by means of profile molding with subsequent baking, or by means of electrochemical and electrophysical processing methods. At the same time, after a small construction change, they can be used for the finalization of RMSP with flat faces by means of grinding of chip lead grooves.

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