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Development of a Metal Cutting Tool Fase in Order to Create the Conditions of Ringed Chips Wrapping

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Abstract. When processing ductile metals with high cutting speed, there is a need to take additional measures for a comfortable and safe formation and removal of chips. In the conditions of large-scale manufacture, it is recommended to produce flow chips in the form of short fragments, while in the conditions of small-lot and single-piece manufacture, it is reasonable to wrap the chips spirally with a rather small turn radius. Such way of chips formation reduces the time of its removal from the working area as well as facilitates its transportation and processing. In order to solve the problem of chip wrapping and breakage, almost all modern manufacturers of tools with replaceable many-sided plates (RMSP) followed the way of complication of tool faces and determination of the areas of effective chip breaking. On the one hand, the suggested solution turns out to be effective; however, as showed the analysis of recommended cutting modes for complex forms of RMSP made by leading manufacturers, they all correspond to the definite cross section of the cut-layer $S/t=0.1$.

1. Introduction.

In the process of metal working, predominantly flow chips are developed which are represented by fragments of different length and form. It was noticed, that during the efficient life, even in constant duty of one and the same tool, the chips of various forms are created which, in its turn, negatively affects the stability of the process. Here are the most important reasons for this [1,5,6,7,8]:

1) The variability of the forces that affect the chips. In the process of formation, the mass of the chips is constantly growing, which provokes the shift of its gravity center. The chips-forming element, which constitutes an obstacle in the motion path of the chips, causes an additional resistance force. These forces create a flexure moment and define the instability of stress distribution at the root of the chips. In the process of cutting, the root of the chips is situated in the zone of plastic flow, that is why even a small change of stress distribution makes the form of the chips change. The form is changing in order to decrease flexure moment and resistance force, i.e. the chips is able to adapt to external forces and obstacles in its way.

2) Tool geometry modification. It is practically impossible to sustain a constant geometry of the cutting edge in the process of cutting because of wear and spoiling, which also leads to the form change of chips.

3) The inhomogeneity of the processed material by its chemical composition and structure, which causes the change of the shearing angle and chips form. Mostly, the cut-layer is hardened to some extent by the previous processing which affects the form of the created chips as well.

The flow chips of the general type, spirally wrapping, are usually hardly breakable, because the chip formation zone constitutes a "plastic hinge" which easily turns under the influence of deviations from chip breakers, thus bypassing these obstacles [1]. That is why the special concern is made here about extreme cases of chips wrapping: the so called flat wrapping when the chip slides on the face, and the ringed wrapping in the sectional plane of chip flow [5]. The second variant is more spread in practice and easier applied in the chip breaking.

Considering the process of restricted cutting with a cutter with the grade angle of the main cutting edge $\lambda = 0$, regardless of its other geometrical parameters, cutting modes, and the processed material, during the process of formation of flow chip the preconditions of its wrapping are created, simultaneously relative to two mutually transverse axles. It is suggested that one of these axles is orthogonal to the diagonal line of the cross-section of cut-layer, while the other axle is parallel to the reference plane and to the diagonal line of the cross-section of the cut-layer of metal. The basis parameter which determines the wrapping radius of the chip in the plane of the frontal cutter's edge is the direction and the speed differential of the widest distant points of the chip at the beginning of its existence as an independent solid body. The variability of the deformation grade of the metal chip by its width, which determines the speed differential of single elements at the beginning of its formation, in its turn, depends on an average ration of chip deformation and the ration between the width and the depth of the cut-layer. The more the average deformation ratio of the chip is as well as the less the ratio between the width and the depth of the cut-layer is, the more intensive is chip wrapping in the front face. In the case of predominant chip wrapping in the front face, the chips flows in the form of helical spiral.

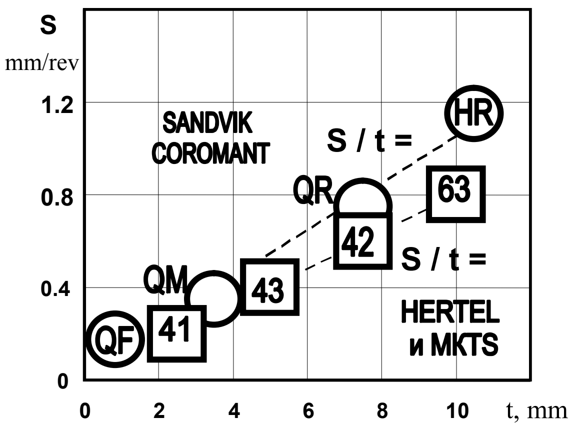

Figure 1. The arrangement of the areas of reliable chip breaking with cutting modes, geometry and the face form of RMSP.

Final appearance of the chip is formed in several steps: 1) its formation; 2) movement on the tool face within the contact length following a certain trajectory; 3) wrapping in the vertical and (or) in the horizontal plane; 4) natural or artificial chip breaking. Most geometrical parameters of the cutting unit and cutting process as a whole have a complex effect on the form and the dimensions of created chips [6]. For instance, the flow direction of the chips on the face depends on the primary φ and the secondary φ_1 angles on the plan [6], on the inclination angle of the main cutting edge λ [5], the ratio between the supply and the cutting depth ***S/t*** (or between the depth and the width of the cut-layer ***a/b***) [1] as well as on the form of the cutting unit on the plan. In case the tool face is plain, the chip wrapping in the sectional plane of its flow is primarily affected by the ratio ***S/t***, while in case it is determined by chip-forming elements [2], the geometry of the plate in the chips flow direction is most important. The form of the chips and its flow direction are correlated [3, 5], however the connection between them is not uniquely defined and depends on the cutting conditions. There is no correlation between the curve radius and the number of chips turns, because their values constitute the results of different chips formation processes: the chips radius characterizes the process of chips wrapping, and the number of turns characterizes the process of chip breaking [1].

Chip breakage is a complex and poorly studied process, because the breaking ability of the chips is determined by a large number of factors connected to physical characteristics of chips material which significantly differ from the characteristics of the source material [4,6]. In general, the chips is broken due to two reasons: in the process of unbending when meeting an obstacle, as well as under the influence of gravity force. While in the first case, in order to break the helical-curve chip into fragments, you need to adjust its hardness by the depth or width of the cut-layer, the second case is hard to describe.

An effective chip breaking, in single cases, can be achieved by means of the choice of appropriate processing modes: delivery ***S***, depth ***t***, and cutting speed ***V***. Many prominent companies manufacturing metal-cutting tools have in their catalogues plates with a plane face and a relatively wide recommended chip breaking zone which matches analogous zones for RMSP with chip-forming elements [2,3].

Within the last years, the stock-list of RMSP for the tools with mechanical mounting has significantly broadened by means of variation of their face form. In the catalogues [2,3], each RMSP form is connected with a certain chip breaking range of cross-sections of the cut-layer. We have analyzed cutting modes which provide with a proper chip breaking without any special plate geometry made by Sandvik Coromant and Hertel [2]. It turned out (Figure 2) that almost all of them lie within the ratio range $S/t = 0.08 - 0.1$, regardless of the form and the dimensions of chip-forming elements. Apparently, it is connected with the fact, that the cross-section of the chips in this area becomes harder, and the chips is more inclined to breaking. By the ratio of $S/t<0.08$, the cross-section of the chips becomes laminar, and the spirally wrapping chip breaks affected by the gravity force or an external force.

In Figure 1, there is a comparison of the areas of chip breaking using turning tools with mechanical RMSP mounting which are sharpened with different face geometries. The line $S/t = 0.1$ divides the area of the cross-sections of the cut-layer into the zones of stable and unstable chip breaking. On the top of it, the centers of the stable breaking zones are marked [1,7] as well as, according to the work [1], the connecting lines of these centers for a plain face, a variable bevel, and a radial impression. According to Figure 1.2, these centers and lines are situated in the zone of stable breaking.

The existence of multiple geometry forms of RMSP faces shows that there are no universal forms with chip breaking flutes which are able to process various materials in a wide range of advances. Usually, for CNC metal-turning lathes, a set of plates is used designed for semi-rough and final turning.

The analysis of the literary sources gives evidence that the existing data are insufficient for the determination of the form and the dimensions of chips using geometrical parameters of cutting units. In case of a complex face topography of RMSP, its influence on the form and the dimensions of created chips either is absent or is given in the catalogues of foreign companies in the form of empirically calculated zones of stable chip breaking.

2. Results and Discussion.

2.1. The conditions of ringed chips wrapping in the sectional plane of its flow.

Having conducted the analysis of literary sources, of publications in Russian and foreign technical periodicals as well as of the reference data concerning the questions of flow chip wrapping and breaking, we were able to make the following conclusions:

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1) The simplest and the most approachable method of chip wrapping and breaking is to change the cutting mode; however, it guarantees a proper chip form only within the range restricted by the ratio $S/t > 0.1$.

2) A chip breaker, a ledge, or a radial groove on the face somehow broaden the range of sustainable chip breaking; moreover, the areas of application of chip-forming grooves and ledges on the face are considerably similar to the areas of stable chip breaking using cutting modes.

3) When performing a restricted cutting, the scheme of wrapping and breaking in the sectional plane of chip flow is the most widespread. Here, a problem arises of the determination of the conditions which help achieve this wrapping using cutting modes as well as the geometry of tool faces. This problem has not yet been solved in a general way.

4) The recommendations concerning the choice of tool faces are as a rule restricted by small changing ranges of cutting modes.

Therefore, a model was suggested of a ringed flow chip wrapping in the sectional plane of its flow.

From the point of view of stable cutting processes, processing safety as well as transport and reprocessing conditions, flat-spiraled chips is the most convenient as it is characterized by the largest value of packed density. This chip form is created by means of wrapping in the sectional plane of its flow.

In figure 2, the cutting unit of a tool is depicted with the root of the chip flowing in the direction ***y'***. Here, ***OAB*** is a conditional shear surface [1], ***O'A'B'*** is the cross-section of the chips, the form of which can be deduced by means of a projection of the shear surface on the normal plane to the axis ***X'***. On the power contact spot ***OO'B'B***, normal and tangential loads are distributed according to a certain law between the chip and the tool face. As a first approximation, we can suppose that the stresses on the conditional shear surface and tangential loads are evenly distributed. Then, the points of application c_s and c_f of the cumulative forces R_S and F_f will match the gravity centers of curvilinear figureures ***O'A'B*** and ***OO'B'B***. If the chips does not meet any obstacles in its way, then, having set the chip flow speed on the tool face as constant, we deduce that $R_S = F_f$, i.e. this is the case when the forces that affect the chips from the side of conditional shear surface as well as from the tool face are balanced.

In a general case, the points of application c_s and c_f do not match which causes the flexure moment that conditions the so called "natural" chips wrapping of ***a*** general kind. Hereby, arm l_v (Figure 2) defines the chip bend in the vertical plane towards the tool face. The arm of force l_h conditions the chips wrapping in the face plane. It is possible, that the correlation between arm l_h and arm l_v defines the correlation between the radius and the pitch distance of the helical spiral of the chips. It follows thence that ringed chips wrapping corresponds with the condition $l_h = 0$, when chips forming and friction forces lie in the same vertical plane. This condition is provided when the horizontal coordinate of the gravity center of chip power contact area matches the tool face [7,8].

In order to follow the condition of ringed chips wrapping in the sectional flow plane, it is necessary to know the direction of its flow and the dimensions of the contact mark. In a general case, the cutting edge can be described as a sequence of points (x_i, y_i, z_i), while its previous position is described as (x_i-S, y_i, z_i), where S is delivery, mm/rev. Let us consider the cross section of the cut-layer which is created by two consequent positions of the cutting blade (figure 4). In case of a curvilinear blade of no particular form, it is always possible to define the coordinates of nodal points of the cross-section of the cut layer for certain values of cutting depth t and delivery S: *B, C* and *O*. Let us assume that angle β_1 is constant in the chips flow direction for any point of the working section and let us apply the scheme with a single conditional surface shear (CSS) which, in figure 2, is presented by the projection ***BAO*** on the general plane. The value of area of the projections of the conditional shear surface on the coordinate planes F_x and F_y, the ratio of which defines the initial chips flow angle, is determined by the sum of elementary areas which are restricted with the tool face from below as well as with the conditional shear surface from above:

$$F_x = \sum (x_i - x_{i+1}) \cdot z_{ci} \, ; \, F_y = \sum (y_i - y_{i+1}) \cdot z_i \, , \tag{1}$$

where z_{ci} is chips height, which, taking into account all the consumptions, equals to

$$z_{ci} = a_{ci} / tg\beta_1 \tag{2}$$

where a_{ci} - is the depth of the cut-layer in the flow direction of the chips.

Further chips flow trajectory on the tool face is defined by the tool face form, thus the equation of the chip flow angle shall be as follows:

$$\eta_d = arctg\left(\frac{\sum (x_i - x_{i+1}) \cdot a_{ci}}{\sum (y_i - y_{i+1}) \cdot a_{ci}}\right) \pm arctg\left(\frac{z_B - z_O}{y_B - y_O}\right). \tag{3}$$

where η_d is the dynamic flow angle [1].

According to (3), it follows that angle η_d depends only on cutting depth, delivery, which determine the nodal points of the cross-section of the cut-layer, and on the cutting edge geometry on the plan.

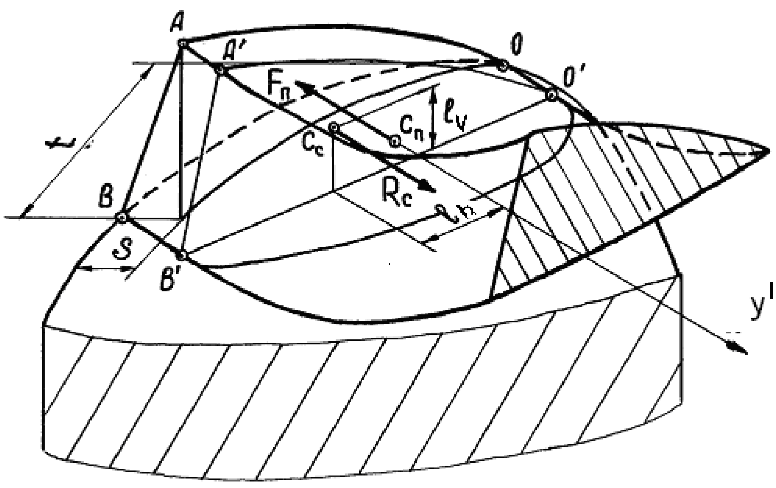

Figure 2. Diagram Curling continuous chip [1].

In the equation (3), the value of the angle of exit is evident in the left part and subtended in the right part, this is why its determination demands the application of the method of successive approximation. There was a computer program developed for the identification of η_d.

This algorithm functions as follows. For the purpose of plotting a conditional shear plane projection in the direction of the initial chips flow, let us define the depth of the cut-layer using the normal line to it $a_{n\,i}$. Then, the chips height on the i[th] section equals to

$$h_i = a_i / tg\beta_1, \tag{4}$$

while the coordinates of the gravity center of shear surface are:

$$x_c = \frac{\sum x_{ci} \cdot \Delta S_i}{\sum \Delta S_i}; \qquad z_c = \frac{\sum z_{ci} \cdot \Delta S_i}{\sum \Delta S_i}, \tag{5}$$

where x_{ci}, z_{ci} - are the coordinates of gravity centers of surface elements which constitute the projections of the conditional shear surface;

ΔS_i - is the area of the surface element of the chips cross-section.

The contact mark of the chips with the tool face is built in the flow direction consequently for each depth of the cut-layer a_i. For this purpose, according to the equation, the plastic length of the chips contact with the tool face is defined and protracted in the flow direction which is determined by the equation (3) so that, in result, there is a contour of the contact mark ***ABOC*** (Figure 2).

If the coordinates of gravity centers of the chips cross-section x_{mi} and contact mark x_{ci} are situated in the same straight line in the flow direction with angle η_s, then the formed chips shall wrap in the vertical plane. If the position of gravity centers does not meet this condition, it is necessary to change the cutting conditions. According to (5), for a positional change of gravity centers by the constant cross-section of the cut-layer, it is necessary to change the coordinates z_O и z_B.

In the conditions of mismatching of gravity centers, the cutting modes can be changed in case of the calculation of recommendations on ringed wrapping, as well as geometrical parameters of the cutting edge can be changed if a new tool is projected.

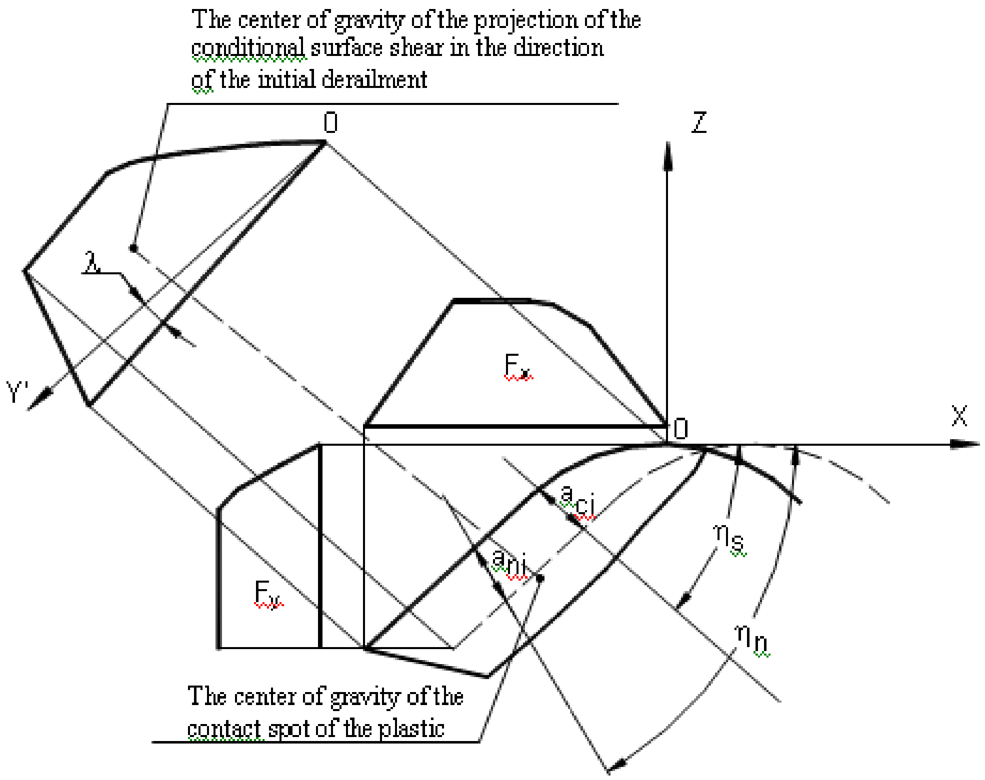

Figure 3. Scheme to the determination of centers of gravity transverse chip, the spots of contact force and angle go chips.

Thus, the developed program, to the specified accuracy, helps calculate the flow angle to the diagonal η_n, the flow angle η_s as a ratio of the area of the projections F_x/F_y as well as the coordinates of gravity centers of the chips height and the plastic contact mark. Moreover, the program is able to define the absolute difference between the coordinates which can be used for the assessment of the form of the created chips. The program is equipped with a function which makes it able to determine the coordinates of any points of the cutting edge profile, the conditional shear surface, and the lengths of the plastic contact mark, as well as to save these values as a text file. The program graphically depicts calculated values and has a zooming function of selected areas.

As follows from the analysis of the algorithm, the front angle, the shear angle, and the angle of slide lines approach on the tool face do not affect the coordinates of gravity centers of the chips cross-section and contact mark; thus, they do not affect the conditions of chips wrapping in the vertical plane as well.

3. Conclusion

For the conditions of restricted cutting, there was the condition of ringed wrapping created in the sectional flow plane. Accordingly, in case of matching forces that affect the chips from the tool face and from the conditional shear surface, a scheme can be realized which allows to create flat-spirally formed chips. The most important parameter defining chips form is the primary angle of its flow on the tool face. For the purpose of determination of the conditions of ringed chips wrapping, there was an algorithm created which helped to conclude that the front angle, the shear angle, and the angle of slide line approach on the tool face do not affect the condition of matching forces which influence the chips from the side of the tool face and the conditional shear surface. It is only the delivery, the cutting depth, and geometrical parameters of the cutting edge that affect the flow angle. This algorithm is helpful when elaborating the recommendations on chips wrapping under changing cutting conditions for a certain geometry of the cutting edge.

The deduced calculated dependences can be used for the designing of chip-forming elements for various materials and processing conditions.

Theoretical determination of effective profile and location ID on the front surface of the instrument should be based on the task of Curling chips, which in turn is inextricably linked with the accepted model of the chip formation. Figure 4 shows the form of the RMSP, the shape of the front surface calculated from the conditions of the circular Curling of the chips. Made plates showed high efficiency and increased bulk density of the chips depending on the cutting conditions 2 to 5 times.

Figure 4. New forms RMSP designed from the condition of the ring Curling.

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