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THE INFLUENCE OF THE WEAR OF THE TOOL CUTTING EDGE ON THE DEFORMATION OF THE SURFACE DETAIL LAYER

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Computing possibilities of estimating the deformation of the surface layer are considered in processing of details with cutting tools at different levels of the wear. Experimental results of the modification of the deformation intensity in the depth of the surface layer for plates with different wear of cutting edge during the process are given. The methods of the estimation of influence of the deformation intensity on the parameters of vibro acoustic signal are shown.

***Key words**: surface layer, deformation, tool wear, the vibro-acoustic signal, the spectrum of vibrations.*

Introduction

In modern engineering, many parts have to work in conditions of high temperatures, in contact with corrosive media, in the presence of high static and dynamic stresses. All these factors lead to the appearance of various defects on the surface of the part. Most often, the birth of such defects occurs in a thin near-surface layer, which is largely formed by the implementation of the appropriate processing technology. Practice established a close relationship between the properties of the surface layer of parts and their performance properties, including strength and durability. You can note the reasons for this connection:

- when the parts are being loaded, the surface layer turns out to be in more difficult conditions in comparison with the core. There are unbalanced atomic bonds there, the yield of dislocations is facilitated, less energy is needed to generate dislocations;
- risks and irregularities, formed on the surface and inherent in each technology of processing parts, are stress concentrators, centers of formation and development of fatigue cracks;
- at the earliest stages of plastic deformation, the interaction of dislocations leads to the formation of micro cracks of an atomic scale, which causes the formation of micro cracks at deformation degrees of about 6…8%, accompanied by a drop in resistance to their propagation [1];
- Using the methods of strain hardening, it is possible to form favorable compressive stresses in the surface layer and to improve the roughness class. However, when the critical temperature is exceeded during the operation of the part, material without strength hardening begins to possess advantages in terms of strength, plastic and elastic properties. The more the material was deformed, the lower the temperature is, the advantage is obtained by the material without strain hardening [2];
- the resistance of parts to corrosion-mechanical destruction depends on the processing technology applied at the finish, because it determines the strength and plastic properties of the surface, the chemical and structural-phase composition, diffusion mobility of atoms, thermodynamic stability etc.
- when applied to the surface of protective coatings, their performance depends largely on the properties of the surface acting as a substrate (micro geometry, cold work, residual stresses, structures);
- the relaxation rate of the properties of the surface layer and its softening during the operation of the part are in close correlation with the applied manufacturing technology.

It should be added to the above said the problem of wear of the cutting tool, because with the blade surface treatment, the wear of the cutting edge leads to an increase in the plastic deformation of the surface layer. In the conditions of automated production, the detection of the moment of attaining critical wear at which deformation of the surface layer becomes higher than the permissible values is an actual problem.

Statement of the question

The purpose of the present studies is to create an integrated system for ensuring the quality of the surface layer during blade processing. Its implementation involves the solution of the following tasks:

- study of the possibilities of calculation methods for evaluating the effect the wear on the blade tool on the deformation of the surface layer of the work piece;
- carrying out experimental studies to identify the patterns of change in the quality of the surface layer at different levels of tool wear;
- the development of a system for diagnosing the state of the cutting tool in the process of cutting to ensure a stable quality of the surface layer.

Results of the study

In the cutting zone, a complex stress-strain state arises, the structure of which depends on the properties of the material being processed, on the initial geometry of the cutting tool and the shape of its wear, the processing regimes. To study deformations of the surface layer by calculation methods, the finite element method (FE) is the most acceptable. For comparison, among the calculated parameters, the strain intensity (ε_{int}), was chosen, which is determined by the formula [1] for three-dimensional space:

$$\varepsilon_{int} = C_{\mu}\left[\left(\varepsilon_y - \varepsilon_\tau\right)^2 + (\varepsilon_\tau - \varepsilon_x)^2 + \left(\varepsilon_x - \varepsilon_y\right)^2 + 1{,}5\left(\gamma_{y\tau}^2 + \gamma_{\tau x}^2 + \gamma_{xy}^2\right)\right]^{0{,}5}, \quad (1)$$

where C_{μ} is a constant depending on Poisson's ratio; ε and γ - linear and angular deformations along the corresponding axes *x*, *y* and *z* and in the respective planes *yz*, *zx* and *xy*.

For a simpler planar model in the formula deformations with the index "z" equate to zero. Graphical representation of the stages of formation of the distribution field ε_{int} in the cutting zone during the formation of chips is shown in Fig. 1.

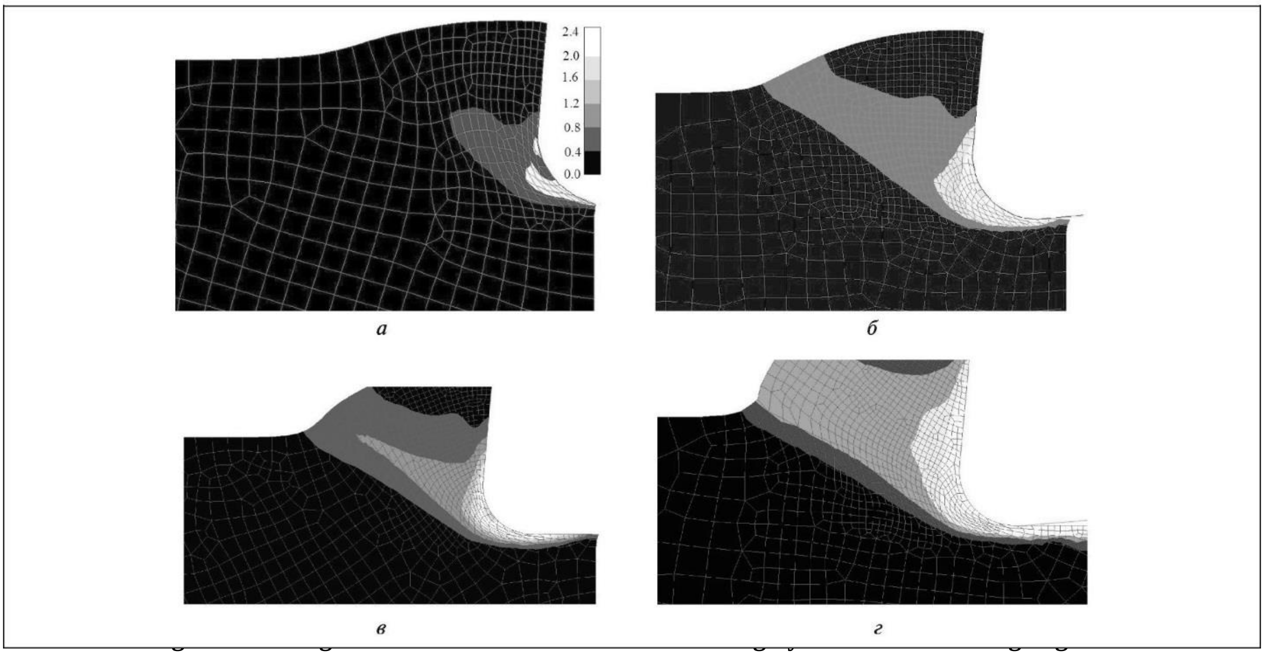
We see a gradual increase in the zone of high values of (ε_{int}), which is formed in the vicinity of the conventional shear plane, as the edge is inserted into the material. The volume of this zone is largely determined by the radius of the rounding of the cutting edge. The larger the radius, the greater the proportion of the material "jammed" by the back surface of the tool is, the greater the depth of penetration is required to start chip formation [4]. Accordingly, shown in Fig. 1, the deformation of the surface layer is much smaller than the deformations of the chips, but it also increases with the introduction of the cutting wedge and increases with increasing of edge radius. It is possible to trace the formation of a crack separating the chips from the results of examining the field of the intensity of the strain rates, the values of which are determined by analogy with expression (1), but instead of the values of deformations, their velocities are substituted into it.

The influence of the geometry of the cutting part of the tool on the intensity of deformations of the surface layer and the depth of their penetration δ is shown in Fig. 2.

To Fig. 2, the following observations can be made:

- with a sharp cutting edge, the deformation of the surface layer changes little when the front and rear angles change. This result corresponds to practical observations, when even with large wear on the back edge of the tool while retaining the sharp cutting edge, the cutting forces change insignificantly. At a depth of 0.3 mm. the strain intensity becomes relatively small, but its values for different angles differ by several times which raises the problem of estimating the uncertainty of computations in the region of small deformations;
- with increasing radius of the rounding radius of the cutting edge the value of ε_{int} increases regularly, but at r = 0,12 mm large deformations of the uppermost layers are observed with minimal deformations at depths greater than 0.2 mm. This anomalous situation requires further comprehension,

but it is difficult to verify, since in practice such radii do not occur when the tool is worn out.



***а* – stage of elastic deformations; *б, в* – transfer of elastic deformations to plastic; *г* – start of distortions**

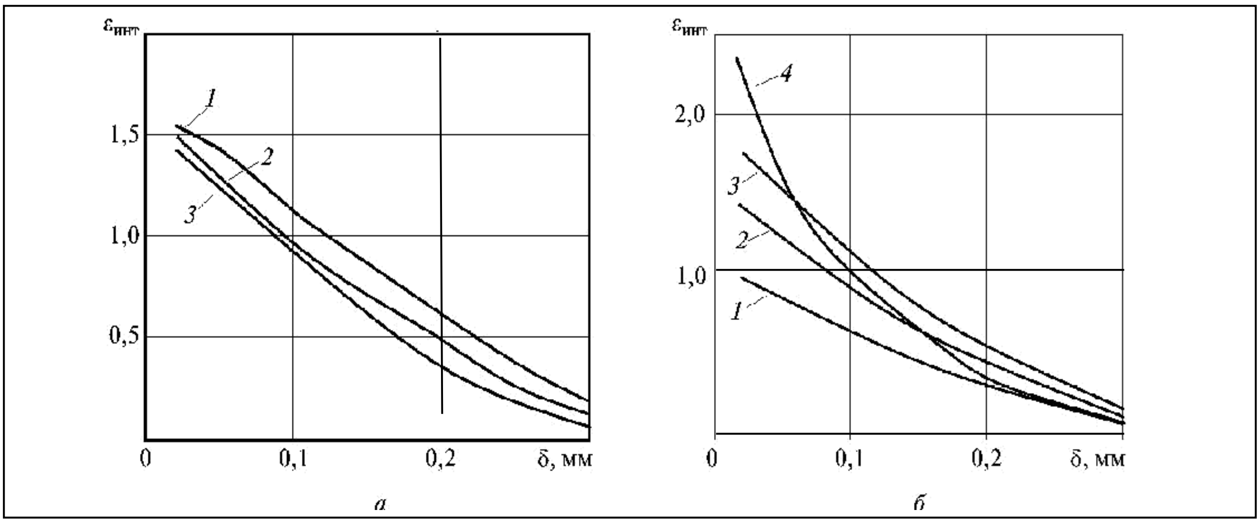


Figure 2. Change of $\varepsilon_{инт}$ according to the depth of surface layer :
a **– in different front and back angle:$1-\gamma=0^0, \alpha=0^0, 2-\gamma=5^0, \alpha=5^0, 3-\gamma=15^0, \alpha=10^0$, ; б – in different radius of rounding: 1 - r = 0,02 mm; 2 - r = 0,05 mm; 3 - r = 0,09 mm; 4 - r = 0,12 mm**

However, the most difficult moment in modeling the shape of wear of the cutting edge is the approximation of the shape of wear in the contact zone by a portion of the circle of radius r. This approach assumes that as the wear chamfer develops over the back surface of the tool, the front surface and the cutting edge itself gradually degrade. As a result, there should be a resemblance of the radiused surface of the cutting edge, the radius of which is the greater, the greater the wear facet on the back face is. Unlike the radius, the size of the chamfer wear is simple to control. A similar approach takes place in tribology [4], where the relative depth of introduction of the indenter, which plays an important role in estimating the moment of transition of external friction to micro cutting (geometric factor), is determined by the ratio of the penetration depth *h* to the radius *r* of the indenter itself. Under some conditions of unevenness in frictional contact and tool wear areas, this approach is acceptable, but it is often necessary to observe a wide variety of geometric forms of wear of a carbide tool.

Sometimes, with wear, one can observe even a decrease in the radius of the rounding of the cutting edge. Such a phenomenon, for example, occurs at high cutting speeds, when wear on the back edge outruns the destruction of the edge from the front face side and there is an effect of self-sharpening.

For the experimental evaluation of the influence of wear on the cutting edge on the deformation of the surface layer, five cutting inserts were used in different stages of wear (Figure 3), which was formally estimated from the width $h_{з}$ of the chamfer of wear along the back edge:

1 - $h_{з}$ = 0 mm; *2* - $h_{з}$ = 0,6 mm; *3* - $h_{з}$ = 0,68 mm; *4* - $h_{з}$ = 1,1 mm; *5* - $h_{з}$ = 0,8 mm. It should be noted that the 2nd sample had almost the same size of the chamfer of wear as the third one, but it had practically a whole cutting edge, and the third sample had traces of destruction (Fig. 3, a). The fourth sample had the largest dimension of the facet of wear (Figure 3, b), but the broken edge had comparatively sharp edges, which was associated with the development of the wear lining along the front face. In the fifth sample (Fig. 3c), the wear face and the volume of fractures are smaller, but the cutting edge smoothly passes into the negative front angle and is closer to the radial shape. Fig. 3 shows the tops of the used specimens of the cutting inserts with the greatest wear.

Cutters equipped with plates with different degrees and forms of wear treated steel billets on planning and turning machines.

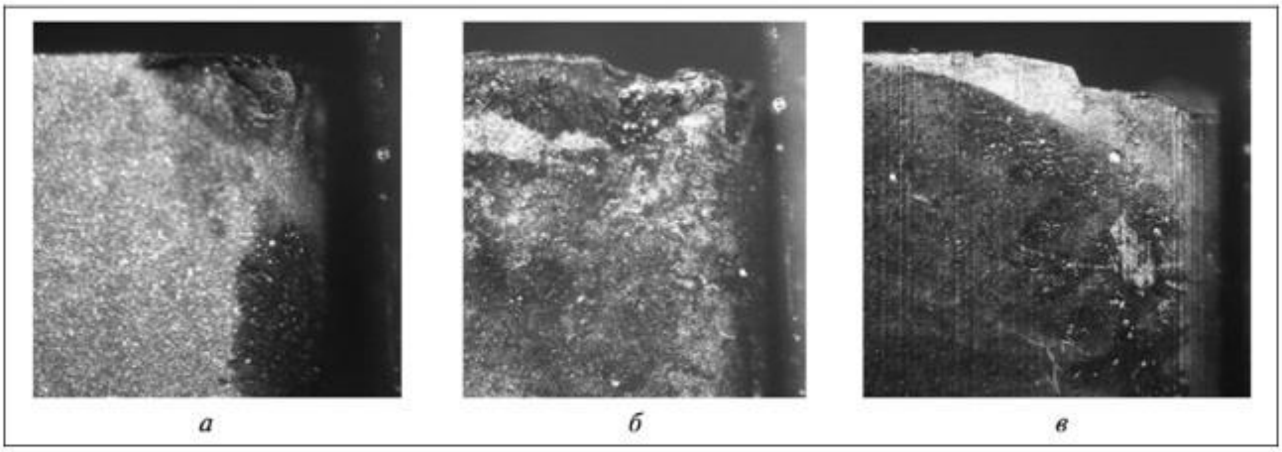


Figure 3. Samples of worn out tops of cutting edges:
***а* - $h_{з}$ = 0,68 mm; *б* - $h_{з}$ = 1,1 mm; *в* - $h_{з}$ = 0,8 mm**

Fig. 4 shows the change in the intensity of deformation along the depth of the surface layer for the described variants of wear of the cutting edge.

On the graphs of Fig. 4 we see that the main deformations are observed in the surface layer located up to a depth of 100 m/km. There is a regular growth of deformations with increasing wear of the cutting edge. The exception is plate number 5, which has a smaller wear dimension on the back face compared to plate number 4, but the deformation of the surface layer when it is used is 35% larger. This indicates that the deformation of the surface layer is determined mainly by the shape of the cutting edge. As another anomaly, we can note plate No. 3, deformations from which at a depth of more than 0.4 mm even slightly exceed the deformations from plate No. 5. As with calculations at depths of more than 0.3 mm, ε_{int} is considerably smaller in comparison with depths of up to 50 microns, but they are characterized by the fact that with little wear, they are almost imperceptible, and with an increase in wear, they sharply increase several times. Judging from the graphs in Fig. 4, then the increase in deformation as the wear of the cutting edge develops at a depth of more than 0.3 mm develops abruptly. For plates No. 3-5 deformations at a depth of more than 0.3 mm are close, and they are several times larger than the deformations accompanying the work of plates No. 1 and No. 2. In contrast to the graphs in Fig. 3, decreasing in accordance with a law close to linear, the graphs in Fig. 4 decrease according to a law resembling a hyperbola. This phenomenon can be explained by the fact that the calculation program did not fully take into account the temperature factor, which has a complex effect on the mechanical properties of the material. The listed features and anomalies suggest that the calculation methods, although they build a qualitatively similar picture of deformation development with increasing tool wear, give higher values of the ε_{int} and can not take into account all the features of the change in the shape of the cutting edge and their effect on deformations of especially deep layers of the treated surface. Without taking into account the surface temperature and temperature gradients that affect the changes in the mechanical characteristics of the material being processed, errors in calculations will be exacerbated. In this section, the issue of monitoring the state of the cutting edge becomes important in order to prevent unacceptable deformations of the surface layer [5].

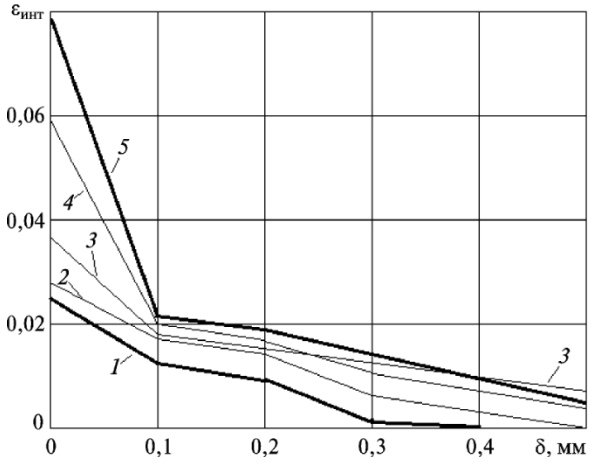


Figure 4. Change of deformations intensity according to the depth of surface layer for plates with different wears of cutting edges: *1* - $h_{\text{з}}$ = 0 mm; *2* - $h_{\text{з}}$ = 0,6 mm; *3* - $h_{\text{з}}$ = 0,68 mm; *4* - $h_{\text{з}}$ = 1,1 mm; *5* - $h_{\text{з}}$ = 0,8 mm

It is known that the destruction of the cutting edge, which causes intensive deformation of the treated surface, leads to an increase in the energy consumed, corresponding to an increase in cutting forces and the amount of heat released. The cutting force can be controlled by changing the active power consumed by the drives on the machine. However, in the final treatment regimes, the method does not always give satisfactory accuracy. This is particularly noticeable for finishing with a large ratio of the power of the applied motor and the amount of cutting power [6]. This situation is peculiar to the processing centers, where both roughing and finishing of parts from different materials and different configurations are carried out. Temperature control in the cutting zone is a difficult task even for laboratory conditions. The relationship between the vibro acoustic activity of the cutting process and the wear of the cutting tool is widely noted in the technical literature [6]. Vibro acoustic (VA) signals are comparatively easy to control with accelerometers, but the disadvantages of VA diagnostic methods include the difficulty of isolating useful information from a variety of parameters of VA signals accompanying cutting. The simplest parameters of VA signals, which are easily obtained in digital or analog form, are the effective amplitudes in the allocated frequency bands. Distortion of the shape of the spectrum of VA signals can be used as a diagnostic indication of the change in the state of the cutting tool [8]. It involves changing the ratio of effective amplitudes for different frequency ranges. The increase in heat release in the contact zone between the surfaces of the tool and the material being processed leads to a change in the mechanical properties in the friction pair, for example, a reduction in the hardness of the material being processed. In [6] it was shown that the amplitude of the high-frequency VA signal in frictional contact in the first approximation with increasing hardness of the softer element of the friction pair increases linearly. Thus, with increasing temperature (and a drop in the mechanical characteristics of the material being processed) in frictional contact under conditions of adhesive friction, the high-frequency components in the signal spectrum of the signal should decrease. On the other hand, the growth of the load in the contact of the tool with the machined surface causes additional deformation of the technological system and increases its potential energy [5], making it less stable. The situation can be aggravated by a decrease in the bearing capacity of the cutting surface with an excessive increase in the contact temperature, which forms the undulation of the surface. When separating the chips, the balance of forces in the technological system is violated, which leads to the emergence of potential energy, the relaxation of elastic deformations with the appearance of oscillations at the natural frequencies of the technological system. From what has been said, it follows that with an increase in the potential energy determined by the cutting forces, oscillations in the technological system in the region of comparatively low frequencies will increase.

This growth is observed both at low and high frequencies in a wide frequency range, which is associated with the appearance of impact processes in contact, accompanied by a decrease in the temperature of the contacting surfaces and the restoration of their hardness. When the motion is sudden, the contact time of the irregularities becomes so small that the adhesive setting does not have time to develop. This determines the reduction in energy costs with relative movement of the contacting surfaces. Thus, in VA control of technological processes, it is necessary to include effective amplitudes in the areas of natural frequencies of the technological system in the number of informative parameters.

Conclusion

An experimental verification of the accuracy of the evaluation of the deformation of the surface layer of a part machined at different values of wear of the cutting edge with the help of computational models based on the CE method showed that the approximation of the shape of wear by a radius surface gives an excessive value of the strain intensity. In this case, there is a qualitative similarity of the results obtained. Comparison of experiments and calculations showed that the values of the deformations of the surface layer of the part are determined not so much by the dimensions of the chamfer of wear of the cutting insert as by the geometrical shape of the current fractures of the cutting edge, which in practice considerably differs from the radius. Without taking into account the effect of contact temperature on the mechanical characteristics of the material being treated, additional discrepancies arise between the results of calculations and experiments. To increase the reliability of the formation of a qualitative surface layer, constant monitoring of the tool state during processing is necessary. For these purposes, it is possible to monitor the active power of the drive under rough processing conditions and vibration signals during finishing.

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ԳՈՐԾԻՔԻ ԿՏՐՈՂ ԵԶՐԻ ՄԱՇՎԱԾՔԻ ԱԶԴԵՑՈՒԹՅՈՒՆԸ ԴԵՏԱԼԻ ԱՐՏԱՔԻՆ ՇԵՐՏԻ ԴԵՖՈՐՄԱՑԻԱՅԻ ՎՐԱ

Պ.Յու. Գասպարյան
Շուշիի տեխնոլոգիական համալսարան

Դիտարկված են մակերևութային շերտի դեֆորմացիաների գնահատման հաշվարկային հնարավորությունները՝ եզրային տարբեր աստիճանի մաշվածքի սայրային գործիքով դետալների մշակման դեպքում: Բերված են կտրման ժամանակ ըստ մակերևույթային շերտի խորության դեֆորմացիաների ինտենսիվության փոփոխման փործարարական արդյունքները, կտրող եզրերի տարբեր մաշվածության սալիկների համար: Բերված են դեֆորմացիաների ինտենսիվության ազդեցության գնահատման մեթոդները վիբրոծայանային ազդանշանի պարամետրերի վրա:

Բանալի բառեր. Մակերևութային շերտ, դեֆորմացիաներ, գործիքի մաշ, թրթռածայնային ազդանշան, տատանումների սպեկտր

ВЛИЯНИЕ ИЗНОСА РЕЖУЩЕЙ КРОМКИ ИНСТРУМЕНТА НА ДЕФОРМАЦИИ ПОВЕРХНОСТНОГО СЛОЯ ДЕТАЛИ

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Рассмотрены вычислительные возможности оценки деформаций поверхностного слоя при обработке деталей лезвийным инструментом с различным уровнем износа. Приведены экспериментальные результаты изменения интенсивности деформаций по глубине поверхностного слоя для пластин с разным износом режущей кромки при резании. Приведены методы оценки влияния интенсивности деформаций на параметры виброакустического сигнала.

Ключевые слова: поверхностный слой, деформации, износ инструмента, виброакустический сигнал, спектр колебаний