Regarding the strength calculations of complex combined tools

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Abstract. The complex combined tools for sequential impact by chip removal and subsequent plastic deformation have a complex load of cutting forces and friction forces. Their design is abundant in different stress concentrators. This fact leads to the choice of a certain approach in determining the security coefficients and the strength conditions of the individual details of the complex system. The results obtained show that when using CAE design systems, it is necessary to strictly observe the ways of contact and interconnection between the individual parts and assemblies in the product.

1. Introduction
In the modern machining, combined tools for machining holes with sequential impact are used. The first part of the tool is cutting and the second part impact by plastic deformation. In practice, the second impact is achieved either by sliding friction or by friction during rolling (Holmberg and Matthews, 2005; Holmberg at al., 2009). In this type of machining is achieved exceptionally high quality performance especially in terms of roughness.

2. Object of research
Figure 1 and figure 2 shows a combined tool for simultaneous machining of holes by chip removing and plastic smoothing (Лефтеров and Аврамова, 2014).
Figure 1. Exploded view of a combined tool for combined impact (Лефтеров and Аврамова, 2014): 1 – tool body; 1a – cooling grooves; 2 – an outer casing for covering the grooves for feeding the coolant; 3 – ring seal; 4 – screw for fastening; 5 – movable smoothing guiding inserts; 6 – a module carrying the cutting insert; 7 – counter body, allowing relocation, setting and regulation of guiding elements; 8 – cutting insert; 9 – screw for fastening; 10 – fixed guiding element.

Figure 2. Exploded Assembled view of a combined tool for combined impact, (Лефтеров and Аврамова, 2014): 1 – tool body; 1a – cooling grooves; 2 – an outer casing for covering the grooves for feeding the coolant; 3 – ring seal; 4 – screw for fastening; 5 – movable smoothing guiding inserts; 6 – a module carrying the cutting insert; 7 – counter body, allowing relocation, setting and regulation of guiding elements; 8 – cutting insert; 9 – screw for fastening; 10 – fixed guiding element.
3. Strategy in strength calculations of complex technical systems

The system shown in figure 1 and figure 2 it is possible to be destroyed or to obtain a large residual deformation due to the complex loading of the separate elements.

In the process of operation, the separate elements forming the body 1 and 2 are loaded in torsion, pressure and bending, and the screws 4 are loaded in shear, the movable smoothing elements 5 and 10 are loaded also in pressure. The present research is not intended to make strength analysis the cutting insert, but for example a module 6 which carries it and is loaded on bending, pressure and torsion.

The normal operation of the tool is inadmissible if residual deformation because it will disrupt the indicators of quality during processing. This also concerns the impact of the elastic deformations of the separate elements, but without disturbing the strength of the technical system as a whole.

The strength of separate elements of the cutting tools should always be considered related to their durability.

The most common type of machine element strength conditions are, equation (1):

$$\sigma < \sigma_{\text{lim}}; \tau < \tau_{\text{lim}}; P < P_{\text{lim}}; M < M_{\text{lim}}$$

(1)

where: $\sigma$ and $\tau$ – operating stresses for the cross-section, which is calculated. Depending on the type of tense state and accepted strength theory, they may be the largest normal tangential or equivalent stress; $\sigma_{\text{lim}}$ or $\tau_{\text{lim}}$ – limit (dangerous) stresses. Achieving or exceeding their values is inadmissible as it leads to loss of working capacity;

$P$ or $M$ – in general these are the forces or torques loading the separate elements of the system shown in figure 1 and figure 2;

$P_{\text{lim}}$ or $M_{\text{lim}}$ – limit values of forces and torques that may lead to a failure.

For each element can be defined the so-called “security factor”, equation (2), (Лефтэр, 2015):

$$s = \frac{\tau_{\text{lim}}}{\tau} \quad \text{or} \quad s = \frac{P_{\text{lim}}}{P}$$

(2)

The most general type of equation to provide strength is as follows, equation (3):

$$\sigma = F(P_1, P_2, P_3, ..., P_i, M_1, M_2, M_3, ..., M_i, a, b, c) \leq \frac{\sigma_{\text{lim}}}{s}$$

(3)

The working stress $\sigma$ is defined as a function of the loads ($P_i, M_i$) and the dimensions of the sections ($a, b, c, ...$).

The ratio of the limit stress $\sigma_{\text{lim}}$ to the required safety factor $s$ is the permissible stress, equation (4):

$$\sigma = \frac{\sigma_{\text{lim}}}{s}$$

(4)

Equation (3) should be used in CAE systems in calculating all designs of cutting tools using the methods of simulation modelling (Василев, 2014), observing the following sequence:

- Calculations at the design to determine the dimensions of the individual components (the limits are predetermined);
- Verifying of all components of the non-monolithic tool.

After the design development of the object, it is necessary for each individual component to perform a verifying calculation and to determine and correct the so-called actual (operational) security factor $s'$, equation (5):

$$s' = \frac{\sigma_{\text{lim}}}{\sigma} \geq s$$

(5)

In many cases, the verification calculations lead to corrections, including a change in the material for production of the individual components.
4. Volumetric strength. Concentrators of stresses and coefficient of stress concentration

The shapes of the individual components of the object under study (figure 1 and figure 2) have a different character, and it is necessary to determine the magnitude and the nature of the distribution of the stresses in the sections away from the places of application of the external load.

Any sudden change of the shape of the element creates the so-called stress concentration. The maximum value of the local stress can be significantly higher than the normal stress and depends mainly on the geometry of the concentrator and its dimensions (Komarovsky and Astakhov, 2002) (figure 3).

![Figure 3. Distribution of stresses in section n-n.](image)

The stress state in the concentrator area is more complex than the stress state of the material in a section away from it.

Figure 4 shows the most typical concentrators of stress occurring in the design shown in figure 1 and figure 2.

Figure 3 shows the distribution of stresses in section n-n in a cylindrical section loaded with force P. The nominal value of the stress in a section with a concentrator n-n without accounting to the effect of the concentrator is determined by a known formula, equation (6):

$$\sigma_H = \frac{P}{\pi.d^2}$$

The ratio of the largest local stress $\sigma_{max}$ to the relative stress $\sigma_{H}$ is called the theoretical stress concentration factor $a_\sigma$ or $a_\tau$, equation (7):

$$a_i = \frac{\sigma_{max}}{\sigma_H}$$

The coefficients $a_\sigma$ and $a_\tau$ do not determine the actual decrease in the strength of the individual components since the largest local stresses differ from the stresses $\sigma_{max}$ or $\tau_{max}$ determined on the basis that the material is fully elastic. With increasing the force P in section n-n (figure 3), where there
is a maximum stress, it will reach the limit of plastic deformation. Upon further increase the force P in the area covered by the plastic deformation, will affect the surrounding (bordering) elements, which in practice are less loaded.

Figure 4. Typical examples of stress concentrators.

These features are not taken into account by modern CAE systems because the calculations are performed using numerical models. The difference between the actual stress distribution and that corresponding to the theoretical conclusions is predominantly determined by the plastic properties of the material and manifested differently at different loads.

In this case, as criteria of the influence of stress concentration, adopt effective coefficient of stress concentration $\kappa_\sigma$ or $\kappa_\tau$. This represents the ratio of the limit stresses (or loads) and the sample with a stress concentrator having the same absolute dimensions and a smooth sample, equation (8):
\[ k = \frac{\sigma_{\text{lim}}}{(\sigma_{\text{lim}})_k}; \quad k = \frac{\tau_{\text{lim}}}{(\tau_{\text{lim}})_k} \]  

(8)

where: \( \sigma_{\text{lim}} \) or \( \tau_{\text{lim}} \) – limit stress values for smooth sample; \( (\sigma_{\text{lim}})_k \) or \( (\tau_{\text{lim}})_k \) – limit stress values for element with concentrator.

5. Strength for variable load strength

In real conditions for the individual elements of a complex design are valid the variable loads (figure 5), amending cyclically over time.

![Figure 5. Types of variable stresses.](image)

In analyzing the loading of the elements of the cutting tools, it is necessary to take into account the three groups of cyclical stresses systematized by some authors.

a) stresses which amend itself in an asymmetric cycle (figure 5 b-d)

The ratio of the minimum stress on the \( \sigma_{\text{min}} \) cycle to the maximum stress \( \sigma_{\text{max}} \) taken with their signs is called asymmetry factor of the cycle and is marked with the letter \( r \), equation (9):

\[ r = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}} \]  

(9)

On figure 5 is marked average stress \( \sigma_m \), and a stress amplitude with \( \sigma_a \), equation (10):

\[ \sigma_m = \sigma_{\text{min}} + \sigma_a; \quad \sigma_{\text{max}} = \sigma_m + \sigma_a; \quad \sigma_a = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2} \]  

(10)

At asymmetric cycle – \( \sigma_m \neq 0; \ \sigma_m \neq \sigma_a; 0 < r < 1 \).

As a particular case of the asymmetric cycle, sub-points b) and c) can be considered.

b) stresses which amend itself in a symmetrical cycle (figure 5 a)), and for this cycle \( r = -1 \), since \( \sigma_{\text{max}} = \sigma_{\text{min}}; \ \sigma_m = 0 \), equation (11):

\[ \sigma_a = \sigma_{\text{max}} = -\sigma_{\text{min}} \]  

(11)

c) stresses which amend itself in a pulsating cycle (figure 5 c))

For this cycle, equation (12):

\[ r = 0; \ \sigma_{\text{min}} = 0; \ \sigma_{\text{max}} = 2\sigma_a; \ \sigma_m = \sigma_a = \frac{\sigma_{\text{max}}}{2} \]  

(12)
The stresses caused by the pulsating load cycle are characteristic of the operation of the cutting tools in view of the pulsating change in cutting forces and at continuity of the process.

6. Conclusions
For the correct strength calculation of complex design of tools, it is necessary:
- Detailed analysis of load on individual elements;
- Accurate determination of the nature of the load;
- Using accurate results are cutting forces, friction forces, and other.
Strength studies must necessarily pass through reporting of stress concentrators abounding in the design due to the complexity of the load patterns.
Simplifying load patterns using the principles of mechanics reduce the authenticity of the results and make them in most cases unsuitable.
When conducting simulation analyzes using CAE design systems directed at cutting tools, the places leading to inaccuracies of the results obtained are the connections and contacts between the individual elements of the design.

7. References
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