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BORING HEADS DESIGN – A GENERALIZED APPROACH

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***Abstract* —** The paper presents the representative model of the boring heads obtained from the generalized model of the cutting tool. The model contains axle and hole type surfaces, some of the edges having adjustment facilities. By particularization of the representative model of the boring heads, a large range of constructive solutions could be obtained. The best boring head for a specific need can be designed after studies and simulations done in conjunction with different optimization criteria. Studies on stress analysis of boring heads, clamping system analysis (done by the elasticity of the tool body) and cutting forces (in order to design a dynamic balanced boring head) are presented in the paper.

***Keywords*—** Boring head, chamfer, cutting tools model, reamer.

I. INTRODUCTION

BORING tools are general considered as the best solutions for manufacturing accurate holes of a large range of sizes and configurations and for different work pieces materials [1]. Companies that produce boring heads develop solutions that enable the obtaining of high accuracy and productivity. There is an increased trend towards the design of combination boring tools (several cutting edges) and also of modular tools whenever is possible [2]-[10].

In order to discover new constructive solutions and recognize the known ones, we started the study from the constructive and cinematic model of the generalized cutting tool. The generalized model consists of an ideal tool body with several stages that can present multiple movements and regulation possibilities, as well as active cutting edges with different shapes and positions [11].

The paper presents a representative model of boring heads, obtained through a first level of customization of the generalized model of the cutting tool.

Constructive solutions of boring heads can be obtained by a creative customization (second level of customization) of the representative model of the boring heads.

In order to optimize the shape of boring heads from the dynamical balance point of view, we have developed the model of the cutting forces related to the representative model.

The most interesting constructive solutions were optimized through several analyzing criteria and perspectives.

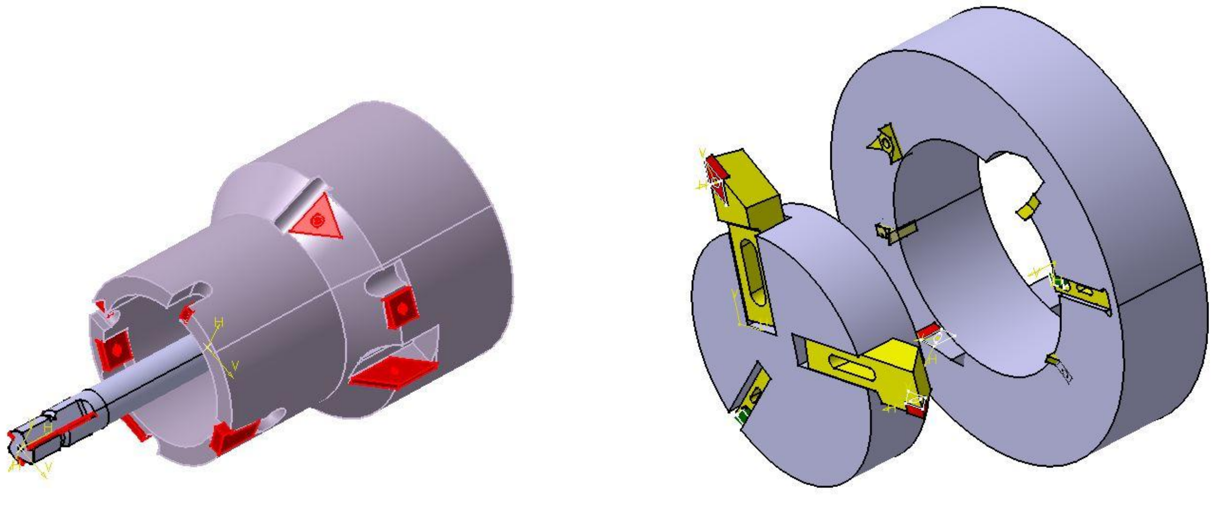

Fig.1. Representative model of boring heads with inserts

II. REPRESENTATIVE MODEL OF BORING HEADS WITH INSERTS

The representative model of boring heads with inserts consists of several cylindrical and conical bodies placed on the same axis (z axis) as in Fig. 1. The main shape of the tool body can be of either the axle type or the hole type. On the cylindrical and conical shapes, there are placed inserts with a cutting role and pads with the role of guiding the cutting tool into the hole. The cutting inserts can be placed on the cylindrical and conical shapes in radial position or in tangential positions (the tangential inserts can be placed on the frontal part or on the cylindrical and conical shapes). The body rotates around the z-axis (as main movement) in order to perform the chipping process and translates along the same z-axis with the aim of bringing new raw material in front of the inserts [12]. Analyzing the representative model of boring heads, we can underline the classification possibilities and the constructive solutions related with each constructive criterion (Table I).

TABLE I
ANALYZING CRITERIA OF THE BORING HEADS REPRESENTATIVE MODEL

Constructive Criterion	Constructive solution - examples
Main shape type	Axle type, hole type
Edge position	On the cylindrical shape, on the frontal shape, on the conical shape, on multiple shapes
Component parts	Monoblock, with brazed inserts, with changeable inserts fixed on the tool body, with changeable inserts fixed on intermediate rigid elements, with changeable inserts fixed on intermediate adjustable elements.
Position of the active elements	Radial, tangential on the frontal shape, tangential on the cylindrical shape
Insert shape	Triangle, square, rhomb, special
Clamping system	Using tool body elasticity, with central screw, with wedge
Edge number	one, two,…

III. MODERN CONSTRUCTIVE SOLUTIONS

In the following, we shall present some constructive solutions obtained by particularization of the representative boring head. These are:

1) *Reamer with multiple edges insert clamped on the frontal face as in Fig. 2;*
2) *Reamer with tangential inserts clamped on the cylindrical face as in Fig. 3;*
3) *Reamer with inserts clamped by the elasticity of the tool body on the frontal face as in Fig. 4;*
4) *Reamer with axial adjustable intermediate body as in Fig. 5;*
5) *Chamfer with axial multiple edges inserts as in Fig. 6;*
6) *Chamfers with adjustable intermediate body with radial or tangential inserts as in Fig. 7;*
7) *Chamfer with adjustable intermediate body and insert clamped by the elasticity of the tool body as in Fig. 8.*

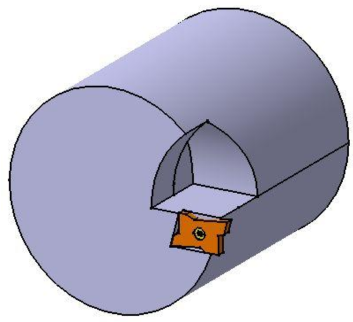

Fig.2. Reamer with multi-edges insert placed on the frontal face

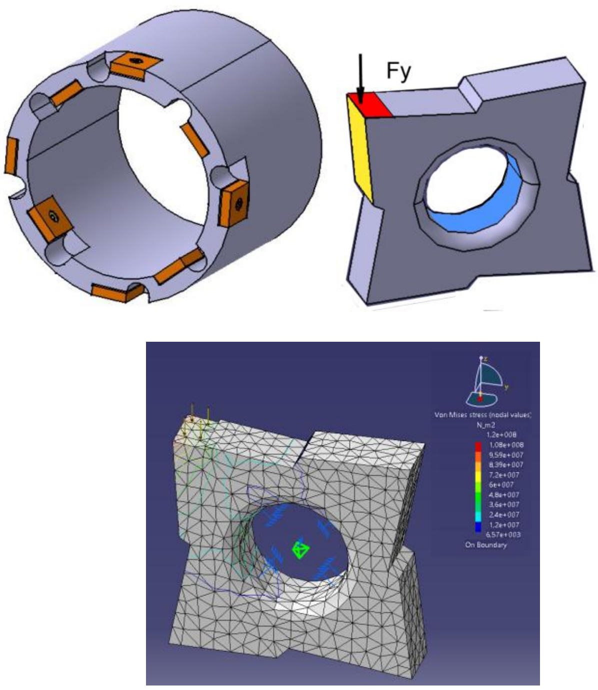

Fig.3. Reamer with tangential inserts clamped on the cylindrical face; Insert shape and finite element method analysis

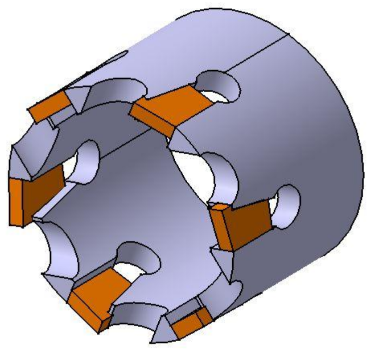

Fig.4. Reamer with inserts clamped by the elasticity of the tool body on the frontal face

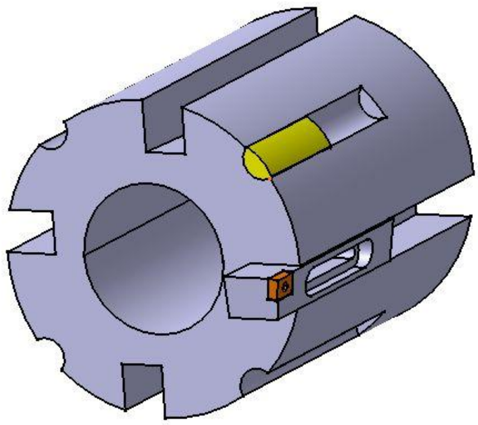

Fig.5. Reamer with axial adjustable intermediate body

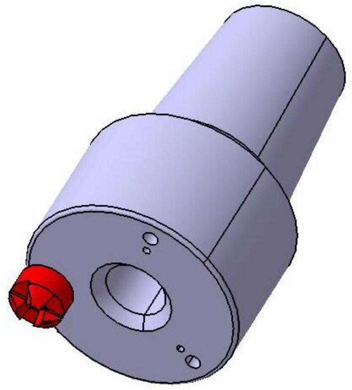

Fig.6. Chamfer with axial multiple edges insert

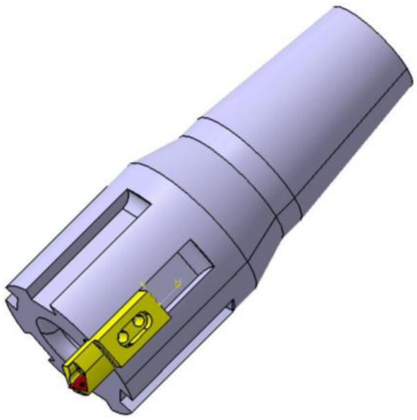

Fig.7. Chamfer with adjustable intermediate body with radial or tangential inserts

IV. OPTIMIZATION OF THE NEW SOLUTIONS

To achieve the most appropriate boring head for a specified application, analysis can be made according to different optimization criteria.

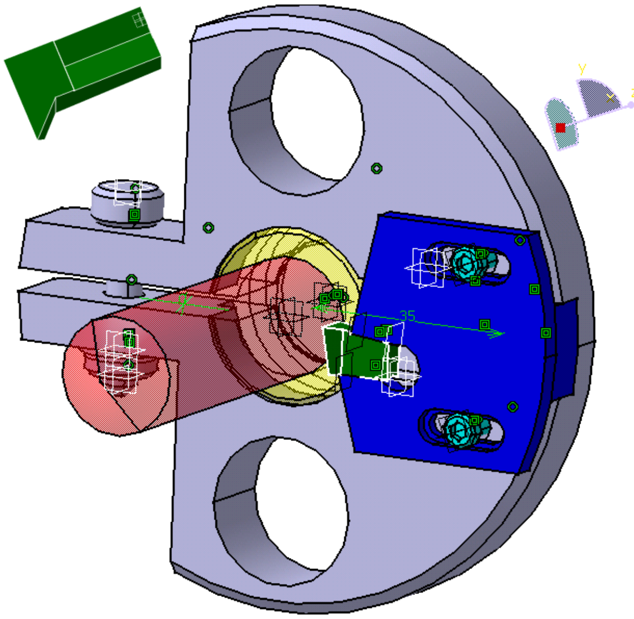

Fig.8. Chamfer with adjustable intermediate body and insert clamped by the elasticity of the tool body

Examples of optimization criteria are:

1) *material economy;*
2) *uniformity of stress with minimal value of the stresses from different perspectives: cutting tool parameters, material with high performance, the type and form of the clamping system etc.*
3) *minimum and uniform forces determined by insert position;*
4) *modularity;*
5) *ability to maintain cutting characteristics and power;*
6) *large utilization areas from the efficiency perspective.*

There are several aspects that can be optimized: insert shape, clamping system and tool body. One of the optimization method starts with the cutting force estimation. After that, the studies can continue with the static or/and dynamic equilibrium analysis and/or the finite element method analysis.

In the following, we shall present some studies on:

1) *The clamping system made by the elasticity of the tool body;*
2) *The design of chamfer inserts; analysis from the stress state perspective.*

A. Generalized Force and Moment Model for boring tools

The aim of a generalized force model is the rapid estimation of the cutting forces and moments for different particular constructive solutions of boring heads.

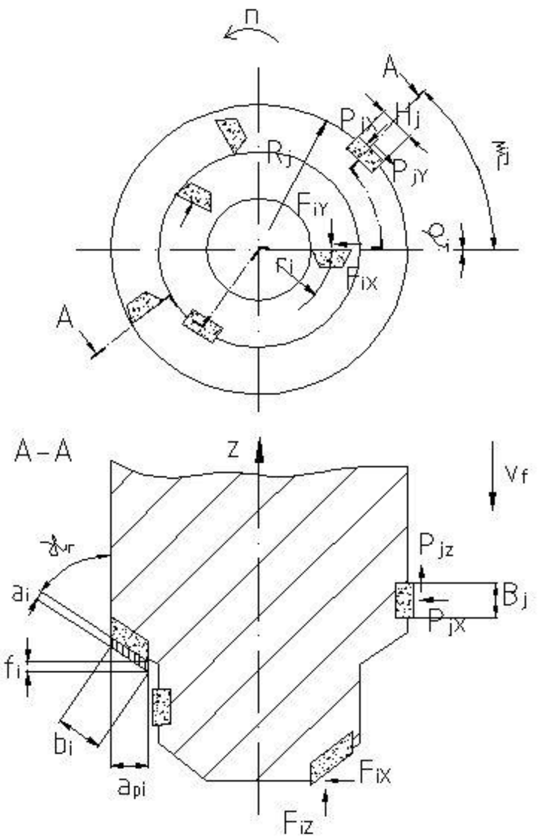

Fig. 9. Forces model for the representative tool

The value and variation of the forces depends on the insert number and their position on the tool body (on the frontal, cylindrical, conical shape, etc.). The loads that act on the boring head are sums of the forces that arise during boring on the inserts added to the sum of the reaction forces that appear on the guide pads as in Fig. 9 [12].

The geometrical parameters are:

1. i=1,…,n – number of the cutting inserts;
2. j=1,…,m – number of the supports and guide pads;

The inserts can be placed on the cylindrical and conical shapes. For each insert there can be defined:

1. r_i - radius of the middle edge position (mm);
2. φ_i - angular position of the edge (degrees);
3. v_{ci} - insert speed (m/min);
4. κ_i - insert cutting edge angle (degrees);
5. γ_i- insert rake angle (degrees);
6. f_i - feed per tooth (mm);
7. a_{pi} - depth of cut per tooth (mm);
8. a_i - chip thickness (mm);
9. b_i - chip length (mm).

Support and guide pads can be placed only on the cylindrical shape of the tool. For each pad there are defined:

1. R_j – radius of the pad position (mm);
2. ξ_j - angular position of the pad (degrees);
3. B_j – width of the guide pad (mm);
4. H_j – high of the guide pad (mm).

Manufacturing parameters are:

1. n – spindle speed (1/min);
2. v_f – feed speed (mm/min);

Other parameters are:

1. F_{xi}, F_{yi}, F_{zi} - components of the cutting force per insert (N);
2. P_{xi}, P_{yi}, P_{zi} - components of the contact force per pad (N);
3. F_f – feed force (N);
4. M_c - torque (Nm);
5. k_{ci} - specific cutting force for each chip type cut by an insert (MPa);
6. $k_{c\ 0.4}$ - specific cutting force (MPa) for f_i =0.4 (mm);
7. k_{cfzi} - specific cutting force for feed per edge (MPa);
8. k - specific contact force (MPa);
9. μ – friction coefficient.

The tangential cutting forces F_{iy} and the friction forces on the support and guide pads P_{iy} causes the torque M_c. The expression of the torque is:

$$\mathbf{M_c = \sum_{i=1}^{n} r_i \cdot F_{yi} + \sum_{j=1}^{m} R_j \cdot P_{yj} = = \sum_{i=1}^{n} r_i \cdot a_{pi} \cdot f_i \cdot k_{ci} + \sum_{j=1}^{m} R_j \cdot B_j \cdot H_j \cdot k \cdot \mu} \tag{1}$$

The specific cutting force $k_{c\ 0.4}$ was established in an experimental way [8] for a chip thickness of a=0.4 (mm), a rake angle of γ=+6^o and κ_r =90^o. Some examples are presented in Table II.

In reality, the chip can have another thickness and the cutting tool can present another rake angle. These parameters affect the value of the specific cutting force. The corrections of the specific cutting force values are made with the following expression:

$$\mathbf{k_{ci} = k_{c0.4} \cdot \left(\frac{0.4}{f_i \cdot \sin\kappa_i} \right) \cdot \left(1 + \frac{6 - (\pm \gamma_i)}{100} \right)} \tag{2}$$

The axial forces F_{iz} and the friction forces on the support and guide pads P_{iz} give rise to an opposite feed force F_f.

TABLE II.

SPECIFIC CUTTING FORCE FOR DIFFERENT WORK PIECE MATERIALS [8]

Material		$k_{c\ 0.4}$ (MPa)
Un-alloyed steel	0.15 % C	1900
	0.15 % C	2100
	0.15 % C	2250
Low alloy steel	Non hardened	2100
	Hardened and tempered	2600
	Hardened and tempered	2700
	Hardened and tempered	2850
Grey cast iron	Low tensile strength	1100
	High tensile strength	1500

The expression of this force is:

$$\mathbf{F_f} = \sum_{i=1}^{n} \mathbf{F_{zi}} + \sum_{j=1}^{m} \mathbf{P_{zj}} = \sum_{i=1}^{n} \mathbf{a_{pi}} \cdot \mathbf{f_i} \cdot \mathbf{k_{cfzi}} \cdot \mathbf{sin\kappa_i} + \sum_{j=1}^{m} \mathbf{B_j} \cdot \mathbf{H_j} \cdot \mathbf{k} \cdot \boldsymbol{\mu} \quad (3)$$

where the "specific cutting force for feed per edge k_{cfzi}" can be computed with the expression [8]:

$$\mathbf{k_{cfzi}} = \mathbf{k_{c0.4}} \cdot \left(\frac{\mathbf{0.4}}{\mathbf{f_i} \cdot \mathbf{sin\kappa_i}}\right)^{0,29} \cdot \left(1 + \frac{6 - (\pm\gamma_i)}{100}\right) \quad (4)$$

The sum of the radial forces F_{xi} that arises on the cutting inserts of a symmetric boring heads is theoretically equal to zero. Otherwise, the hole will result at a larger diameter.

In the case of asymmetrical boring heads (especially for deep hole boring) when the condition of zero radial forces sum cannot be fulfilled, the support and guide pads are used in order to balance the boring head radial load. The condition is:

$$\sum_{i=1}^{n} \vec{\mathbf{F}}_{xi} + \sum_{j=1}^{m} \vec{\mathbf{P}}_{xj} = \mathbf{0} \quad (5)$$

"The friction coefficient μ" between the support and guide pads and the raw material is difficult to be exactly established. In this case, the previous equation cannot be solved with precision. The solution is to design a boring head at which the resultant of the radial forces should fall between the support pad and the guide pad, however bringing closer to the support pad can determine an oversize hole.

The dividing of the large cutting edge into several cutting edges placed in different positions on the tool body reduces the values of the radial forces on the guide pad.

B. Clamping system done as a result of the elasticity of the tool body

The clamping system by the elasticity of the tool body is very economic from the space point of view. It requires precise shapes of the elements in order to assure the safe clamping and dynamic stability. Our purpose was to establish the optimal shape of the inserts and of the pocket [13]. The system of coordinates is the cutting one where y is the direction of the main cutting force. The solving of the equilibrium equations written for the forces on the main cutting force direction y and on the tool clamping direction z as in Fig. 10 indicates that the inserts and tool holders must have special gradients in order to assure a safe clamping. Angle θ_1 describes the inclination of insert support surface and angle θ_2 the inclination of the insert clamping surface. The best values are θ_1=2…15° and θ_2=2…6°.

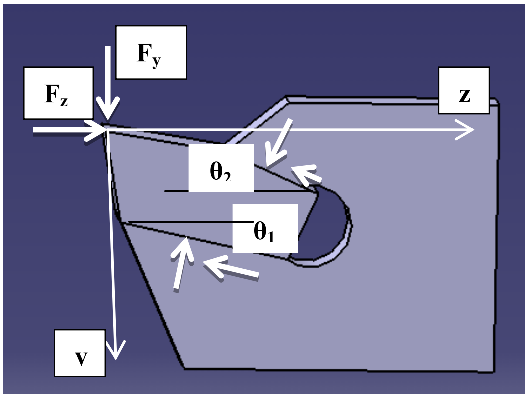

Fig.10. Equilibrium analysis of the clamping system realized due to the elasticity of the tool body

Another study was made about the tool body. Several models were design, each of then having a different shape of the insert pockets in the curve area. Some on them were round with radius range between (1,1…1,8)*h_i (where h_i is insert high). Some others had splits with different lengths. The finite element method indicates the stress state in each case as in Fig. 11. The study allowed the choice of the best solution.

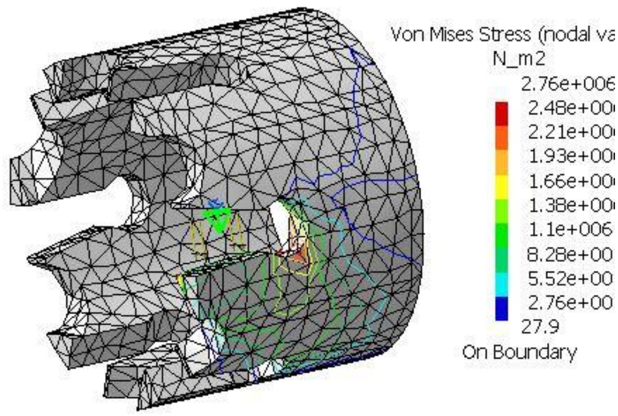

Fig.11. Stress state analysis of the reamer tool body with pockets for the inserts clamped by the elasticity of the tool body

C. The design of chamfer inserts; analysis from stress state perspective.

The need of high productivity determines the design of complex tools that can manufacture complex shapes during the same operation. We analyzed a complex tool that contains both a bore or reamer (axle type) and a chamfer body (hole type). In this case, the chamfer insert must have a special form with the active part like a bill.

In Fig. 8 the insert for chamfering is placed radial and clamped due to the elasticity of the tool body. The shape of the insert and the Finite element method analysis is presented in Fig. 12.

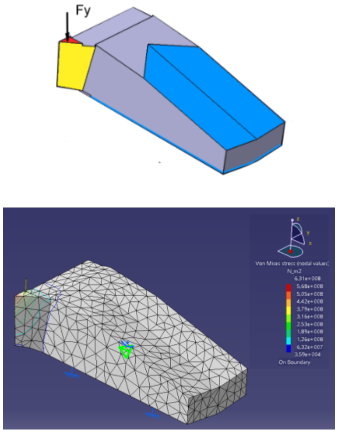

Fig.12. Stress state analysis of a radial chamfering insert clamped due to the elasticity of the tool body

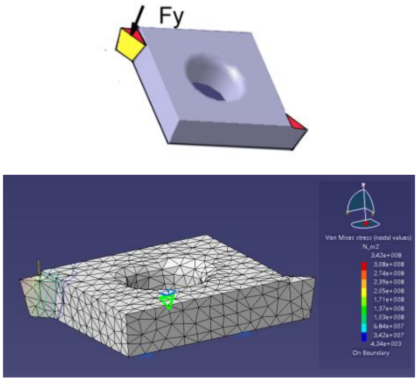

Fig.13. Stress state analysis of a radial chamfering insert clamped with screw

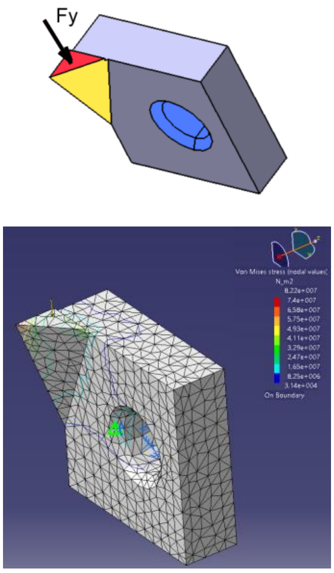

Fig.14. Stress state analysis of a chamfering insert placed tangential on the frontal shape

On the chamfer body the insert can have the shape as in Fig. 13, positioned on the radial direction.

Another solution of the insert is shown in Fig. 14. It is placed tangential to the frontal shape of the tool body.

The finite element method allows the estimation of the stress state and the deformations in every case. The cutting force was 800 (N) and the clamping force – 300 (N). The results are:

1) *For the chamfering insert clamped due to the elasticity of the tool body – Von Misses maximum stresses – 549 (MPa); Maximum deformation – 0.027 (mm);*
2) *For the radial chamfering insert– Von Misses maximum stresses – 342 (MPa); Maximum deformation – 0.0054 (mm);*
3) *For the tangential chamfering insert on the frontal shape - Von Misses maximum stresses – 74 (MPa); Maximum deformation – 0.0038 (mm);*

Analyzing the results, we can observe that the tangential insert placed on the frontal shape is the best solution.

V.CONCLUSION

This paper presents a methodology for cutting tools design. It starts from the representative tool for a class of tools (in our study for boring heads). Through customization the designer can get a wide range of tools. Choosing the best for a given application can be done using analysis as presented in this paper: prediction of the forces that lead to an optimal location of the inserts on the tool body, clamping systems analysis, inserts designing, development of modular solutions etc.

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