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CONTRIBUTION ON THE DESIGN OF THE SIDE AND FACE MILLING CUTTERS WITH INDEXABLE INSERTS

Brindasu Paul Dan[1], Beju Livia Dana [1]
"Lucian Blaga" University of Sibiu
dan.brindasu@ulbsibiu.ro; livia.beju@ulbsibiu.ro

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Abstract: The paper analyses a wide range of modern side and face milling cutters in order to realise a constructive optimization of them. The first step was the establishing of the main functions of the product. A tree diagram offers new ideas for innovative solutions. The second step was the design of side and face milling cutters. The problems that were taken into account were the clamping forces, the reaction forces and the stress state in the tool body and in the insert. The conclusions allow the optimization of the design of the side and face milling cutters.

1. INTRODUCTION

The new tool materials, current manufacturing technologies and the functions that the current tools must meet, have led to major changes of the tools shapes. In particular, the side and face mills which are high productivity tools with several teeth, left the mono-block shape. The current trend is to build tools with changeable inserts which are fixed on the tool body or on intermediate elements.

This paper aims to provide a method for obtaining the optimal shape of a side mill starting from the functions they must fulfilled. At the beginning, a research of the main side milling shapes was done, the results being presented in a tree diagram. Another analysis was focused on the types of function that must be met by a tool [3]. After that, the most interesting elements was studied. These were: the clamping forces, the reaction forces and the stress state in the tool body and in the insert. The results of these studies allow the side mills design optimization.

2. CONSTRUCTIVE SOLUTIONS OF THE SIDE AND FACE MILLING CUTTERS

Side and face milling have had a remarkable evolution in the last years due to the attentive studies related to these products [1,2]. A study of these cutting tools from the value analysis perspective allows the obtaining of existing solutions (realised by specialized cutting tools companies) and of other original technical solutions. In figure 1, a tree structure that shows the technical solution of side and face milling cutters (produced by SANDVIK and ISCAR Companies,). is presented as a result of an original creative study based on some criteria considered important from the value analysis point of view. The classification of these mills was made according to the material type, of the active part, construction type, cutting area, inserts position, insert positioning, insert clamping system, insert pocket position and fixation area. The study shows the main analysing criteria and the most interesting solutions for each criteria. Such an analysis allows the obtaining of the known solutions but also of new ones by stimulating the creativity of the designers.

Figure 1.a Tree structure of the side and face milling cutters [4,5]

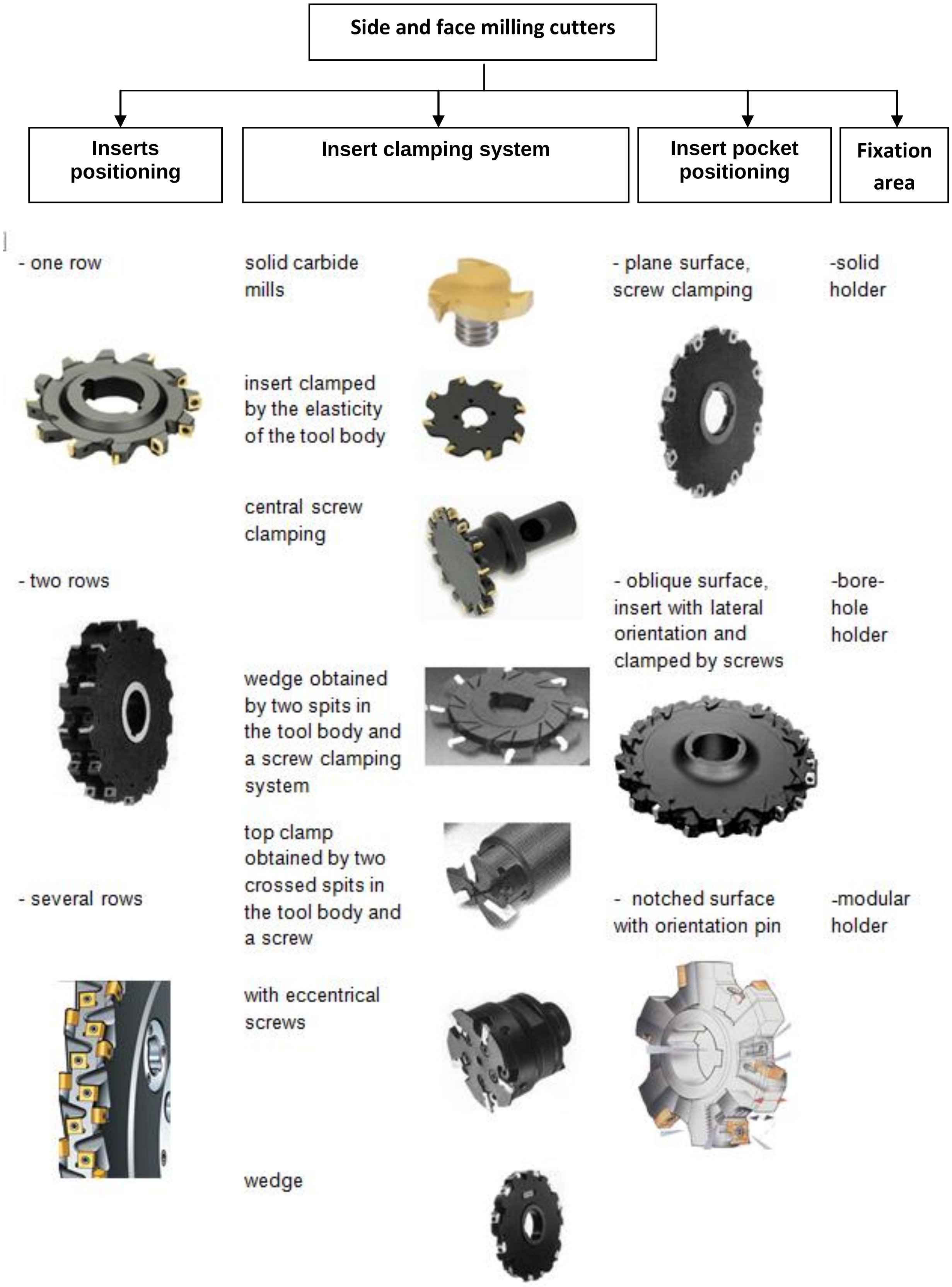

Figure 1.b Tree structure of the side and face milling cutters [4,5]

3. MAIN FUNCTIONS OF A CUTTING TOOL

An optimal design should start from the functions which must be met by a product. In the case of a cutting tool, the main functions are:

THE PRODUCTIVITY FUNCTION. The new cutting tools materials allow more intensive manufacturing processes, that determine higher volumes of manufactured material in the unity of time. At the same time, the new clamping systems are more efficient because they determine shorter auxiliary time necessary for tool reconditioning. This is why the productivity of new, modern tools is much greater than that of classical tools.

THE PRECISION FUNCTION. The precision of the cutting tools with indexable inserts is determined by the precision of all cutting tool elements. Clamping systems are carefully designed and manufactured in order to assure a high precision, reability and safety. Inserts are produced by specialized cutting tools companies and ordered depending on the necessary precision level.

THE REABILITY FUNCTION. Cutting tools bodies, intermediate elements and clamping elements are made of materials with continuously improved characteristics. The durability, maintainability and reconditioning capacity are greater than those of classical milling cutters and the higher prices of modern tools are quickly damped in time.

THE MANUFACTURING TIME FUNCTION. The manufacturing time criterion is favourable for new cutting tools because, at present, new modern software in design, processes simulations, manufacturing preparation and manufacturing processes is used. The existing databases, computing facilities, modularised principles allow an easier and more rapid design and manufacturing implementation.

THE MANUFACTURING POSSIBILITIES FUNCTION. The manufacturing possibilities function is important in the case of specialized companies that use the proper, typical elements. The slitting inserts and the insert pockets in the tool body are very well studied and modularly designed for different constructive solutions. The optimal constructive solutions are developed from one generation of tools to another on the basis of the development of economic function.

THE MATERIAL ECONOMY FUNCTION.The material economy criterion is another aspect taken into account when tackling the cutting tool domain (from the active area to the clamping one) in a unitary and generalised way. Things are doing better in this field too. The new optimization software (CAE – computed aided engineering) is more efficient as regards the time and information level than the experimental methods (photoelasticity, holography, Moire analysis). The inserts shape (with greater depth) and insert position (the tangential one is preferred) allows an optimal stress state and greater durability.

THE ENERGY FUNCTION. The energy criterion is taken into account in designing the active area in order to obtain thick chips, which determine a small level of energy consumption.

THE INFORMATIONAL FUNCTION. The informational function is one of the most important one. Correct and complete databases that allow the storing of huge volumes of information must not be redundant. The use of these databases and of specific software (EXCELL, CATIA, ProEngineering) determines a rapid design of a new dimensional range. Due to the modularisation concept, new constructive solutions can be obtained easily with the help of the informational structures presented before. .

THE ERGONOMICAL AND AESTHETIC FUNCTION.The dimensions of the new generation of cutting tools are smaller because of the new material and of the three-dimensional design, finite element method analysis etc. The shape and dimension of the cutting tool are correlated with user possibilities (physical, psychic and intellectual).

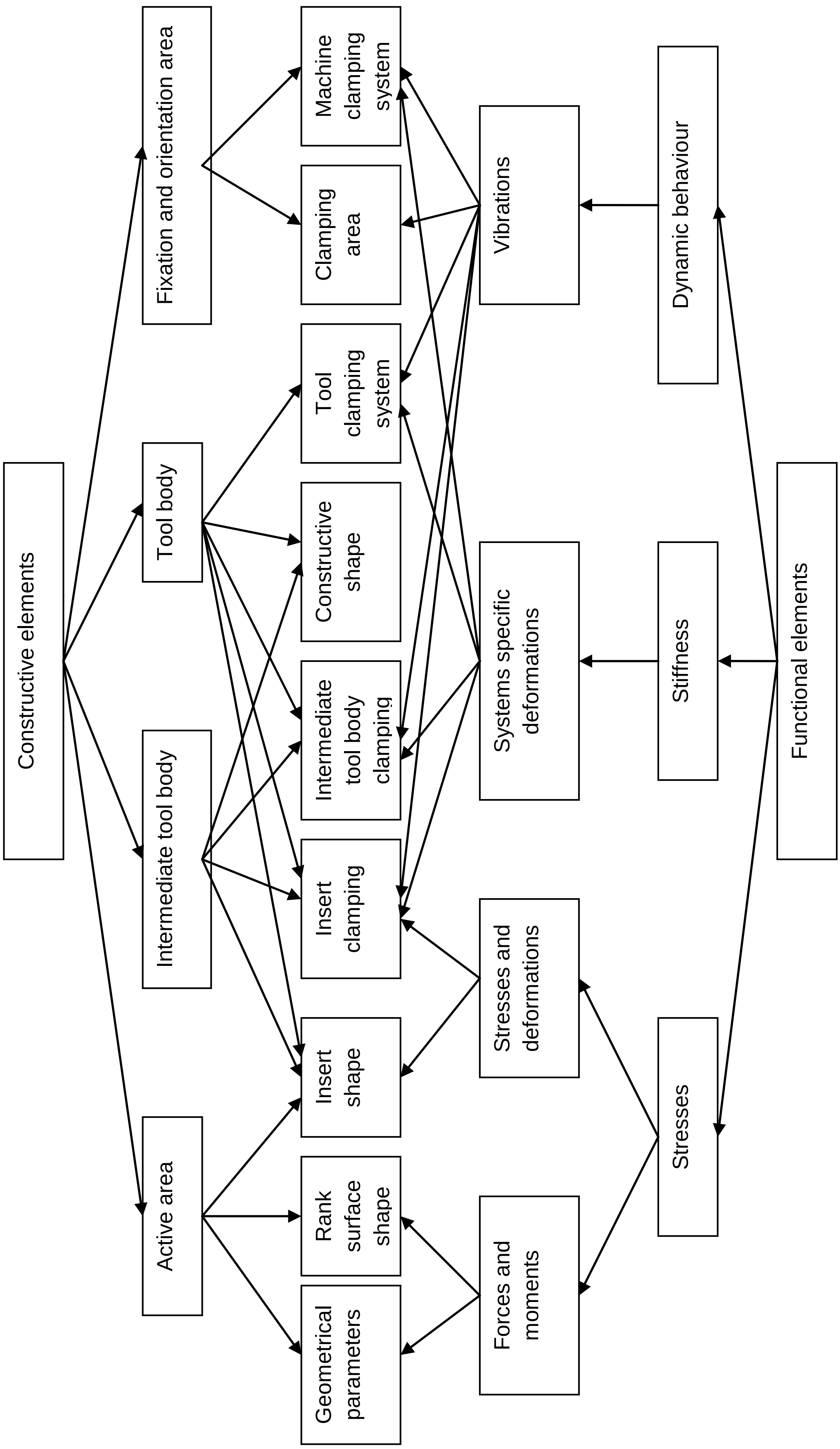

Figure 2. Modular framework connection for indexable inserts tools optimization

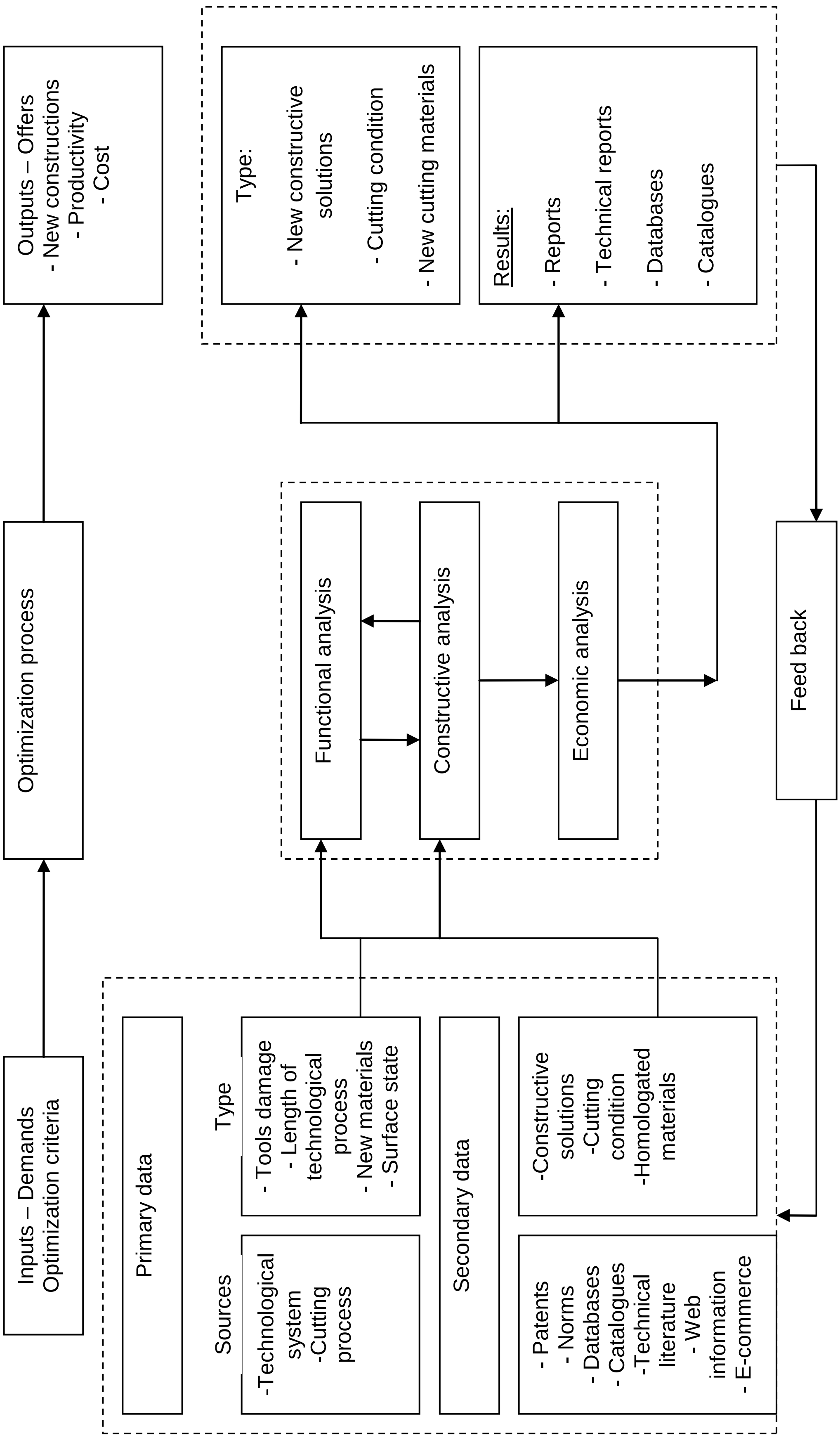

Figure 3. Information flow in cutting tools optimization

The shapes of these tools are aesthetical and protect the worker at the same time (round corners, attractive colours and shapes).

The Ecological FUNCTION. Because of the high reliability, these tools are part of the durable products category. This means that they are good for the environment.

4. OPTIMIZATION STUDY ON THE SIDE AND FACE MILLING

A holistic image of the optimization process, including constructive-functional links and information flows for the side and face milling optimization, is presented in figures 2 and 3.

4.1. INSERT CLAMPING SYSTEMS

The most usual clamping systems for the side and face mills are the following (fig.1):

- solid inserts – tool body and inserts form one object;
- a clamping system realized by the elasticity of the tool body ;
- a wedge realized by two spits in the tool body and a screw clamping system;
- top clamp system realized by two crossed spits in the tool body and a screw clamping system.

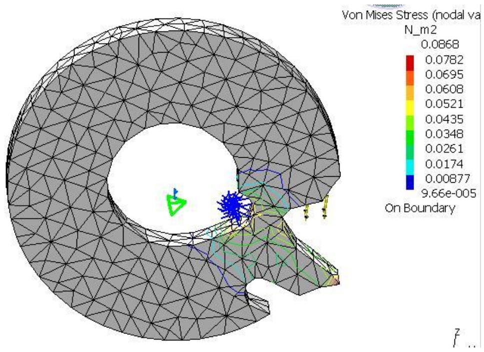

Figure 4. Finite element method analysis for a single body for the side and face mill

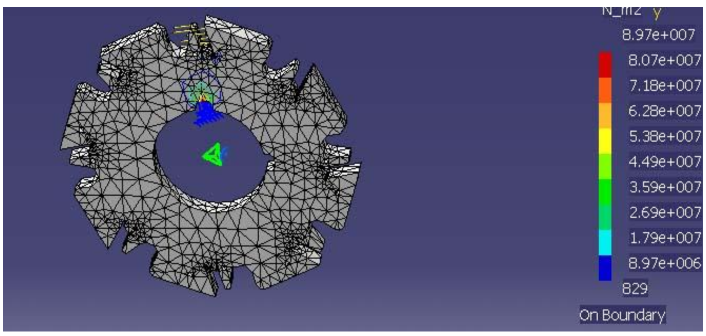

Figure 6. Clamping system with wedge realized by two spits in the tool body and a screw clamping system

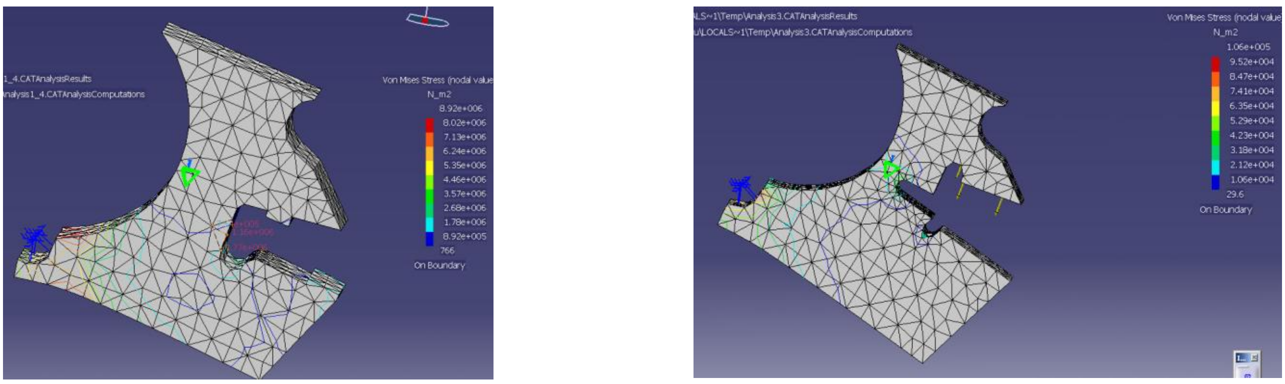

Figure 5. Stress state in the side and face milling bodies in the insert clamping system due to the elasticity of the tool body (a- clamping area ends with a round area; b- clamping area ends with a split that increases the elasticity of the tool body)

4.2. CUTTING TOOL BODY SHAPE

The milling body was analysed using the finite element method in order to underline the importance of the holes between teeth, milling core and wedge trench necessary to assure the stability and reliability of the cutting tool (fig.4).

For the side and face milling tools with inserts clamped by the elasticity of the tool body, it's very important to design the clamping area in such a way that it will assure minimal stresses in the tool body (fig. 5).

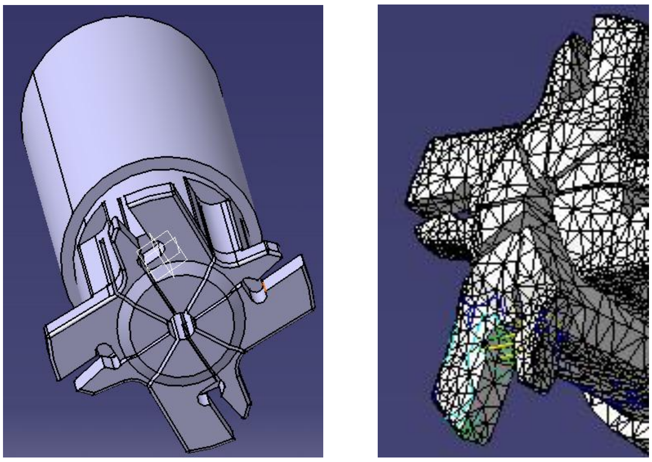

Figure 7. Clamping system with top clamp realized by two crossed spits in the tool body and a screw

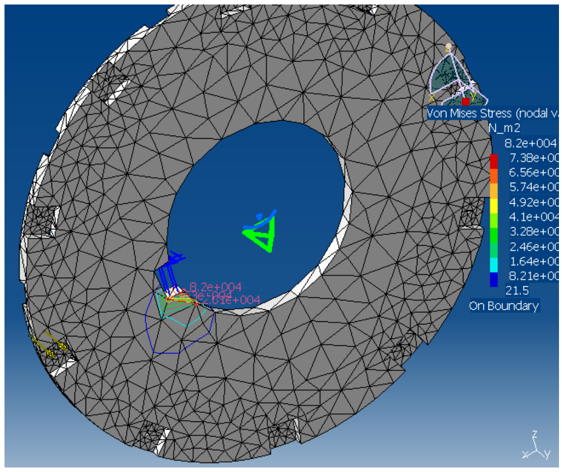

Figure 8. Finite element method analysis for face milling with tangential inserts

From the stress point of view, the best constructive solutions of the insert pocket are the following:

- clamping area ends with two round areas;
- clamping area ends with a round area.

Another new clamping system is the wedge system realized by two spits in the tool body and a screw clamping system. This system can be used in intensive manufacturing processes where the forces have a high level. In these situations we can also use side and face mills with a top clamp realized by two crossed spits in the tool body and a screw clamping system (fig. 6). When the radius of the wedge trench is too small and near a hole between two teeth, the stresses in the tool body increase and the tool body can crack.

This is true for side and face mills with a small width and central hole (the milling width is equal with the split width). Here, the position of the wedge trench in relation to the mill teeth is important. In the case of this constructive solution, we recommend for the mill core a value higher than (0.4* d) where d is the central hole diameter. For the mills used for external and internal manufacturing operations, even for a small width, where the insert is clamped by the elasticity of the tool body, the thickness of the mill can be increased in the mill core area (fig.6)

For internal manufacturing the proposed solution is more interesting. It presents a shank and some splits with a length of about (4…5) multiple milling width (fig. 7). The area between the two spits becomes a veritable top clamp. A supplementary screw assures a strong clamp.

These new constructive solutions were verified from the stress state point of view and assure a precise and easy orientation and clamping of the inserts on the tool body

The finite element method analysis (fig. 8) of the side and face milling cutters with alternate tangential inserts shows a stress state which doesn't cause problems in the tool body.)

In order to study the main solutions viewed through the material economy criterion we start by calculating the cutting forces.

Figure 9 shows a comparison between the stress behaviour and deformations for the main constructive solutions described. Here similar loads have been used for all analyzed milling cutters.

The maximum cutting forces calculated with formulas (1..3) are suitable for the machining of a 6 mm width hole. (Tangential force Ft=800 N, Radial force Fr=200 N).

$$F = p\,S_a \quad [N] \tag{1}$$

$$S_a = f_z\,a_p \quad [mm^2] \tag{2}$$

$$f_z = h_m \sqrt{\frac{D}{a_e}} \quad [mm] \tag{3}$$

Where:

- p = specific cutting pressure
- S_a = chip area
- f_z = chip thickness
- a_e= milling radial depth
- $h_m \approx 0{,}08$ (medium chip pressure)
- D = mill diameter
- a_p = chip width

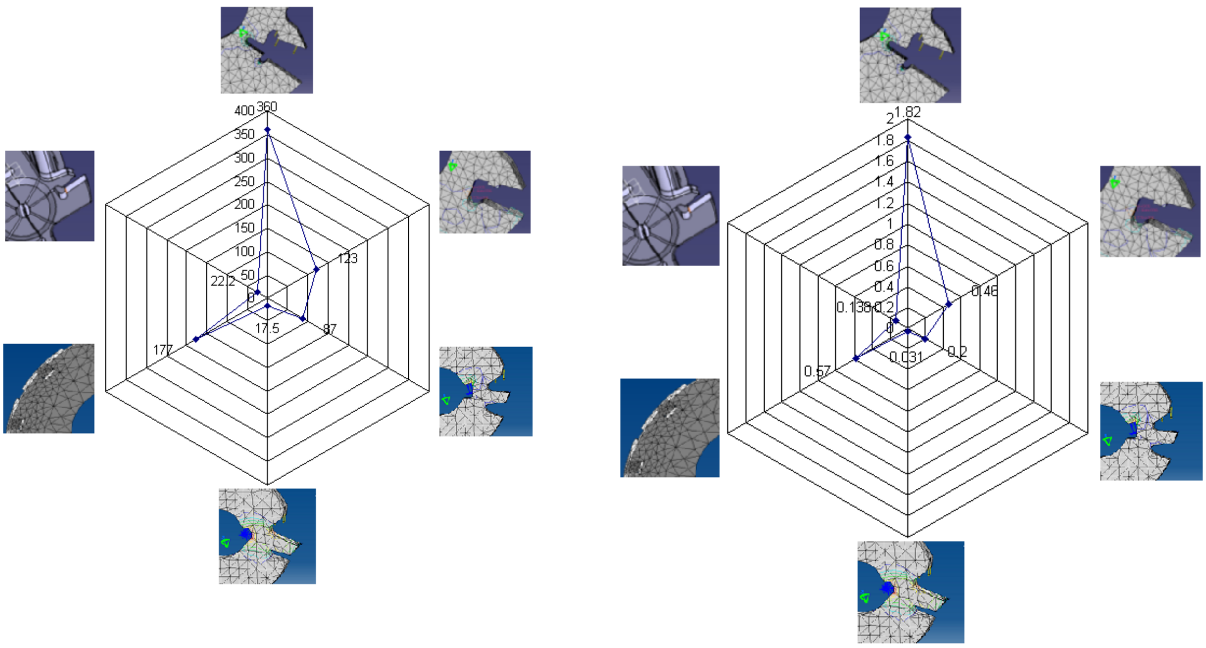

Figure 10. Maximum parameters obtained by finite element method analysis
a - Von Mises stresses [MPa] , b- Displacements [mm]

The software used for the analysis is CATIA V5. The performed study for static loads revealed that in some constructions (fig. 5-b) the maximum stress values appear and this shows that in a dynamic condition at intensive machining there is the danger of breaking them. These solutions remain interesting and modern but it's recommendable to use them only for small milling widths – maximum 4 mm. Other constructive solutions show high stress values (fig. 5-a and 5-b), but they don't exceed the admissible values in a dynamic condition. For other milling cutter types (fig. 4 and 7) the stress values are lower.

It is worthy to note that each element of the fixation area counts. For a solid carbide mill the use of a semi-round wedge trench reduces the stress value 4 times as much as a mill with a rectangular wedge trench.

The displacements keep the same ratio for the chosen solutions (fig. 9-b). The highest displacements (over the limits) appear for the same milling cutter presented in fig. 5-b. It is worthy to note that these displacements are on a circular direction.

This way, we notice that we have to use more optimization criteria in order to find the optimal usability domain for the obtained solutions.

5. CONCLUSION

The performed analysis shows how to obtain flexible, resistant and modern cutting tools by using research methods based on optimizing criteria (material economy).

In the future new constructive solutions will appear because of the material evolution and of new research carried out in the technological field (design and manufacturing). The informational and economic criteria presented by the value theory will lead to new intelligent cutting tools that will probably have a permanent dialogue with machine tools and with the user. The modularization principle will determine the maintaining of valuable solutions (from the design and manufacturing points of view) and their including into new products.

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