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Specialized Screw for Clamping of Cutting Tool Inserts

Karol Vasilko[1] and Zuzana Murčinková[1*]

[1]Faculty of Manufacturing Technologies, Technical University of Košice, 080 01 Prešov, Bayerova 1, SR, Slovakia.

Authors' contributions

This work was carried out in collaboration between both authors. Author KV designed the clamping screw and realized practical applications and testing. Author ZM managed the literature searches and analytical and numerical calculations. Both authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

The paper presents the design of easy-to-use and sophisticated cutting tool insert clamping that is applied for turning tools. The simplified analytical calculation and von Mises stress fields obtained by Finite Element Method are provided. The technical solution of clamping screw is based on the specialized screw head that is of hexagonal-conical shape. The higher axial force in screw arising from the tightening, higher contact pressure clamping the cutting tool insert. The frictional force between screw head and the insert surfaces presses the cutting tool insert into its seating when tightening and helps to get out the insert when un-tightening. The design of clamping specialized screws gives the possibility to use them in integrated cutting tools with two or more cutting tool inserts.

Keywords: Cutting tool insert; clamping; axial force; screw head; contact.

**Corresponding author: E-mail: zuzana.murcinkova@tuke.sk;*

1. INTRODUCTION

Each producer of cutting tool inserts provides the various designs of clamping in cutting tool holder to obtain precise and stabile connection when machining. Mainly, the clamping mechanisms are based on mechanical connection using mainly the screw/s [1-3]. The screw connection can be placed either visibly, i.e. outside, the tool holder, or inside its body when the screw head is protected from forming chips and cutting fluids. The most important property of clamping is its stiffness given by stiffness of screw and thus its reliability [4]. The simplicity and speed of assembling and disassembling are other important properties. In present, it is very important to choose the tool clamping system which adapts to conditions of e.g. the high speed machining [5] or the cryogenics temperatures [6].

Fig. 1 presents selected patents of clamping devices for cutting inserts from 2008-2013. Each mechanism is of more or less complicated design. In Fig. 1, A, the clamping device [7] has two clamping elements (screws) perpendicular to each other. Next technical design [8] (Fig. 1B) needs oblique hole difficult for drilling and special screw. The clamping device [9] (Fig. 1C) intended for cutting-off avoids the screw joint, however it involves special additional device to the opening position for insertion or removal of an insert. Patents [10] (Fig. 1D) and [11] (Fig. 1E) are of similar principle involving the component for tangential contact with inner wall of insert by screw pressure. Mentioned designs need complex shape features either inside tool holder or special elements as separately part of tool holder.

The technical solution presented in paper provides considerable increase in clamping stiffness by use of only one component and, moreover, self-locking clamping using the friction force between the clamping screw head and quite large contact area between screw head and insert.

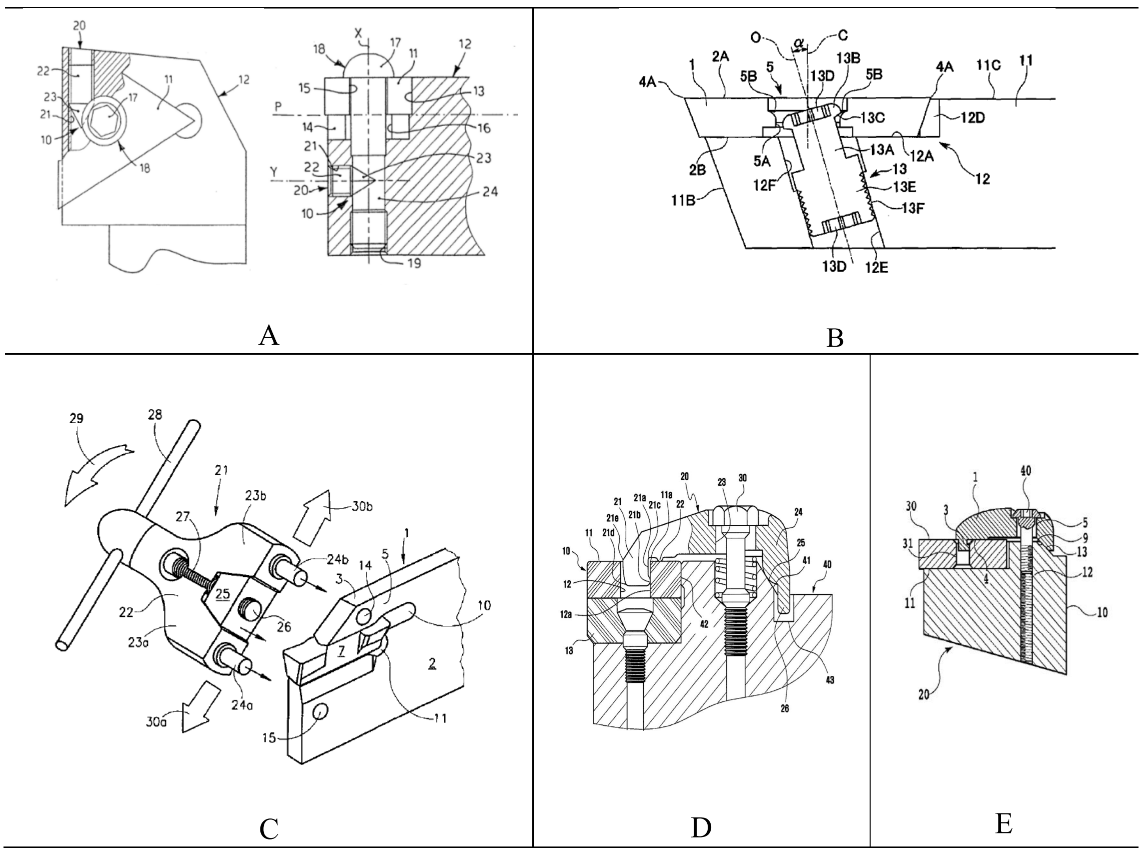

Fig. 1. Selected patents of clamping devices

2. DESCRIPTION OF TECHNICAL DESIGN

The technical solution of the cutting tool inserts clamping is based on the application of one specialized clamping screw of hexagonal-conical shaped head with metric thread along screw shaft and the axis perpendicular to the upper surface of cutting tool insert (Fig. 2). The screw is of normalized metric thread.

The phases of cutting-tool insert clamping are shown in Fig. 3. The bolthole in tool holder body is in vicinity of insert so that the screw head can contact insert from above. The axis of bolthole is perpendicular to the upper and lower tool holder surfaces. In phase *a*, the inclined surface of cutting tool holder is contacted by the rim bolt. Tightening the screw, the second contact appears while the screw shaft is bended – phase *b*. Next tightening causes bending of screw shaft and deformation od specialized screw head. Thus, the surface of the screw head contacts the upper flat surface of the cutting insert and locks insert in seating by the friction force – phase *c*. An inclined surface of tool holder causes increased contact pressure and contact area. Phase *d* is un-wanted phase when the screw is over-tightened and contact is not appropriate. Theoretically, the screw can even achieve plastic deformation.

The final clamping occurs in the phase *c* with the planar contact between the screw head and the insert surfaces. At the same time, the cutting tool insert is being pressed into the seating by the friction force. When the screw is being un-tightening at the opposite direction, the cutting tool insert is being pushed out of the tool holder bed by the friction force.

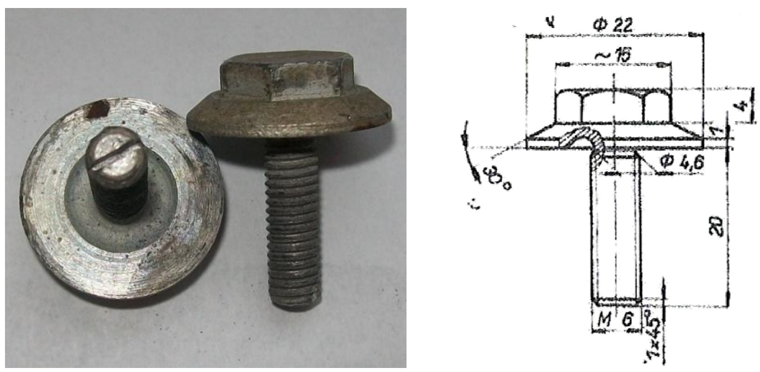

Fig. 2. Design of specialized clamping screws

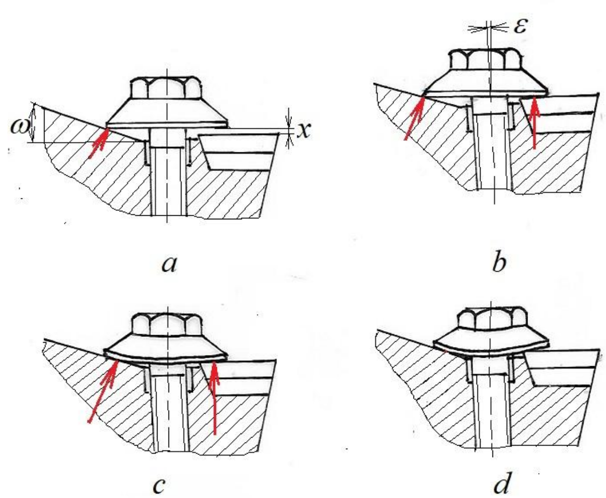

Fig. 3. Individual phases of clamping; a – contact of screw head and a tool holder's back part, b – contact of screw head and surface of insert, c – planar contact, 4 – deformation of screw head when over-tightening

3. ANALYTICAL AND NUMERICAL VERIFICATION

The screw is subjected to torsion in the phase *a* and tension, torsion and bending of screw shaft in phase *b*. In phase *b*, when the slope of screw axis is of angle ε, the both rims of screw head are in contact with tool holder.

For calculation, in phase *c*, the specialized screw head can be simplified as a simply supported beam with the stepped cross-section which is subjected to the screw force. That force causing the bending of specialized screw head, Fig. 4 (the angle of beam position is much larger for better representation). Knowing slope angle of "beam" by using the one of methods for calculation of beam deflection, the axial force F_{ax} of screw and then resulting stress can be calculated.

Final axial force F_{ax}:

$$F_{ax} = F_{ax}^{phase\ c} \tag{1}$$

Axial force in phase *a* is zero.

The axial tension stress in the screw body σ_{ax}:

$$\sigma_{ax} = \frac{F_{ax}}{A_r} \tag{2}$$

where A_r is cross section area of screw shaft for reduced diameter of metric thread.

Based on principal relations of screw connection (more in [12,13]), torsional moment M_T in thread when tightening:

$$M_T = \frac{d_2}{2} F_{ax}.\tan(\gamma + \varphi') \tag{3}$$

where d_2 is mean diameter, γ is helix angle, φ' is reduced frictional coefficient.

The shear stress τ:

$$\tau = \frac{M_T}{W_p} \tag{4}$$

where M_T is torsional moment, W_p is polar modulus.

According to the von Mises theory of failure (maximum-distortion-energy theory), the equivalent stress σ_e is:

$$\sigma_e = \sqrt{\sigma^2 + 3\tau^2} \tag{5}$$

Bending stress σ_b in the screw shaft:

$$\sigma_b = \frac{M}{Z} \tag{6}$$

where M is bending moment, Z is section modulus.

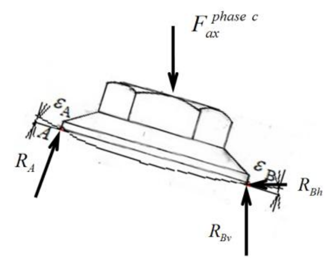

Fig. 4. Screw head deflection

Resulting stress in outer fibres σ_I and σ_{II} of the screw shaft:

$$\sigma_I = \sigma_e + \sigma_b$$
$$\sigma_{II} = \sigma_e - \sigma_b \tag{7}$$

Material of screw is steel with ultimate strength is *Rm*=1100-1250 MPa and yield stress is *Re*=min. 950 MPa. Then the allowable stress using factor of safety 1,2 is σ_{allow} = 792MPa.

Clamping force F_c to overcome the resistance in the threads:

$$F_c = \frac{M_T + M_f}{l} \tag{8}$$

where M_f is frictional moment of bearing surface of nut when tightening, l is wrench arm distance (100 mm). The calculation shows that the maximum clamping force that causes screw shaft failure is 127.8 N taking into account the allowable stress σ_{allow}. The value of clamping force for screw with parameters in Fig. 2 is 42 N what is lower as allowable force 127,8 N.

Fig. 5 provides the von Mises stress distribution in phase *b*, i.e. the screw head contacts the insert face. The values of the von Mises stress distribution correspond with prescribed vertical displacement 0,08 mm (boundary condition), it is a case the inclination angle ω (Fig. 3) of tool holder surface (on the left) is 0º27´. In that position the right rim of screw head contacts the insert face.

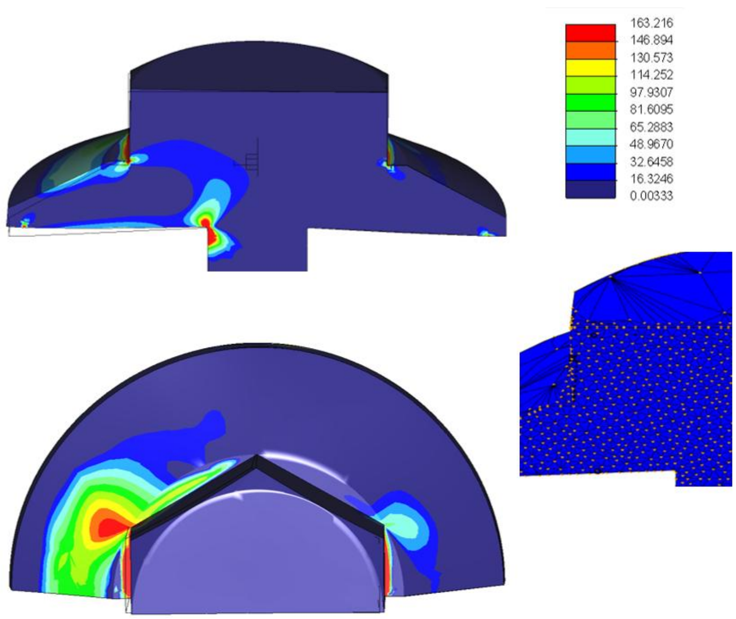

Fig. 5. Von Mises stress distribution and FE mesh

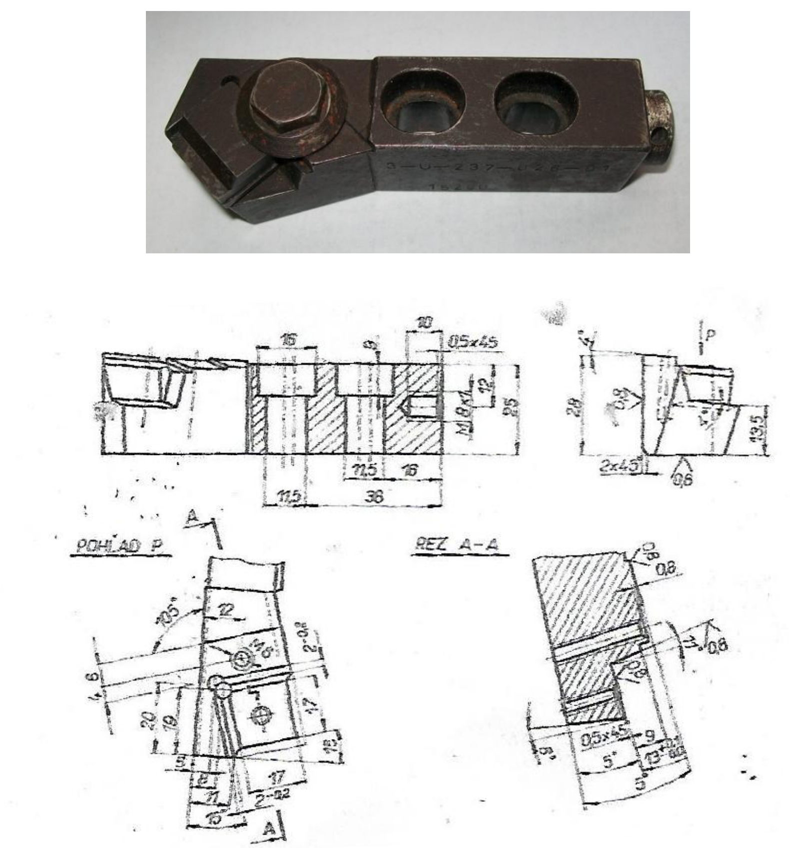

Fig. 6. Tool holder with one cutting insert and its drawing

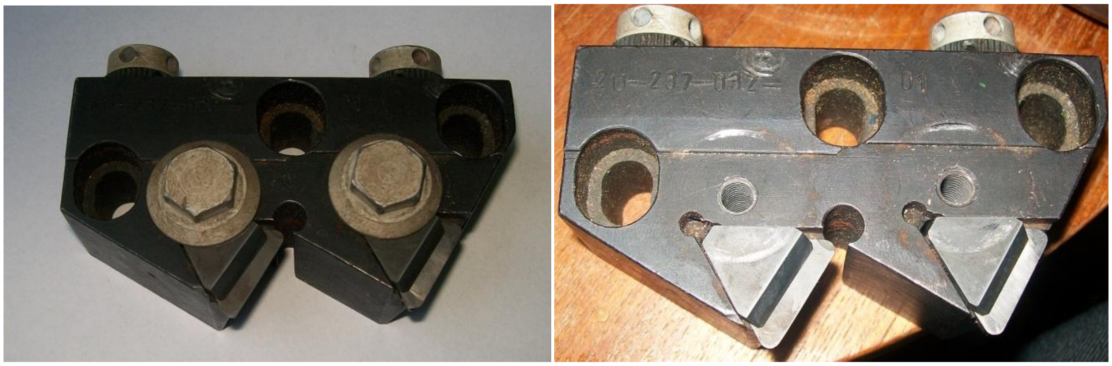

Fig. 7. Integrated cutting tool with two replaceable inserts

The used version of Finite Element Method (FEM) implemented in commercial software is p-version of FEM. The number of three-dimensional solid p-finite elements is 6023, Fig. 5. The maximum achieved polynomial order of shape functions is 7. The achieved convergence of von Mises stress is 3,2%.

Position of the hexagonal screw head in Fig. 5 causes the lower stress values comparing to other possible positions when tightening. If the screw is being tightened, the contact areas and pressures increase on the both sides of the specialized screw head. The contacts are planar.

4. PRACTICAL APPLICATIONS

The solution has been applied to a single-wedge cutting tools (Fig. 6), as well as more complex integrated tools for synchronic machining of multiple surfaces (Fig. 7).

Regarding the simple design, the clamping is suitable for integrated cutting tools, Fig. 7. Visible abrasion areas from the screw head on the inserts and elevated area of the holder in Fig 7, left, prove the reliability of clamping and correct function of clamping system.

5. CONCLUSION

The presented clamping screw provides a simple sophisticated structure to clamp a cutting insert into a tool holder securely and stably. When exchanging the insert, the screw does not to be dismount completely, only un-tighten. Moreover, the simple structure of clamping gives the possibility to design integrated cutting tools with two or more cutting tool inserts. The presented clamping is characterized by self-locking screw/insert contact.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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