DETERMINATION OF THE BORE DIAMETER FOR THREADING WITH CHIPLESS TAPS

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Abstract. The paper presents an analytical methodology for determining the diameter of the workpiece used in thread tapping with chipless taps, with the aim of achieving the required accuracy of the internal thread through cold plastic deformation. The method is based on the assumption of material volume conservation during the deformation process and establishes a relationship for calculating the theoretical workpiece diameter as a function of the thread parameters. Since material deformation is not uniform, a volume correction coefficient, determined experimentally, is introduced. The method enables the calculation of the actual workpiece diameter, taking into account the behavior of the material during deformation. The results can be used to improve thread-forming accuracy and to facilitate the programming and computer-based automation of the calculations.

Keywords: chipless tapping, cold plastic deformation, internal thread forming, volume conservation, workpiece diameter

1. Introduction

Thread forming taps are designed for cold forming threads in ductile materials. These include aluminum, copper, brass, zinc, low carbon steels, and free machining stainless steels. They displace material rather than cut or remove it.

A thread former, however, has no flutes (Fig.1). Instead, it is slightly polygonal in shape and presses the thread profile into the material. This geometry makes the tool more solid and less susceptible to fracture loads. The edges are not worn down by cutting-related wear, which later becomes noticeable in the tool life.

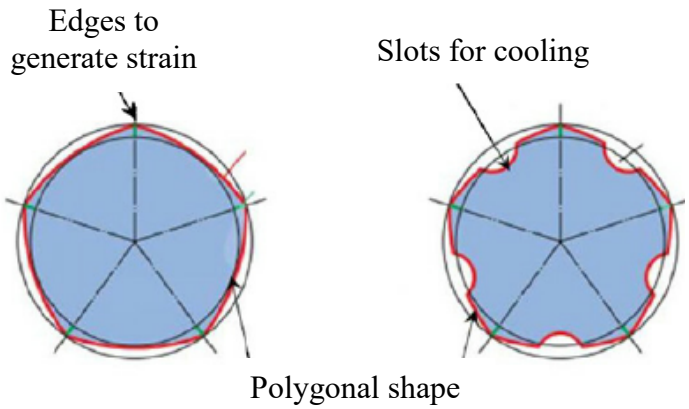


Fig. 1 – Cross section of thread forming tool.

During thread forming, the grain flow in the material is preserved – this ensures more stable threads, longer tool life, and very constant dimensional accuracy (Fig.1). When cutting, the grain flow (microstructure) is severed [1]. The microstructure in the material loses its continuity, and the cutting edges create notches that can later affect the load-bearing capacity. The opposite happens during thread forming. The grain structure is deformed, not separated. A densified, continuous grain flow is created, which makes the thread more stable and reduces notch sensitivity.



Fig. 2 – Grain flow in cuting thread (a) and forming thread (b).

The need to obtain data concerning the diameter of the semifinished-product is of great importance for achieving the required accuracy of the internal thread produced by cold plastic deformation. In some specialized studies, the following relationships are recommended:

$$\boldsymbol{D_{sr} = D - 0,6\sqrt{p}} \tag{1}$$

or

$$\boldsymbol{D_{sr} = f} \tag{2}$$

where: D_{sr} = diameter of the semi-finished product; D = the outside diameter of the nut; p = the thread pitch; f = the cross-sectional parameters;

Based on relationships (1) and (2), an accurate profile of the internal thread cannot be obtained, since the specific behavior of each material during the cold deformation process is not taken into account [2].

The present paper proposes an analytical methodology for determining the blank diameter in order to achieve the required accuracy of the internal thread.

1.1. Advantages and disadvantages/limitations of forming thread

1.1.1. Advantages of forming thread

No Chips. Without chips, there is no risk of chip congestion, no crater formation in blind holes, and no additional effort for chip evacuation. The component remains clean, which is a real advantage, especially in automated systems and series processes. In manufacturing environments that demand absolute cleanliness – for example, in electronic assemblies or food-related processes – even a single chip can lead to rejects. Working chip-free prevents exactly that.

Longer Tool Life and Higher Thread Strength. The material is cold-hardened and not cut. This ensures robust threads and long tool life because no cutting edges wear out.

Process Stability and Good Automation Capabilities. Thread forming delivers reproducible results and runs very reliably in modern CNC environments. This is a clear advantage for series production.

Better Surface Quality in the Thread. The surface of the formed thread is smoother and denser because no cutting notches are created. This improves the load-bearing capacity, and screws start more easily.

1.1.2. Disadvantages/limitations of forming thread

Higher Torques Required. Thread forming requires about 40–50% more torque than cutting. The machine must have this power reserve, otherwise the process cannot be used reliably.

Material Dependence: Cold Formability is Mandatory. Only ductile, formable materials are suitable for this. Very hard or brittle materials lead to cracks, dimensional problems, or tool damage.

Stricter Requirements for Bore, Lubrication, and Parameters. Core hole diameter, lubricant, and process parameters must fit exactly. Incorrect core holes or a lack of lubrication threaten tool breakage and faulty threads.

2. Analytical Determination of the Semi-Finished Product Diameter in the Case of Threading with Tapless Taps

Fig. 1 presents the main dimensional elements of the threaded joint, having the following parameters: H = 0, 86603 p; H_1 = 0, 54127 p; h_3 = 0, 61343 p; d_2 = d – 0, 64952 p; d_1 = d – 1, 22687 p; D = d; D_2 = d_2; D_1 = d_1; r = 1, 4434 p.

The accuracy of rolled thread production depends to a great extent on the diameter of the semi-finished product, which is not equal to the mean diameter of the thread [3].

Initially, the assumption of constant volume is considered to be satisfied, and the equality between the volumes of the semi-finished product and the rolled part over a length equal to one thread pitch is established (Fig. 1).

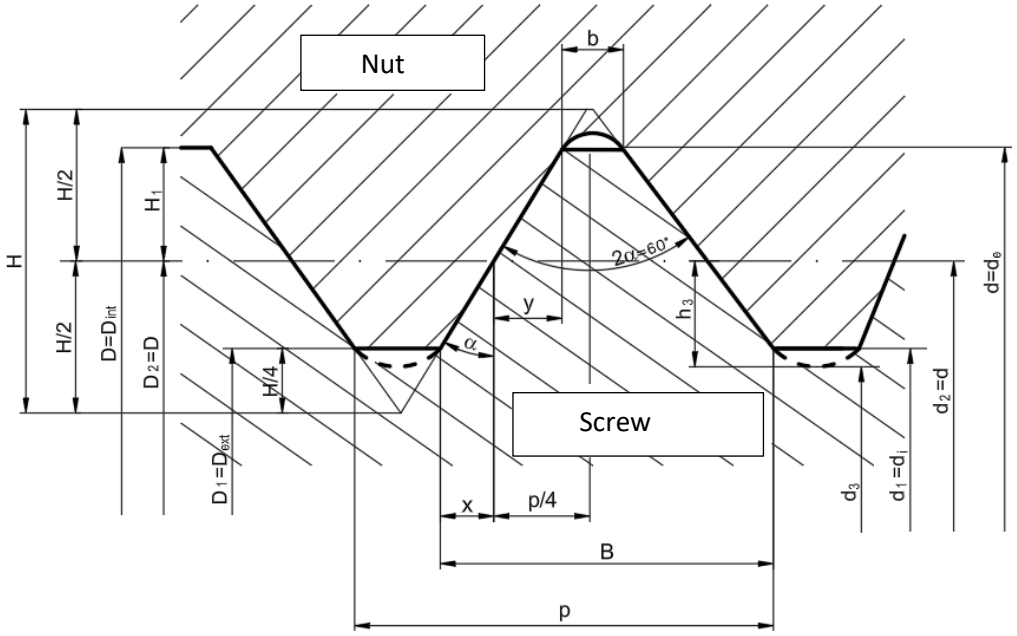


Fig. 3 - Main dimensional elements of the metric thread.

The volume of the semi-finished product over a length equal to one thread pitch is:

$$V_s = \frac{\pi \cdot D_s^2}{4} p \quad (3)$$

The volume of the rolled part over a length equal to one thread pitch is:

$$\boldsymbol{V_p = \frac{\pi \cdot D_{int}^2}{4} p - V_g} \tag{4}$$

$$\boldsymbol{\frac{\pi \cdot D_s^2}{4} p = \frac{\pi \cdot D_{int}^2}{4} p - V_g} \tag{5}$$

where Vg is the volume of the void, which is the volume of a truncated pyramid.

$$\boldsymbol{V_g = \frac{1}{3} H (A_B + A_b + \sqrt{A_B . A_b})} \tag{6}$$

where:

$$\boldsymbol{H = \frac{D_{int} - D_{ext}}{2}} \tag{7}$$

and A_B, A_b are the areas of the bases of the truncated pyramid.

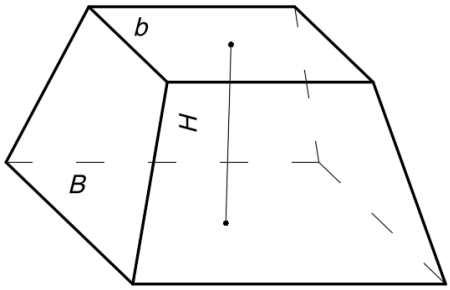


Fig. 4 – Volume of the truncated pyramid

The areas of the bases are:

$$\boldsymbol{A_B = D_{ext} \cdot B;} \qquad \boldsymbol{A_b = D_{int} \cdot b} \tag{8}$$

The dimensions B and b are expressed in terms of the thread elements according to Fig. 3.

$$\boldsymbol{B = 2\left(\frac{p}{4} + x\right) = \frac{p}{2} + 2x} \tag{9}$$

$$\boldsymbol{b = 2\left(\frac{p}{4} - y\right) = \frac{p}{2} - 2y} \tag{10}$$

but:

$$\cot\alpha = \frac{D_{int}-D}{2y} \qquad \Rightarrow y = \frac{D_{int}-D}{c\cot\alpha} \tag{11}$$

$$cot\,\alpha = \frac{D-D_{ext}}{2x} \quad \Rightarrow \quad x = \frac{D-D_{ext}}{2\,cot\,\alpha} \tag{12}$$

consequently:

$$B = \frac{p}{2} + 2\frac{D-D_{ext}}{2\cot\alpha} = \frac{p}{2} - \frac{D-D_{ext}}{\cot\alpha} \tag{13}$$

$$b = \frac{p}{2} - 2\frac{D_{int}-D}{2\cot\alpha} = \frac{p}{2} - \frac{D_{int}-D}{\cot\alpha} \tag{14}$$

Substituting into equations (8), we obtain:

$$A_B = \pi \cdot D_{ext}\left(\frac{p}{2} + \frac{D-D_{ext}}{\cot\alpha}\right);\ A_b = \pi \cdot D_{int}\left(\frac{p}{2} - \frac{D_{int}-D}{\cot\alpha}\right) \tag{15}$$

Substituting equations (7) and (15) into equation (6), we obtain:

$$V_g = \frac{D_{int}-D_{ext}}{6}\left[\pi \cdot D_{ext}\left(\frac{p}{2} + \frac{D-D_{ext}}{\cot\alpha}\right) + \pi \cdot D_{int}\left(\frac{p}{2} - \frac{D_{int}-D}{\cot\alpha}\right) + \sqrt{\pi^2 D_{ext}D_{int}\left(\frac{p}{2} + \frac{D-D_{ext}}{\cot\alpha}\right)\left(\frac{p}{2} - \frac{D_{int}-D}{\cot\alpha}\right)}\right] \tag{16}$$

$$V_g = \frac{D_{int}-D_{ext}}{6}\pi\left[D_{ext}\left(\frac{p}{2} + \frac{D-D_{ext}}{\cot\alpha}\right) + D_{int}\left(\frac{p}{2} - \frac{D_{int}-D}{\cot\alpha}\right) + \sqrt{M}\right] \tag{17}$$

$$D_s = \sqrt{D_{int}^2 - \frac{2}{3}\frac{D_{int}-D_{ext}}{p}\left[D_{ext}\left(\frac{p}{2} + \frac{D-D_{ext}}{\cot\alpha}\right) + \sqrt{M}\right]} \tag{18}$$

where:

$$\boldsymbol{M = D_{ext} D_{int} \left(\frac{p}{2} + \frac{D - D_{ext}}{\cot \alpha}\right)\left(\frac{p}{2} - \frac{D_{int} - D}{\cot \alpha}\right)} \quad (19)$$

Transforming equation (18) according to STAS 510-61 and performing the necessary substitutions, we obtain:

$$\boldsymbol{D_{int} = D; D = D_2; D_{ext} = D_1} \quad (20)$$

$$\boldsymbol{D_s = \sqrt{D^2 - \frac{2}{3}\frac{D - D_1}{p}\left[D_1\left(\frac{p}{2} + \frac{D_2 - D_1}{\cot \alpha}\right) + D\left(\frac{p}{2} - \frac{D - D_2}{\cot \alpha}\right) + \sqrt{M}\right]}} \quad (21)$$

where:

$$\boldsymbol{M = D \cdot D_1\left(\frac{p}{2} + \frac{D_2 - D_1}{\cot \alpha}\right)\left(\frac{p}{2} - \frac{D - D_2}{\cot \alpha}\right)} \quad (22)$$

Particularizing equation (21) for the triangular metric thread, according to STAS 510-61, where:

$D_2 = D - 0{,}64952 \cdot p$; $D_1 = D - 1{,}08254 \cdot p$; $\propto = 30^0$;

we obtain:

$$\boldsymbol{D_s = \sqrt{D^2 - 0{,}7216933\left[(D - 1{,}08254 \cdot p) \cdot 0{,}75 \cdot p + D \cdot 0{,}125 \cdot p + \sqrt{D(D - 1{,}08254 \cdot p) \cdot 0{,}75 \cdot p \cdot 0{,}125 \cdot p}\right]}}$$

$$\boldsymbol{D_s = \sqrt{D^2 - 0{,}721693\left[0{,}75 \cdot D \cdot p - 0{,}811905 \cdot p^2 + 0{,}125 \cdot D \cdot p + \sqrt{0{,}09375 \cdot D^2 - 0{,}101488 \cdot D \cdot p^2}\right]}}$$

$$\boldsymbol{D_s = \sqrt{D^2 - 0{,}631481 \cdot D \cdot p + 0{,}585946 \cdot p^2 - p\sqrt{0{,}048829 \cdot D^2 - 0{,}052859 \cdot D \cdot p}}} \quad (25)$$

Using equation (25), the theoretical diameter of the semi-finished product can be determined as a function of parameters D and p.

During the threading process, the deformation of the material is not uniform, which makes it necessary to correct the diameter of the semi-finished product by reducing it by a

certain amount [4]. This correction can be achieved by reducing the volume and introducing a correction coefficient:

$$\boldsymbol{k = \frac{V_{sr}}{V_{sr} + \Delta V}} \tag{26}$$

In which:

$V_{sr} -$ is the actual volume that the semi-finished product should have;

$\Delta V -$ is the volumetric correction.

Volumes V_{sr} and $V_{sr} + \Delta V$ can be determined experimentally by applying Archimedes' principle before and after plastic deformation to the semi-finished products from which correctly formed parts are obtained.

$$\boldsymbol{V_{sr} = \frac{G_1}{\gamma_1}\ ;} \quad \boldsymbol{V_{sr} + \Delta V = \frac{G_2}{\gamma_2}} \tag{27}$$

where:

G_1 and G_2 are the weights of the volumes of liquid displaced before and after plastic deformation.

γ_1 and γ_2 are the specific weights of the liquid at the temperatures at which the two measurements are carried out.

Taking into account equations (27), equation (26) becomes:

$$\boldsymbol{k = \frac{G_1 \cdot \gamma_2}{G_2 \cdot \gamma_1}} \tag{28}$$

In the case when:

$$\boldsymbol{\gamma_1 = \gamma_{2,} \Longrightarrow k = \frac{G_1}{G_2}} \tag{29}$$

where:

$$\boldsymbol{G_1 = G_1' - G_2^{"} \; and \; G_2 = G_2' - G_2^{"}} \tag{30}$$

G_1' and G_2' are the weights of the semi-finished product and the plastically deformed part, respectively, measured in air, while $G_1^{"}$ and $G_2^{"}$ are the weights of the semi-finished product and the plastically deformed part, respectively, measured in liquid [5].

The measurements can be carried out using an analytical balance.

Based on the above, the actual diameter of the semi-finished product is:

$$\boldsymbol{D_{sr} = D_s \cdot \sqrt{k}}$$
$$\boldsymbol{= \sqrt{D^2 - 0,631481 \cdot D \cdot p + 0,585946 \cdot p^2 - p\sqrt{0,048829 \cdot D^2 - 0,052859 \cdot D \cdot p}} \cdot \sqrt{k}} \quad (31)$$

3. Conclusions

The analytical method presented provides specialists with a relationship for calculating the diameter of the semi-finished product in the case of threading with tapless taps, based on the assumption of constant volume of the semi-finished product and the rolled part, as well as on the change in volume occurring during the manufacturing process.

This method also offers the possibility of programming the calculations on a computer.

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