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INVESTIGATION OF THE PROCESS OF THREAD EXTRUSION USING THE ULTRASOUND

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Досліджено та змодельовано процес видавлювання різі з накладанням ультразвукових коливань. На основі реологічної моделі деформування ідеального пружно-пластичного тіла розроблені залежності для розрахунку контактних тисків та питомої сили тертя. Змодельовані контактні явища, що проходять в зоні деформації. Визначені оптимальні параметри видавлювання різі. Аналітично визначено діаметр отвору під видавлювання різі з накладанням ультразвукових коливань

Ключові слова: ультразвукове видавлювання різі, частота коливань, амплітуда коливань, контактний тиск

Исследован и смоделирован процесс выдавливания резьбы с наложением ультразвуковых колебаний. На основе реологической модели деформирования идеального упруго-пластического тела выведены зависимости для расчета контактных давлений и удельной силы трения. Смоделированы контактные явления, которые проходят в зоне деформации. Определены оптимальные параметры выдавливания резьбы. Аналитически определен диаметр отверстия под выдавливание резьбы с наложением ультразвуковых колебаний

Ключевые слова: ультразвуковое выдавливания резьбы, частота колебаний, амплитуда колебаний, контактное давление

1. Introduction

Threaded joints are the most common kind of detachable connections in mechanical engineering. An analysis of the existing methods for obtaining internal threads [1, 2] reveals that one of the promising methods of the formation of threaded surfaces is the method of plastic shape-formation (extrusion) of threads by spiral fluted taps. This method possesses considerable technological capabilities, high operational output and creates quality surface of the thread, which improves performance of the threaded joints.

There are many factors, however, which limit its application. Tensile strength of the material's workpiece must not exceed 500 MPa. In order to enable the process of thread-formation in line with this method, it is necessary to apply a considerable torque, which leads to the destruction of taps of small diameters. This method cannot be used when making threaded holes in the parts made of stainless and heat-resistant steels [3]. These shortcomings can be eliminated through the intensification of the process of extrusion of the thread by ultrasound. Thus, this issue is interesting and relevant. Research in this direction has great applied importance related to the possibility of saving energy and improving operational and technical properties of the thread.

2. Literature review and problem statement

Functions of threaded connections are very diverse. Hence it follows a great variety of types of the utilized threads: metric, trapezoidal, pipe, conic, and others.

Modern machine-building employs various methods for obtaining threaded surfaces. Paper [1] gives the classification of methods for obtaining threaded surfaces, namely: machining (turning, planing, milling, grinding), electroerosion, electrochemical, ultrasonic treatment, sintering, casting, processing by plastic deformation. The disadvantage of the publication is the lack of a detailed analysis of the advantages and shortcomings of each of the processing techniques.

It is noted in [2] that the most promising method of manufacturing a thread is knurling. This method is based on the principle of a gradual pressing the tool into the workpiece. The authors performed analysis of the process of contact interaction between a tool and a part and determined the optimal loading algorithm. It is noted that the ultrasonic oscillations are successfully applied both for cutting a thread by taps and knurling a thread by taps-knurls [2]; they allow obtaining good quality of the thread even in such viscous materials as copper. But the paper, however, failed to determine the optimal parameters of ultrasonic oscillations when obtaining a thread by this technique.

Patent [3] describes development of the device for measuring the parameters of ultrasonic oscillations. A shortcoming of this device is the absence of a switching bus with personal computer.

As is noted in article [4], the ultrasound has become widespread in the process of machining internal threads of small and medium diameters in the parts made of heat-resistant and titanium alloys. When ultrasonic oscillations (of frequency 18–44 kHz) with low amplitude are applied to a cutting tool – the tap, the torque and axial force are reduced by 25–30 %, with quality of the thread being improved. The application of ultrasound makes it possible to increase the productivity of making a thread by up to 3 times (by reducing the number of taps in the set) and instrument resistance by to 1.5–2 times, as well as eliminate cases of taps failures. The authors did not report determining the power factors arising in the process of cutting a thread using the ultrasound.

Ultrasound tapping of internal threads in the hard-to-process materials is carried out by taps that operate under the mode of longitudinal [5] or lengthwise-turning oscillations. The application of ultrasound made it possible to improve productivity of machining by 1.5–2 times.

Taps for cutting a thread with a diameter larger than 8 mm differ from those typical by the existence of a shank to be fixed in a waveguide hub and they have a resonance length, usually halfwave. The paper does not address obtaining a thread by the methods of plastic deformation, which is why the results received cannot be applied to the formation of a thread by knurling.

Employing the ultrasound contributes to the more intensive plastic deformation. Thus, it is necessary to accept a diameter of the hole that is slightly larger than in the case of making a thread without ultrasound. The optimal value of amplitude of oscillations when treating threads of diameter 6–12 mm with a step of 1 mm is in the range of 0.003–0.004 mm; for the thread M12 it grows to 0.004–0.006 mm [6].

The issue of cutting a thread with average diameters (M8–M18) under the influence of ultrasound was addresses in papers [7–10]. Most attention is given to the treatment of a thread with a small diameter [11]. A great effect on the processes of treating a thread by with the method of plastic deformation is exerted by a diameter of the hole [12, 13].

Papers [6–13] failed to determine the necessary diameter of a hole for cutting a thread, which is why this issue is relevant for designing technological processes of manufacturing threads with the use of ultrasound.

Article [14] deals with manufacturing complex surfaces on a tool of the type of a machining center with 6 degrees of freedom using the ultrasound. The issue of the influence of ultrasonic oscillations on the quality of manufacturing the surfaces of complex geometrical shape was not explored sufficiently enough.

The research into ultrasonic processes of assembly is addressed in paper [15]. The study was conducted by the method of finite elements. A shortcoming of this method is the impossibility to track the dynamics of change in the factors of influence on the process in real time.

Article [16] reports a procedure to study the process of obtaining threaded surfaces of the mounting products by the method of plastic deformation. The method of finite elements was employed for this purpose. The procedure proposed in this publication does not take into consideration the influence of ultrasonic oscillations and can be used only when designing a technological process of cutting a thread employing the methods of plastic deformation.

In paper [17], authors proposed a method for estimating the wear for a tool with a complex cutting edge. The conclusion was made that the forces and moments of cutting greatly depend on the geometrical cross section of the cutting plate. The method for the assessment of wear that was suggested in this publication is applicable only when making a thread by using metal cutting processes and it does not take into consideration oscillatory processes that occur in this case.

In article [18], authors devised a new method for rapid and economical manufacturing of bolt joints, exploiting a combination of the processes of formation and shape-forming. The developed method makes it possible to swiftly make the threading holes in the joint of metallic alloys, such as steel and aluminum alloys. It would be expedient to explore this process for the case of applying the ultrasonic oscillations.

3. The aim and objectives of the study

The aim of present work is to improve efficiency of obtaining internal threads by plastic deformation when imposing ultrasonic oscillations to the tool. This will make it possible, based on the study of the mechanics of the process, to prepare recommendations for basic parameters of the technological process.

To achieve the set aim, the following tasks have to be solved:

– to explore the contact interaction between a tool and a part during extrusion of the internal threads when imposing ultrasonic oscillations to the tool, or to the part;

– to devise a procedure for estimating contact pressures and specific force of friction during extrusion of the thread when imposing ultrasonic oscillations;

– to determine which factor influences most a decrease in the contact pressure and to determine the impact of this factor on the magnitude of specific force of friction.

4. Materials and methods of research

A description of the ultrasonic extrusion of a thread has been built based on the application of rheological models of materials that reflect their actual elastic plastic properties. Such an approach makes it possible to identify a mechanism of the influence of ultrasound on the process of extrusion of a thread.

The study into power parameters was carried out using a chart of loading a perfect elastic plastic body.

When investigating the effect of the machining method on torque, we used the following materials: Steel 10, aluminum alloy AK4.

5. Modelling a process of contact interaction between a tool and a part when imposing the axial ultrasonic oscillations

A working process of making a thread when ultrasound is imposed implies the following. At the same time with the main motion (rotation around the axis) and the motion of feeding a tool, oscillations in the axial direction are imposed with a frequency of 20...22 kHz and a small (a few micrometers) amplitude.

At rotation of the tap with a thread step P_t and circular velocity V, and its simultaneous oscillation in the direction of the part's axis at frequency f and amplitude ξ, equation of motion of the tap along the part's axis is described by the following dependence

$$u(t)=\frac{V\cdot P_t\cdot t}{\pi\cdot D}+\zeta\cdot\sin\omega\cdot t, \quad (1)$$

where V is the circular speed; P_t is the thread's step; t is the current time; D is the average diameter of the thread; ζ is the amplitude of oscillations; $\omega=2\pi f$, here f is the oscillation frequency.

The motion of a tap along the part's axis leads to the introduction of its teeth into the inner surface of the part along the normal to the generatrix of the thread's profile.

$$u_n(t)=\left(\frac{V\cdot P_t\cdot t}{\pi\cdot D}+\zeta\cdot\sin\omega\cdot t\right)\cdot\mathrm{tg}\,\varphi\cdot\cos\alpha/2, \quad (2)$$

where φ is the angle of the generatrix of the tap's cone; α is the angle of the thread's profile.

Displacement (2) during contact between the tap's teeth and the surface of the workpiece causes contact pressures p (Fig. 1). Because function (2) is periodical, the process of extrusion will be accompanied by three periods of deformation, namely: elastic and plastic and during unloading.

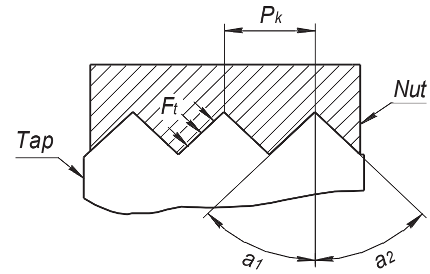

Fig. 1. Contact pressures acting on the spiral of a tap chamfer

By analogy with [20, 21], we shall consider a loading chart for a perfect elastic plastic body that makes it possible to link contact pressure p to displacement u and velocity u of the tool (Fig. 2). Chart (Fig. 2) shows: 1 – region of elastic loading; 2 – region of plastic deformation; 3 – region of unloading; δ – coordinate of the beginning of contact between a tool and a part; K_n – rigidity of linear section in the direction normal to the generatrix of the tap's tooth; u_{mt} – maximal displacement velocity of the tool over the period of oscillations in the value of function (2).

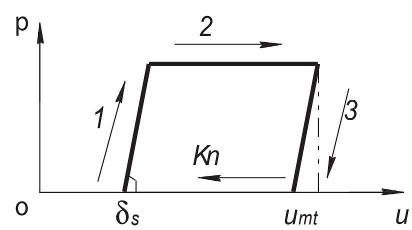

Fig. 2. Load chart of the ideal elastic plastic body

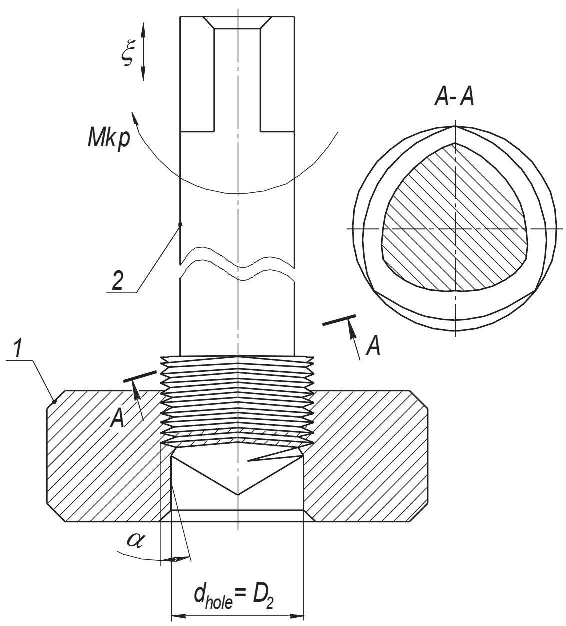

Fig. 3. Schematic of thread-tapping with longitudinal oscillations: 1 – a product; 2 – a tap

The expression that describes characteristic of loading of the part's material by the tool, which moves in line with law (2), takes the form:

$$p(u_n,\dot{u}_n)= \begin{cases} 0, & (u_n \le \delta_s)\wedge(\dot{u}_n \ge 0), \\ k_n(u_n-\delta_s), & (\delta_s \le u_n \le \delta_s + p/k_n)\wedge(\dot{u}_n \ge 0), \\ p, & (\delta_s + p/k_n \le u_n \le u_{nm})\wedge(\dot{u}_n \ge 0), \\ p+k_n(u_n-u_{nm}), & (u_{nm}-p/k_n \le u_n \le u_{nm})\wedge(\dot{u}_n \le 0), \\ 0, & (u_n \le u_{nm}-p/k_n)\wedge(\dot{u}_n \le 0), \end{cases} \quad (3)$$

where u_{mt} is the maximum speed of body's displacement over the period of the value of function (2), it is calculated from the following dependence:

$$u_{nm}=\zeta\cdot \operatorname{tg}\varphi\cdot\cos\frac{\alpha}{2}\left[\frac{V\cdot P_t}{\pi\cdot D\cdot\zeta\cdot\omega}\arccos\left(-\frac{V\cdot P_t}{\pi\cdot D\cdot\zeta\cdot\omega}\right)+ + \sqrt{1-\left(\frac{V\cdot P_t}{\pi\cdot D\cdot\zeta\cdot\omega}\right)^2}\right],$$

where δ_s is the coordinate of the beginning of contacting between a surface of the tool and a part.

When extruding a thread with imposing ultrasonic oscillations, the contact pressure according to (3) takes the form of a periodic function

$$p(t)= \begin{cases} k_n\left[\left(\frac{V\cdot P_t\cdot t}{\pi\cdot D}+ +\zeta\cdot\sin\omega\cdot t\right)\operatorname{tg}\varphi\cos\frac{\alpha}{2}-\delta_s\right], & t_1\le t\le t_2, \\ p, & t_2\le t\le t_3, \\ p+k_n\left[\left(\frac{V\cdot P_t\cdot t}{\pi\cdot D}+ +\zeta\cdot\sin\omega\cdot t\right)\operatorname{tg}\varphi\cos\frac{\alpha}{2}-u_{nm}\right], & t_3\le t\le t_4. \end{cases} \quad (4)$$

Using the theorem of impulses, we shall obtain a relation that links constant static pressure p to the parameters of tool motion to the characteristics of the treated material.

$$p_c=\frac{1}{T}\int_{t_1}^{t_1+T} p(t)\mathrm{d}t, \quad (5)$$

where t_1 is the initial period of time; T is the period of oscillations.

Substituting (4) in (5) and calculating the integral, we shall obtain:

$$p_c=\frac{k_n}{2\cdot\pi}\left[\delta\tau_1-\left(\delta+\frac{p}{k_n}\right)\tau_2+u_{nm}\tau_3-\left(u_{nm}-\frac{p}{k_n}\right)\tau_4+ +\zeta\cdot\operatorname{tg}\varphi\cos\frac{\alpha}{2}(\cos\tau_1-\cos\tau_2+\cos\tau_3-\cos\tau_4)+ +(\tau_2^2-\tau_1^2+\tau_4^2-\tau_3^2)\frac{V\cdot P_t\cdot\operatorname{tg}\varphi\cdot\cos\alpha/2}{2\cdot\pi\cdot D\cdot\omega}\right], \quad (6)$$

where $\tau_i=\omega\cdot t_i$.

Moments of switching characteristic (4) t_1 were determined for the following reasons. Assume that a tap travels distance δ_s over time t_1, then, equating expression (2) to δ_s, we shall obtain:

$$\sin\omega t_1=\frac{1}{\zeta\cdot\operatorname{tg}\varphi\cdot\cos\alpha/2}\left(\delta_s-\frac{V\cdot P_t\cdot t_1}{\pi\cdot D}\operatorname{tg}\varphi\cdot\cos\alpha/2\right). \quad (7)$$

Substituting values ωt_1 in (7), we shall obtain

$$\sin\tau_1=\frac{1}{\zeta\cdot\operatorname{tg}\varphi\cdot\cos\alpha/2}\left(\delta_s-\frac{V\cdot P_t\cdot\tau_1}{\pi\cdot D\cdot\omega}\operatorname{tg}\varphi\cdot\cos\alpha/2\right). \quad (8)$$

Similarly, equating the respective moments of switching a characteristic to (2), we shall obtain

$$\sin\tau_2=\frac{1}{\zeta\cdot\operatorname{tg}\varphi\cdot\cos\alpha/2}\left(\delta_s+\frac{p}{k_n}-\frac{V\cdot P_t\cdot\tau_2}{\pi\cdot D\cdot\omega}\operatorname{tg}\varphi\cdot\cos\alpha/2\right); \quad (9)$$

$$\tau_3=\arccos\left(-\frac{V\cdot P_t}{\pi\cdot D\cdot\omega\cdot\zeta}\right); \quad (10)$$

$$\sin\tau_4=\frac{1}{\zeta\cdot\operatorname{tg}\varphi\cdot\cos\alpha/2}\times \times\left(u_{nm}-\frac{p}{k_n}-\frac{V\cdot P_t\cdot\tau_4}{\pi\cdot D\cdot\omega}\operatorname{tg}\varphi\cdot\cos\alpha/2\right). \quad (11)$$

Equations (8)–(11) hold for the modes of pulse deformation, which are implemented under condition

$$\zeta\cdot\operatorname{tg}\varphi\cos(0.5\cdot\alpha)\ge p/k_n. \quad (12)$$

For the modes of continuous deformation, which are implemented under condition

$$\zeta\cdot\operatorname{tg}\varphi\cos(0.5\cdot\alpha)\le p/k_n, \quad (13)$$

values of t_1 are derived from the following equations:

$$\tau_1=-\tau_3=-\arccos\left(-\frac{V\cdot P_t}{\pi\cdot D\cdot\omega\cdot\zeta}\right), \quad (14)$$

$$\tau_4=2\pi+\tau_1. \quad (15)$$

The values of τ_2 are derived from (29). In order to calculate contact pressure from (26), it is necessary to have values of δ_s, which we shall find from the following considerations. Residual (plastic) deformation over a period of oscillations is determined from:

$$h_o=u_{nm}-\delta_s-\frac{p}{k_n}. \quad (16)$$

Average rate of deformation over the period of oscillations will be determined as a ratio of the residual deformation (16) to the period of oscillations:

$$V_{cp}=\frac{h_o}{T}=\frac{\omega}{2\pi}\left(u_{nm}-\delta_s-\frac{p}{k_n}\right). \quad (17)$$

By substituting the magnitude of $\frac{VP_t}{\pi D}\operatorname{tg}\varphi\cos\frac{\alpha}{2}$ in (17) instead of V_{cp}, we shall obtain:

$$\delta_s=u_{nm}-\frac{p}{k_n}-\frac{2\cdot V\cdot P_t}{D\cdot\omega}\operatorname{tg}\varphi\cdot\cos\frac{\alpha}{2}. \quad (18)$$

To determine k_n, which is included in (6), it should be noted that rigidity denotes such a value of the contact pressure that causes the unit of elastic deformation. Based on these considerations, the rigidity is derived from

$$k_n = \frac{p}{\varepsilon_{sp}}, \tag{19}$$

where ε_{sp} is the elastic deformation of the thread.

Refs [5, 6, 17] contain the expression for determining elastic deformation

$$\varepsilon_{sp} = \frac{P_t p}{4(E+p)}\cos\frac{\alpha}{2}, \tag{20}$$

where E is the modulus of elasticity of the part's material.

Substituting dependence (20) in (21), we shall obtain:

$$k_n = 4(E+p)/(P_t\cos(\alpha/2)). \tag{21}$$

The value of contact pressure p according to [6, 17] is equal to $7\sigma_m$ of the machined material. Therefore, using the derived relation (6), it is possible to calculate contact pressures when extruding a thread applying the axial ultrasonic oscillations. The expression for estimating specific force of friction will be determined as the product of contact pressure (6) by friction coefficient η:

$$F_m = \eta\frac{k_n}{2\pi}\left[\delta\tau_1 - \left(\delta + \frac{p}{k_n}\right)\tau_2 + u_{nm}\tau_3 - \left(u_{nm} - \frac{p}{k_n}\right)\tau_4 + \right.$$
$$+\zeta\cdot\mathrm{tg}\,\varphi\cos(0{,}5\cdot\alpha)(\cos\tau_1 - \cos\tau_2 + \cos\tau_3 - \cos\tau_4) +$$
$$\left. + \left(\tau_2^2 - \tau_1^2 + \tau_4^2 - \tau_3^2\right)\frac{VP_t\,\mathrm{tg}\,\varphi\cos\alpha/2}{2\pi D\omega}\right]. \tag{22}$$

Let us examine the effect of modes of extruding a thread on the contact pressures and specific friction force.

6. Modelling a process of contact interaction between a tool and a part when imposing the torsional ultrasonic oscillations

A schematic of the process of extruding a thread when imposing torsional oscillations is shown in Fig. 4.

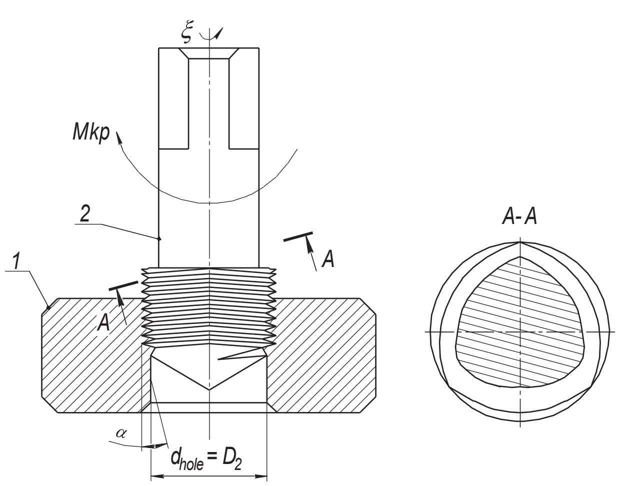

Fig. 4. Schematic of extruding a thread at torsional oscillations: 1 — a part; 2 — a tap

The equation of motion in the case for imposing torsional oscillations is described by the following dependence:

$$u(t) = P_t(Vt + \zeta\sin\omega t)/(\pi D). \tag{23}$$

The motion along the normal to the generatrix of tap's profile:

$$u_n(t) = \frac{P_t}{\pi\cdot D}\mathrm{tg}\,\varphi\cos\frac{\alpha}{2}(Vt + \zeta\cdot\sin(\omega\cdot t)). \tag{24}$$

Similar to (4), the expression for determining a contact pressure at different stages of loading in the case for imposing torsional oscillations takes the form

$$p(t) = \begin{cases} k_n\left[\dfrac{P_t\cdot\mathrm{tg}\,\varphi\cdot\cos\alpha/2}{\pi\cdot D}\times \times(Vt + \zeta\cdot\sin\omega\cdot t) - \delta_s\right], & t_1 \le t \le t_2, \\ p, & t_2 \le t \le t_3, \\ p + k_n\left[\dfrac{P_t\cdot\mathrm{tg}\,\varphi\cdot\cos\alpha/2}{\pi\cdot D}\times \times(Vt + \zeta\cdot\sin\omega\cdot t) - u_{nm}\right], & t_3 \le t \le t_4. \end{cases} \tag{25}$$

By calculating equation (5) taking into consideration (25), we shall obtain the expression for determining a contact pressure when extruding a thread while imposing torsional oscillations

$$p_c = \frac{k_n}{2\pi}\left[\delta_s\tau_1 - \left(\delta_s + \frac{p}{k_n}\right)\tau_2 + u_{nm}\tau_3 - \left(u_{nm} - \frac{p}{k_n}\right)\tau_4 + \right.$$
$$\left. + \frac{P_t\cdot\mathrm{tg}\,\varphi\cdot\cos\alpha/2}{\pi\cdot D}\left[\begin{matrix}\zeta(\cos\tau_1 - \cos\tau_2 + \cos\tau_3 - \cos\tau_4) + \\ + \dfrac{V}{2\omega}\left(\tau_2^2 - \tau_1^2 + \tau_4^2 - \tau_3^2\right)\end{matrix}\right]\right]. \tag{26}$$

For the case of torsional oscillations, the maximum value of function (23) is determined from the following dependence:

$$u_{nm} = \frac{\zeta\cdot P_t\cdot\mathrm{tg}\,\varphi\cdot\cos\alpha/2}{\pi\cdot D}\times$$
$$\times\left[\sqrt{1 - (V/(\zeta\cdot\omega))^2} + \frac{V}{\zeta\cdot\omega}\arccos(-V/(\zeta\cdot\omega))\right]. \tag{27}$$

The value of δ_s is derived from the following equation:

$$\delta_s = u_{mt} - p/k_n - 2\pi V/\omega. \tag{28}$$

For the modes of pulse deformation, which are implemented under the following condition:

$$\frac{\zeta\cdot P_t\cdot\mathrm{tg}\,\varphi\cdot\cos(\alpha/2)}{\pi\cdot D} \ge \frac{p}{k_n}, \tag{29}$$

as is the case for longitudinal oscillations, the moments of switching a characteristic of load τ_i are derived from the following equations:

$$\sin\tau_1 = \frac{1}{\zeta}\left(\frac{\pi\cdot D\cdot\delta_S}{P_t\cdot\mathrm{tg}\,\varphi\cdot\cos(\alpha/2)} - \frac{V}{\omega}\tau_1\right), \tag{30}$$

$$\sin\tau_2 = \frac{1}{\zeta}\left(\frac{(\delta_s + p/k_n)\pi D}{P_t\cdot \mathrm{tg}\,\varphi\cdot\cos(\alpha/2)} - \frac{V}{\omega}\tau_2\right), \quad (31)$$

$$\tau_3 = \arccos\left(-V/(\zeta\cdot\omega)\right), \quad (32)$$

$$\sin\tau_4 = \frac{1}{\zeta}\left(\frac{(u_{nm} - p/k_n)\pi\cdot D}{P_t\cdot \mathrm{tg}\,\varphi\cdot\cos(\alpha/2)} - \frac{V}{\omega}\tau_4\right). \quad (33)$$

For the modes of continuous deformation, under condition

$$\frac{\zeta\cdot P_t\cdot \mathrm{tg}\,\varphi\cdot\cos(\alpha/2)}{\pi\cdot D} \le \frac{p}{k_n} \quad (34)$$

moments of switching a characteristic of the load is determined from the following dependences:

$$\tau_1 = -\tau_3 = -\arccos\left(-V/(\zeta\cdot\omega)\right); \quad (35)$$

$$\tau_4 = 2\pi + \tau_1. \quad (36)$$

The magnitude of τ_2 is derived from dependence (30).

The expression for estimating specific force of friction will be obtained similar to (22):

$$F_m = \eta\frac{k_n}{2\pi}\left[\delta_s\tau_1 - \left(\delta_s + \frac{p}{k_n}\right)\tau_2 + u_{nm}\tau_3 - \left(u_{nm} - \frac{p}{k_n}\right)\tau_4 + \right.$$
$$\left. + \frac{P_t\cdot \mathrm{tg}\,\varphi\cdot\cos\alpha/2}{\pi\cdot D}\left[\begin{array}{l}\zeta(\cos\tau_1 - \cos\tau_2 + \cos\tau_3 - \cos\tau_4) + \\ + \dfrac{V}{2\omega}\left(\tau_2^2 - \tau_1^2 + \tau_4^2 - \tau_3^2\right)\end{array}\right]\right]. \quad (37)$$

Derived expression (37) allows us to calculate specific friction force both for the modes of pulsed and continuous deformation.

7. Modelling a process of contact interaction between a tool and a part when imposing the radial ultrasonic oscillations

The use of the techniques for extruding a thread, described in the previous chapter for the range of threads M24...M60, is associated with certain difficulties, namely the need to supply oscillations of large power, which is due to the large areas of cross-section of the tool. In paper [22], authors proposed a technique for extruding a thread of M24...M60, which implies the following. The hole of nut 1 (Fig. 5) receives a casing of the tool with evenly arranged deforming elements 2 whose length is slightly larger (by 4–5 steps) than the height of the nut.

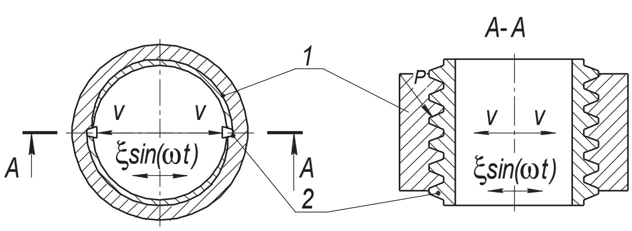

Fig. 5. Schematic of extruding a thread with radial oscillations: 1 — nut; 2 — deforming elements

Deforming elements 2 are exposed to the forces, equal in magnitude, under which the deforming elements move at speed V and are implemented into the surface of the nut's hole nut simultaneously over the entire length (height). At a moment when the working tops of deforming elements come in contact with the surface, the hole of the nut (or a tool) is set into rotary and translational (along the thread's step) motions. The introduction of deforming plates results in the occurrence of contact pressures p, acting normal relative to the thread-forming profile of the deforming element.

This technique has obvious advantages over knurling a thread by the thread-knurling heads, which are designed for tapping a thread of large diameters. However, tapping a thread in a step over 2 mm, as well as in nuts made of materials with hardness larger than HB 200 HB, is impossible using this technique. That is why, in order to enhance technological capabilities of this technique, it is suggested to impose ultrasonic oscillations in the direction of the implementation of deforming elements into the surface of the nut.

By analogy with the stated above, we shall write the equation of complete motion of the tool:

$$u(t) = Vt + \zeta\sin(\omega t). \quad (37)$$

The radial motion of deforming elements 2 is normal to the generatrix of the thread's profile:

$$u_n(t) = u(t)\sin\frac{\alpha}{2} = \left(Vt + \zeta\sin(\omega t)\right)\sin\frac{\alpha}{2}. \quad (38)$$

A characteristic of the load for this case takes the form similar to (3). The expression for u_{nm} has the following values:

$$u_{nm} = \zeta\sin(0.5\cdot\alpha)\times$$
$$\times\left[\sqrt{1 - \left(V/(\zeta\cdot\omega)\right)^2} + V/(\zeta\cdot\omega)\cdot\arccos\left(-V/(\zeta\cdot\omega)\right)\right]. \quad (39)$$

A dependence of the magnitude of the contact pressure in the interaction between a tool and a part takes the form of a periodic sequence of pulses (40)

$$p(t) = \begin{cases} k_n\left[\left(Vt + \zeta\sin\omega\cdot t\right)\sin\dfrac{\alpha}{2} - \delta_s\right], & t_1 \le t \le t_2, \\ p, & t_2 \le t \le t_3, \\ p + k_n\left[\left(Vt + \zeta\sin\omega\cdot t\right)\sin\dfrac{\alpha}{2} - u_{nm}\right], & t_3 \le t \le t_4. \end{cases} \quad (40)$$

For the modes of pulse deformation, which are implemented at oscillation amplitude

$$\zeta \ge \frac{p}{k_n\sin(\alpha/2)},$$

switching moments t_i in (40) are determined from the following equations:

$$\sin\tau_1 = \left(\zeta\sin\frac{\alpha}{2}\right)^{-1}\cdot\left(\delta_s - \frac{V\sin\dfrac{\alpha}{2}}{\omega}\tau_1\right); \quad (41)$$

$$\sin\tau_2 = \left(\zeta\sin\frac{\alpha}{2}\right)^{-1}\cdot\left(\delta_s + p/k_n - \tau_2\cdot\left(V\sin\frac{\alpha}{2}\right)\Big/\omega\right); \quad (42)$$

$$\tau_3 = \arccos\left(-\frac{V}{\zeta\omega}\right); \quad (43)$$

$$\sin\tau_4 = \left(\zeta\sin\frac{\alpha}{2}\right)^{-1}\cdot\left(u_{nm} - \frac{p}{k_n} - \frac{V\sin\frac{\alpha}{2}}{\omega}\tau_4\right). \quad (44)$$

The derived expressions (40)–(44) allow us to calculate contact pressures when extruding a thread with radial ultrasonic oscillations.

8. Analysis of the influence of axial and torsional oscillations on contact pressure, specific friction force, and torque

Contact pressures when extruding a thread while imposing the axial and torsional oscillations are derived from dependences (6), (22), respectively, while specific friction force – from dependences (25), (36).

Results of calculations are shown in Fig. 6–8. They show that the axial oscillations substantially reduce contact pressure, while the torsional only slightly. At the same time, specific friction force is significantly reduced both in the first and second cases, though the axial oscillations are more effective.

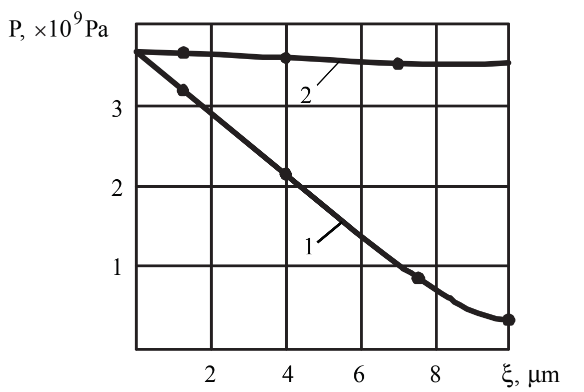

Fig. 6. Dependence of contact pressure on the oscillation amplitude: 1 — axial oscillations; 2 — torsional oscillations

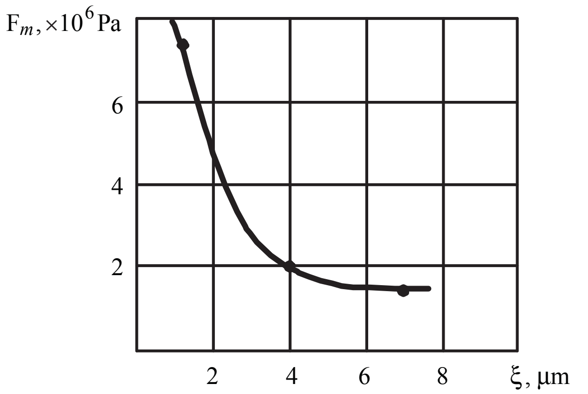

Fig. 7. Dependence of specific friction force on the amplitude of axial oscillations

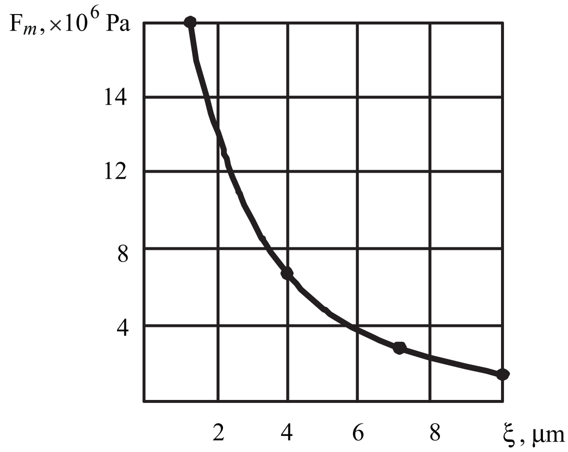

Fig. 8. Dependence of specific friction force on the amplitude of torsional oscillations

The results of calculations have shown that the extrusion of a thread when imposing the ultrasound significantly decreases torque. More effective in terms of reducing the torque is the application of axial oscillations.

The application of axial oscillations almost completely eliminates the effect of friction on the calibrating part of the tap.

9. Discussion of results of studying the processes of extruding a thread when imposing the ultrasonic oscillations on a tool

Rheological models of deformation of the perfect elastic-plastic body are widely and successfully used to describe the processes of deformation when the oscillations are imposed [10].

In the present work, we constructed nonlinear mathematical models to study the processes of plastic deformation, consisting of the equations of tool displacements, and equations that take into consideration elastic-plate properties of the machined material. Such a structure of the mathematical model most fully reflects the processes occurring at tapping a thread when imposing the ultrasonic oscillations. This mathematical model describes complex motion of the tool (rotational and oscillatory motion of the tap). These models do not take into consideration strengthening of the material of the nut in the process of extrusion since accounting for this factor requires extensive research into processes of strengthening of the surface layer at small plastic deformations. At this stage of research, this factor was considered to be constant, which is why it is necessary to conduct additional studies in the future.

The shape of the acquired curves (Fig. 6–8) is explained by the fact that an increase in the amplitude of oscillations leads to a decrease in the time of contact between a tool and the machined surface, which is why contact pressure, specific friction of axial and torsional oscillations over a period decrease accordingly within a change in the examined factors.

The benefit of present study is a detailed analysis of the contact interaction between a tool and a part, as well as consideration of mechanical properties of the machined material, which makes it possible to choose the modes of machining and provide maximum operational productivity.

In carrying out the present research, in order to simplify a mathematical model, we assumed that the phenomenon of surface strengthening exerts little effect on the magnitude of contact pressure and friction force at plastic deformation, according to studies [19, 20]. Undertaking a detailed research into the impact of the process of surface strengthening is relevant in the case of machining viscous and plastic materials (steel of the type 321S51, titanium alloys). It should be noted that these materials are not used in the production of mounting products in general machine building. The study of this process can be carried out based on the analysis of elongation curves; detailed investigation of this issue could become a subject of the further research.

10. Conclusions

1. When studying a contact interaction between a tool and a part subjected to the ultrasonic oscillations in axial and radial directions, as well as when imposing torsional oscillations, it was established that the application of axial oscillations is 50 % more efficient on average. A decrease in the contact pressure is the largest at imposing the axial oscillations. The time of contact between a tool and a part under the pulse mode is minimal, which is why the average value over a period of the oscillations of power factors is, respectively, minimal. This was established by solving analytical dependences.

2. We proposed new procedures for the calculation of contact pressure and specific friction force when extruding a thread while imposing axial, radial and torsional oscillations. The system of the derived dependences, which describes the influence of oscillation amplitude, oscillation direction, deformation rate, and mechanical properties of the machined material on the magnitude of contact pressure, makes it possible to estimate parameters of the process of plastic deformation when imposing the ultrasound. By employing such a description, it is possible to derive the value of contact pressure and friction forces for each region of the load chart.

3. As follows from the obtained results of the study, the largest effect on the magnitude of contact pressure is exerted by the amplitude of oscillations and their direction. It is expedient to apply the axial oscillations. The value of the oscillation amplitude depends on the diameter of the thread to be treated.

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EFFECT OF MICROWAVE DRYING OF THE SPINES OF BOOK BLOCKS ON THE QUALITY OF PRINTED MATERIALS

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Досліджено кінетику природного та мікрохвильового висушування клейових з'єднань книжкових блоків. Визначені класифікаційні ознаки сушильних пристроїв. Розроблено імітаційну модель розподілу вологи в заклеєному корінці книжкового блока. Встановлені закономірності впливу теплопровідності матеріалів, формату видання, його товщини, характеристик паперів та клеїв на процес висушування. Визначено оптимальні режими сушіння та їх вплив на якість книг

Ключові слова: корінці книжкових блоків, клейові з'єднання, мікрохвильове висушування, якість друкованих книг

Исследована кинетика природной и микроволновой сушки клеевых соединений книжных блоков. Приведена классификация сушильных устройств. Создана имитационная модель распределения влажности в заклеенном корешке книжного блока. Установлены закономерности влияния теплопроводности материалов, формата издания, его толщины, характеристик бумаг и клеев на процесс сушки. Определены оптимальные режимы сушки и их влияние на качество книг

Ключевые слова: корешки книжных блоков, клеевые соединения, микроволновая сушка, качество печатных книг

1. Introduction

An analysis of modern designs and technologies for the production of printed books reveals that a significant part of semi-finished products in bookbinding must undergo a process of gluing. It requires an additional operation of drying, which under natural conditions is a time-consuming process. It is known that natural drying of glued joints is difficult to