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THEORETICAL PREREQUISITES TO THE WORKING SURFACES OF THE SCREW WORKING BODIES

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Summary. *It is known that during operation of screw working bodies (SWB) the outer edges of the spiral face the most excessive wear, so one should strengthen it with the external spinning along outer diameter while their production. There were suggested the design of the device and theoretical essentials for determination of strain effort of the workpiece in order to reinforce the latter were elaborated. Analytical correlations for determining of radiality tangential strain effort as well as torque to rotate the screw during the rotational spinning.*
Key words: *screw working bodies, reliability, durability, performance characteristics.*

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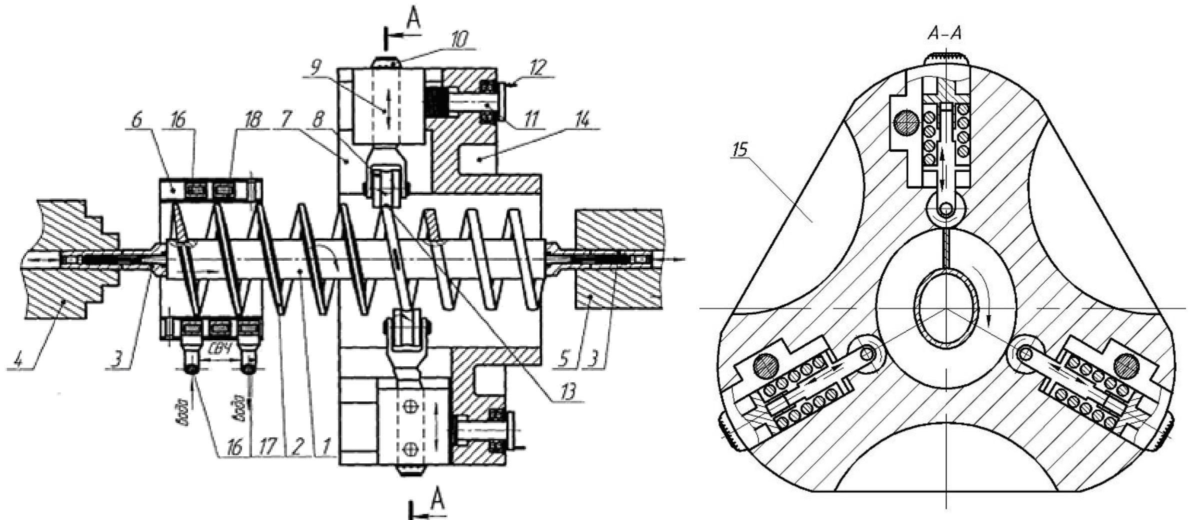
Problem setting. It is known that during operation of screw working bodies (SWB) the outer edges of the spiral face the most excessive wear. That is why one should strengthen the outer edge of screw surface with rotation spinning method during production process of SWB with improved operation reliability and durability.

Analysis of the latest research and issues. The problems of improvement of reliability and durability were exposed by Moshnin E.N. [1], Poluhin I.P. [2], Kosilova A.G. [3], Gevko B.M. [4], Pilipec' M.I. [5], Rogatins'kij R.M. [6], Rimar V.H. [7] and many others.

Research implementation. During operation of screw working bodies the outer edges of the spiral face the most excessive wear. The authors suggested reinforcement of the outer edges of the spiral by means of spinning (Fig. 1) during production of screw working bodies with up-graded reliability and durability.

The screw working body, consisting of a barrel or pipe 1 and rigidly welded to it screw stripe 2, is deadly locked by two ends to turning lathe with collet fixtures 3 from both sides of mentioned construction elements. From the left end of collet fixture the screw working body is fixed into jaw or other chuck 4 of popular design. The screw working body is also fixed into deadhead 5 with the possibility of circular and axial rotation. Inductor 6 is rigidly mounted (no image on the technical drawing) at the left side of screw working body on the foundation slab of the turning lathe, which embraces with internal diameter the screw stripe 2 along its external diameter with the possibility of relative motion. The reeling-out unit 7 is rigidly mounted on foundation slab of the turning lathe rightward to the inductor 6, which is surrounded with three crimping wheels 8 into holders 9 with regulating dial scales 10 and the mechanism 11 of their relative axial motion for location of the crimping wheels 8 with handles 12 during formation of external contour of the screw stripe 2. Here, the crimping wheels 8 are located on the angle that equals the ascending angle of screw spiral. Besides, the half-round circular slots 13, which are made in crimping wheels 8 along their external diameter, form the outer surface of the thickened screw stripe with required shapes and dimensions. Two types of windows 14 and 15 are proportionally made around the hull in order to decrease the weight of the reeling-out unit 7. The screw tubular spiral with in-hale 16 and out-hale 17 pipes for liquid refrigerating agent of the high frequency current inductor 18 is made to secure the normal operation of the device and the inductor 6 as well as for heat withdrawal from the heating area.

The device operation goes as follows. Left and right shaft 1 ends are mounted into collet fixtures 3; the left one is rigidly fixed inside the jaw chuck of turning lathe and the right one – into deadhead 5.



a) b)

Figure 1. a) Device to produce screw working bodies with up-graded operation reliability and durability; b) intersection A-A

Before this they mount the inductor 6 with his internal hole as well as internal diameter and reeling-out unit 7 on screw working body. The crimping wheels 8 are meanwhile moved in the uppermost position with regulating dial scales 10. After rigid fixation of reeling-out unit 7 on the foundation slab of turning lathe, they start mounting of crimping wheels 8 in holders 9 on required crimping diameter and step by means of dial scale 10 and handle 12. Here the allowance rate is divided on three wheels according to the following sequence: the first and the second crimping wheels crimp the screw stripe on allowance rate 0,35 Δ, where Δ – allowance rate; the third crimping wheel is on allowance rate 0,3 Δ with deviation error of 10…20%. The reeling-out unit 7 is moved into rightmost position, then they switch on the inductor 6, heat the left end of screw stripe 2 and turn on the lathe with spindle. Then the jaw chuck 4 rotates and moves the screw working body around, which with screw stripe 2 along the outer diameter 5 interacts with crimping wheels 8 of crimping head. The latter moves in axial direction on pre-determined step of screw working body and increases its thickness along outer diameter up to pre-determined dimensions.

Having finished the technological process of crimping of screw stripe, they stop the turning lathe, dismantle the screw working body from the foundation slab and fix the next one instead.

In some cases of crimping of screw working bodies one can operate under cold conditions.

To determine the strain effort of perpetual screw's blank part in the mentioned above device let us have a look at analytical model on Fig. 2.

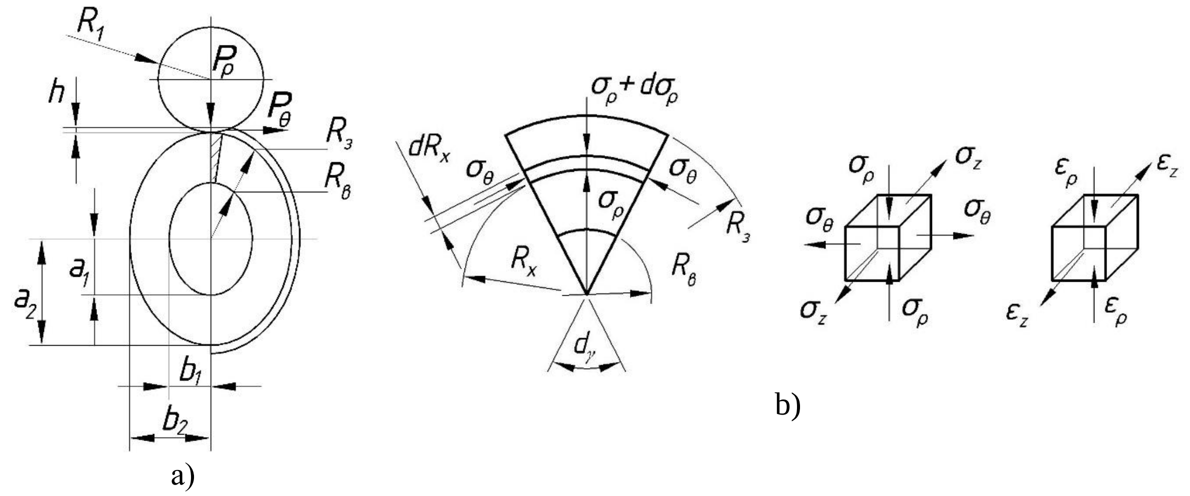


Figure 2. Analytical model to determine the strain effort for perpetual screw's blank part: a) scheme of interaction between perpetual screw and crimping wheel; b) stress condition of elementary sector

During deformation of outer edge of perpetual screw, there appears axis-symmetric strain, which allows determining stress condition at the spot of deformation by means of investigation of stress condition of elementary sector (Fig. 2b) on the angle *dγ*. The affiliated stresses here are equal to zero, and radial stresses σ_ρ and tangential stresses σ_θ are the main ones.

Let us investigate the balance condition of stripe with width dR_x, which is located at the distance R_x from the center at small transpositions of the blank part in polar coordinates system. Let us design the forces on the radius heading through the center of sector and compare their sum to zero with an eye on the fact that changes in the perpetual screw material's thickness is determined with the dependency:

$$S = S_B \sqrt{\frac{R_B}{R_X}}, \tag{1}$$

where S_B – thickness of perpetual screw material at internal diameter, mm;

R_B – internal radius of perpetual screw, mm.

As the screw working body is ellipsis-shaped then the internal radius is equal to:

$$R_B = a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}. \tag{2}$$

Correspondingly, the external radius of perpetual screw is:

$$R_з = a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}. \tag{3}$$

Having taken into account the formula (2.83), the balance equation will be recorded as follows:

$$(\sigma_\rho + d\sigma_\rho)\cdot S_B\sqrt{\frac{R_B}{R_X + dR_X}}\cdot d\gamma\cdot\left(R_X + dR_X\right) - \sigma_\rho R_X\, d\gamma\, S_B\sqrt{\frac{R_B}{R_X}} - \\ - 2\sigma_\theta d\, R_X\, S_B\sqrt{\frac{R_B}{R_X + dR_X}}\sin\left(\frac{d\gamma}{2}\right) = 0. \quad (4)$$

Having taken into account the fact that after simplifications for small angles $\sin\left(d\gamma/2\right) = d\gamma/2$, we will obtain:

$$\sigma_\rho\sqrt{\frac{R_B}{R_X + dR_X}}R_X + \sigma_\rho\sqrt{\frac{R_B}{R_X + dR_X}}dR_X + d\,\sigma_\rho\sqrt{\frac{R_B}{R_X + dR_X}}R_X - \\ - \sigma_\rho\sqrt{\frac{R_B}{R_X}}\cdot R_X - \sigma_\theta d\, R_X\sqrt{\frac{R_B}{R_X + dR_X}} = 0. \quad (5)$$

As the change of perpetual screw’s thickness is inconsiderable and it does not remarkably influence upon radial stresses, we will simplify the formula (5) down to under-the-root expressions. Then we will obtain the balance equation:

$$\sigma_\rho d\, R_X + d\,\sigma_\rho R_X - \sigma_\theta d\, R_X = 0\,. \quad (6)$$

To solve the equation (6), we use the plasticity equation without relevance to material enforcement as the strain occurs in heated condition:

$$\sigma_\rho - \sigma_\theta = \beta\,\sigma_S\,, \quad (7)$$

where β – coefficient accounting on action of axial stress, β=1,15;

σ_S – flow of stress for perpetual screw’s material, MPa.

Having substituted the equation (7) into the equation (6) we will solve the differential equation and obtain:

$$\sigma_\rho = -\beta\sigma_S \ln R_X + C_1. \quad (8)$$

The integration constant C_1 we determine according to boundary conditions. On the edge of interaction between crimping wheel and perpetual screw there appear the contact stresses σ_k. Then:

$$C_1 = \beta\sigma_S R_з + \sigma_k\,. \quad (9)$$

Having substituted the values from the formula (9) into formula (8) we will get:

$$\sigma_\rho = \beta\sigma_S \ln\frac{R_з}{R_X} + \sigma_k\,. \quad (10)$$

The maximal radial stresses appear at internal edge of the perpetual screw, then:

$$\sigma_{\rho\max} = \beta\sigma_S \ln \frac{a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}}{a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}} + \sigma_k . \tag{11}$$

Radial force of perpetual screw's strain is determined according to the formula:

$$P_\rho = \sigma_{\rho\max} F , \tag{12}$$

where F – contact area between crimping wheel and the perpetual screw, mm^2.

According to the analytical model on Fig. 1, the contact area will be computed due to the formula:

$$F = l \cdot S_3 , \tag{13}$$

where l – the length of contact arc between crimping wheel and the blank part, mm;

S_3 – the thickness of perpetual screw's material on outer radius, mm.

The contact arc's length will be computed as follows:

$$l = \arccos\left(\frac{R_1 - h}{R_1} \right) \cdot R_1 , \tag{14}$$

where R_1 – radius of crimping wheel, mm;

h – the value of perpetual screw's material strain in radial direction, mm.

Having substituted the equation (14) into equation (13) and basing on the equation (1) we will get:

$$F = \arccos\left(\frac{R_1 - h}{R_1} \right) \cdot R_1 \cdot S_B \sqrt{\frac{R_B}{R_3}} . \tag{15}$$

Then the radial strain effort is equal to:

$$P_\rho = \left(\beta\sigma_S \ln \frac{a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}}{a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}} + \sigma_k \right) \arccos\left(\frac{R_1 - h}{R_1} \right) \times$$
$$\times R_1 S_B \sqrt{\frac{a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}}{a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}}} . \tag{16}$$

The tangential strain effort will be found according to the formula:

$$P_\theta = \left(\beta\sigma_S \ln \frac{a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}}{a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}} + \sigma_k \right) \arccos\left(\frac{R_1 - h}{R_1} \right) R_1 \times$$
$$\times \sin\left(\frac{R_1 - h}{2R_1} \right) S_B \sqrt{\frac{a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}}{a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}}}. \quad (17)$$

The torque required to rotate the perpetual screw is determined as follows:

$$M = m \cdot P_\theta \cdot R_з ; \quad (18)$$

$$M = m \left(\beta\sigma_S \ln \frac{a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}}{a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}} + \sigma_k \right) \arccos\left(\frac{R_1 - h}{R_1} \right) R_1 \times$$
$$\times a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}} \sin\left(\frac{R_1 - h}{2R_1} \right) S_B \sqrt{\frac{a_1^2 b_1^2 \left(\frac{\cos^2\theta}{a_1^2} + \frac{\sin^2\theta}{b_1^2} \right)^{\frac{3}{2}}}{a_2^2 b_2^2 \left(\frac{\cos^2\theta}{a_2^2} + \frac{\sin^2\theta}{b_2^2} \right)^{\frac{3}{2}}}}, \quad (19)$$

where *m* – the number of simultaneously working crimping wheels.

The analysis of dependencies between spinning momentum and stripe height was carried out on the basis of the formula (18) according to the program attached in the annexes. Due to calculation results, we made a graph (Fig. 3) of torque dependency being necessary for rotation of perpetual screw from radius of crimping wheel.

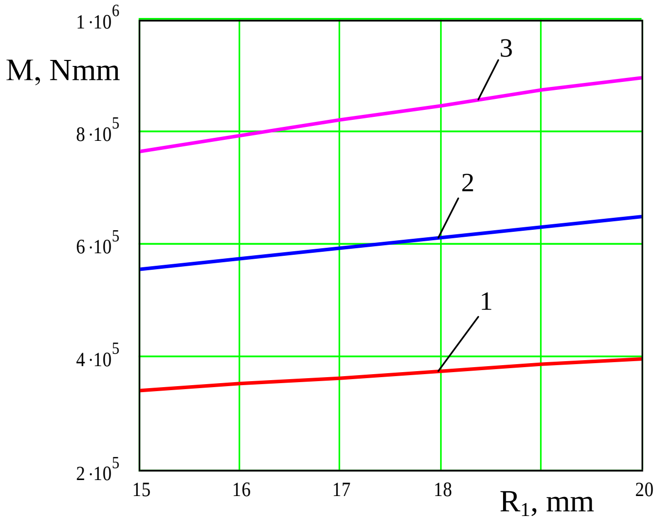


Figure 3. Graph of torque dependency being necessary for rotation of perpetual screw from radius of crimping wheel: 1 – R_3=50 mm; 2 – R_3=60 mm; 3 – R_3=70 mm

Apparently, from the graphs, the radius of forming crimping wheel influence slightly on the value of torque for the perpetual screw under process of enforcement. In addition, during enforcement of outer edge from the side of small semi-axis of ellipsis during transition on the big semi-axis the momentum grows in 1.3 – 1.5 times.

Having based on accomplished research, one can make the following conclusions:

There was elaborated the design of device for rotated crimping of MWB along its external diameter in order to improve the operation reliability and durability, which has all rights reserved. The authors presented the analytical dependencies to determine the radial, tangential strain effort and the value of torque being necessary for rotated reeling.

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ТЕОРЕТИЧНІ ПЕРЕДУМОВИ ЗМІЦНЕННЯ РОБОЧИХ ПОВЕРХОНЬ ГВИНТОВИХ РОБОЧИХ ОРГАНІВ

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Резюме. *Як відомо, в процесі роботи гвинтових робочих органів (ГРО) найбільше зношення зазнають зовнішні кромки спіралі. Тому є доцільним зміцнювати її зовнішнім обкатуванням по зовнішньому діаметру в процесі їх виготовлення. Запропоновано конструкцію пристрою й розроблено теоретичні передумови визначення зусилля деформації заготовки з метою її зміцнення. Виведено аналітичні залежності для визначення радіальності тангенціального зусилля деформації, а також крутильного моменту для обертання шнека під час ротаційного обкатування.*

Ключові слова*: гвинтові робочі органи, надійність, довговічність, експлуатаційні властивості.*

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