Development of methods for calculating cutting modes when processing the internal cycloidal screw surface using the original method used in drilling

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Annotation. In this paper, we consider the problems that arise when using screw volumetric machines when working with chemically aggressive media. To solve this problem, it was proposed to use a chemically resistant material of fluoroplast for the manufacture of screw machine clips. To implement the process of creating clips, the kinematics of methodagerotor drilling of cycloidal screw holes was proposed, and a method for calculating processing modes was developed.

Introduction
Single-screw pumps and units based on a screw pair are widely used in various industries for pumping oil-containing products, volumetric dosing of viscous substances, and even in 3D printing [1]. The working body of single-screw pumps is a screw pair: the rotor and the cage. The main surface of these parts is a complex profile screw surface, which is generally characteristic of parts of modern machines [2]–[5]. Most manufacturers of screw machines and dispensers use injection molding of elastomeric materials in a form where the hole profile is formed by using a rod made using a similar technology as the rotor of such machines [6]–[9]. The materials most common in the manufacture of screw machine clips include: nitrile butadiene rubber (NBR), ethylene propylene rubber (EPDM), fluoro rubber (FKM), polyurethane (PU). But foundry materials used in the creation of screw clips do not have sufficient chemical resistance to use them for transporting chemically aggressive media, such as: ammonia, aniline, acetone, butyl acetate, arsenic, ammonium phosphate, ethyl acetate, and others.

To solve the problem of using single-screw pumps with chemically active substances, it was proposed to use fluoroplast (PTFE) as the material of the cage, which is not susceptible to the effects of the above materials. But fluoroplast cannot be cast into a casting mold, it can only be processed by mechanical methods. There are some variants of processing a complex-profile screw surface by blade methods: stretching, "drilling", milling with a disk cutter [10]–[11], however, the implementation of these methods is practically impossible.

The pulling method has several disadvantages such as the complexity of chip removal in connection with the length of the screw holes, the complexity of manufacturing tools, as well as the kinematics of the movement of the broach, that is, the tool must not move along the straight path, and to twist in a spiral, which complicates the use of this method. Milling with a disc cutter, since the availability of the inner surface of the holder is very limited, the tool stiffness is greatly reduced by...
reducing the cross section of the holder, which will reduce the already not very high quality of the surface obtained as a result of milling. The method of laser drilling is based on a complex mutual kinematics of the movement of the clip and the profiled tool, as a result of which the trajectory of the cutting edge describes the full profile of the cycloidal screw surface. With this method, the greatest complexity is created by the shape of the cutting tool, as well as the joint complex kinematics of the movement of the tool and the clip.

Methods

Let's focus on the method of "drilling", as of all these methods, it is the most promising in terms of implementation in production.

Figure 1 shows the kinematics of the drilling method. The position (1) shows the shape of the intended instrument. Position (2) denotes a billet in the form of rolled products, the tool guide is a bronze bushing, shown in position (3). With the mutual complex rotational movement of the workpiece and the tool, as well as the axial feed of the tool, the internal cycloidal helical surface is formed. The proposed processing method is performed using a kinematic system with three controlled coordinates, two rotational and one translational. With this method of processing, the most important aspect for obtaining a high-quality surface of the screw cage is strict compliance with the joint kinematics of the movement of the rotor-tool and the workpiece-cage:

$$ N_p = \left( 2N_o + \frac{S}{h} \right), $$

Even a small deviation in the speed of rotation of the tool or workpiece can lead to jamming of the tool or incorrect formation of the cycloidal screw surface.

For stable cutting conditions, it is necessary to choose the tool sharpening, so that the material is cut, and not plastically deformed, and choose the cutting angles: back, front. Based on the recommendations for processing PTFE, the front angle should be at least 10°. Since the shape of the "drill" corresponds to the shape of the rotor that rotates in the screw cage, the back angle can be made 0° to give additional rigidity to the tool. Selecting a suitable cutting edge for forming a complete profile of the internal screw surface, the analysis of the intersection of the tool surfaces with the workpiece and the already processed area was performed.
Drawing 2 shows a simulation written in the program "Graphing Calculator-Desmos". The section of the workpiece (POS. 1) and the tool (POS. 2) is presented. the intersection point of the back and front surface of the tool describes the "ellipse" trajectory in the workpiece (POS.3). During the simulation, it was found that in different sections at different times, the front and rear angles change in different ranges. For the front and rear corners, the range is from -12.5 ° to +12.5°, which is unacceptable, so it was decided to choose the cutting edge so that the rear angle varies from 0 to +25°, and the front angle is separately sharpened and is in the range of 10 ° to 35°, which is acceptable for processing soft materials such as fluoroplast [12]–[14].

![Figure 2. The trajectory of the cross section of the cutting edge and tool angles](image)

We calculate the required cutting power and torque for eccentric drilling of plastic material[15]–[18]. When calculating the drilling capacity, it is necessary to calculate the specific material removal-Q (cm³ / min):

\[
Q = \frac{s_{\text{min}} \cdot \pi \cdot D^2}{4 \cdot 1000},
\]

where \(s_{\text{min}}\) — minute tool feed (mm / min);
\(D\) — drill diameter (mm).

Using this formula, it is not possible to calculate the specific material removal when drilling a cycloidal screw surface, because the cross-sectional area differs from classical drilling. Then, according to (Fig. 3), the formula for the specific removal of material for eccentric drilling after all transformations will have the form:

\[
Q = \frac{s_{\text{min}} \cdot \pi \cdot (d_r^2 - d_o) + 16 \cdot e \cdot d_r \cdot s_{\text{min}}}{4 \cdot 1000},
\]

where \(s_{\text{min}}\) — table feed of the tool[mm/min];
\(d_r\) — rotor diameter[mm];
\(d_o\) — hole diameter in the workpiece[mm];
\(e\) — the eccentricity of the rotor-tool[mm].
The calculation of the required power $P$ (kW) for traditional drilling is calculated as follows:

$$P = \frac{Q \cdot k_c}{60000 \cdot \eta},$$  \hspace{1cm} (4)

where $Q$ — specific material consumption [cm$^3$/min];

$k_c$ — specific cutting force [N / mm$^2$], table value;

$\eta$ — the efficiency of the main drive of the cutting movement of equipment, dimensionless value;

Substituting the formula (3) in (4), and presenting the minute feed as a product $s_{min} = s_{rev} \cdot n$, where

$s_{rev}$ — tool feed per revolution, $n$ — relative speed of the tool relative to the clip, $n = (N_p - N_o)$.

Receive:

$$P = \frac{k_c \cdot s_{rev} \cdot n \cdot (\pi \cdot (d_r^2 - d_o^2) + 16 \cdot e \cdot d_r)}{\eta \cdot 240000000},$$ \hspace{1cm} (5)

where the coefficient 240,000,000 is used for converting units of measurement.

Then, the required torque can be calculated using the following formula:

$$M = \frac{k_c \cdot s_{rev} \cdot (\pi \cdot (d_r^2 - d_o^2) + 16 \cdot e \cdot d_r)}{\eta \cdot 25263}.$$ \hspace{1cm} (6)

Find the relationship between the speed at the edge of the cutting edge at the maximum radius of the eccentric drill from the angle of rotation of the rotor.

$R$ — maximum radius of rotation of the cutting edge of the tool in this section, constant value [mm];

$\alpha$ — the angle of rotation of the clip-blank, the angle of rotation of the rotor, respectively, is 2 times greater, since its rotation speed is twice as large [degrees];

$r$ — the radius of rotation of the cutting edge in the clip, a variable value, depends on the angle of rotation of the clip [mm];

$V_o$ — speed of the rotor cutting edge in the cage [m/min];

$V_p$ — rotor cutting edge speed [m/min];

$\theta$ — the angle between the velocity vector [degrees];

$V_{rev}$ — speed of the rotor cutting edge relative to the cage [m/min].
The modulus of the sum of vectors is calculated using the formula:

\[
\vec{V}_{rev} = \vec{V}_o + \vec{V}_p = \sqrt{|\vec{V}_o|^2 + |\vec{V}_p|^2 - 2 \cdot |\vec{V}_o| \cdot |\vec{V}_p| \cdot \cos \theta},
\]

(7)

Rotor cutting edge speed:

\[
|\vec{V}_p| = \frac{\pi \cdot 2 \cdot R \cdot N_p}{1000},
\]

(8)

where \(N_p\) — rotation speed of the tool rotor [rpm].

Speed of the rotor cutting edge in the cage

\[
|\vec{V}_o| = \frac{\pi \cdot 2 \cdot R \cdot N_o}{1000},
\]

(9)

where \(N_o\) — the speed of rotation of the workpiece-clips [rpm].

The value " \(r\) " is unknown, so we will find the dependence of this value on \(\alpha\) and other known values. According to Figure 5, by the cosine theorem, the dependence takes the following form:

\[
r^2 = R^2 + e^2 - 2 \cdot R \cdot e \cdot \cos (180 - 2\alpha),
\]

(10)

where \(e\) — the eccentricity between the axes of rotation of the tool and the workpiece [mm].

Then, formula (9) takes the form:

\[
|\vec{V}_o| = \frac{\pi \cdot 2 \sqrt{R^2 + e^2 - 2 \cdot R \cdot e \cdot \cos (180 - 2\alpha)} \cdot N_o}{1000},
\]

(11)

According to Figure 5, by the cosine theorem, the last component of the formula (7), namely \(\cos \theta\) has the form:

\[
e^2 = R^2 + r^2 - 2 \cdot R \cdot r \cdot \cos (\theta),
\]

\[
\cos (\theta) = \frac{R^2 + r^2 - e^2}{2 \cdot R \cdot r}
\]

(12)
According to formula (13), the speed distribution of the cutting edge of the tool relative to the angle of rotation of the clip will have the following form, and the point of extremum and therefore the maximum cutting speed will be located at the angle \( \alpha = 90^\circ \): figure 6.

Substitute (12), (11), (10), (9), (8) to the formula (7):

\[
V_{rev} = \frac{2\pi N_0}{1000} \sqrt{R^2 + e^2 + 2 \cdot R \cdot e \cdot \cos(180 - 2\alpha)}.
\]  

(13)

**Results and discussion**

According to formula (13), the speed distribution of the cutting edge of the tool relative to the angle of rotation of the clip will have the following form, and the point of extremum and therefore the maximum cutting speed will be located at the angle \( \alpha = 90^\circ \): figure 6.
Then, the maximum and minimum cutting speed for a specific cutting edge section will be:

\[ V_{rev,\text{max}} = \frac{2\pi N_o (R + e)}{1000}, \quad (14) \]

\[ V_{rev,\text{min}} = \frac{2\pi N_o (R - e)}{1000}. \quad (15) \]

Based on the graph shown in Figure 6, the cutting speed will not be constant, but will vary in the range of 40% and this is considered only one section of the cutting edge, with the highest cutting speed. Such a change can both positively and negatively affect the quality of the resulting surface [19]–[20].

According to (6) it is possible to find out the torque on the tool, as well as the cutting force acting on the tool. But this is the total force that does not show the load distribution along the cutting edge, so the development of methods for determining the distribution of cutting force is a promising task.

**Conclusions**

As a result of analysis of modern methods of forming of internal helical surfaces of the clips are single screw pumps, it was identified that the most promising method blade processing not casting materials clips is the method of "drilling", the implementation of which involves a number of technologicheskaya, but it is feasible and enables a high quality inner cycloidal helical surfaces. The developed method of calculating the cutting moment and cutting speed requires experimental confirmation.

In the future, it is planned to develop a design of the installation based on the proposed kinematics of the movement of the tool and the workpiece, which will clarify the processing modes and geometry of the tool.

**References**

[1] Enríquez-Méndez Y.M., Torres-Toledano J.G., Rojas-Sánchez F.A. Progressive cavities pump: a case of study // Gasmexico/ — 2015. P. 1–17.

[2] Vasiliev A.S., Goncharov A.A. Some aspects of problematics in designing technological complexes // IOP Conference Series: Earth and Environmental Science. — 2018. P. 1–7.

[3] Vasiliev A. S. Directed formation of operational properties of parts in technological environments // Bulletin of the South Ural state University, 2017, no. 17, Pp. 33–40.

[4] Lizardsyn P. I., Heifets M. L., Klimenko S. A., Vasiliev A. S. Technological and operational inheritance of quality indicators in the life cycle of machine-building products // Reports of the national Academy of Sciences of Belarus, 2005, no. 2, Pp. 130–135.

[5] Averchenkov V. I., Vasiliev A. S., Heifets M. L. Technological heredity in forming the quality of manufactured parts // science-Intensive technologies in mechanical engineering. — 2018. no. 10. Pp. 27–32.

[6] Goncharov A. A., Vasiliev A. S., Gemba I. N. Modern methods of processing screw surfaces of screw pump rotors // Bulletin of the Rybinsk state aviation technological Academy named after P. A. Solovyov, 2017, no. 1, Pp. 202–208.

[7] Goncharov A. A., Gemba I. N. Processing of complex profile details of the type of rotation bodies on CNC machines // Chief mechanic. — 2015. no. 8. Pp. 26–31.

[8] Vasiliev A. S., Goncharov A. A. Special strategy for processing complex conical screw surfaces of working bodies of single-screw compressors // Notes of the mining Institute. — 2019. no. 235. Pp. 60–64.

[9] Goncharov A. A., Ahmad D. N., Schadilov, A. S., Expansion of technological possibilities of the standard equipment with CNC for machining of the helical surfaces of the rotor single screw pumps // Guide. Engineering journal with Appendix. — 2018. no. 8. P. 8–13.
[10] Maksimova E. sh., tyutrin Nikolay Orestovich, problems of manufacturing parts from fluoroplast-4 by mechanical processing methods. Irkutsk national research technical University // life cycle of structural materials (from receipt to disposal) Irkutsk, April 26–28, 2017. P. 138–144.

[11] Valovsky V. M. Screw pumps for oil production, Moscow, publishing house "Oil economy", 2012., 248s.

[12] Erenkov O. Yu., Ivakhnenko A. G., Hosen R. I. New combined methods of processing polymer materials by cutting on the basis of preliminary physical, chemical and mechanical effects. Vladivostok: Dalnauka, 2007. 219 p.

[13] Gavrilova A.V. Improving the quality of blade processing of polymer materials by preliminary mechanical deformation of blanks: abstract dis. Cand. tech. sciences'. Komsomolsk n/A: 2009. Typewriting.

[14] Composite materials based on polytetrafluoroethylene. Structural modification / Yu. K. Mashkov [et al.]. — Moscow: Mashinostroenie, 2005. — 240 p.

[15] Calculation of cutting forces when processing plastic materials in a wide range of thicknesses of the cut layer / Grubiiv S. V. / / Izvestiya Vuzov. Ser. "Engineering", — 2018. — № 2. — P. 3–10.

[16] Petrushin S.I., Proskokov A.V. Theory of constrained cutting: Chip formation with a developed plastic-deformation zone. Russian Engineering Research, 2010, vol. 30, no. 1, pp. 45–50.

[17] Rosenberg J. A. Cutting of materials. Kurgan, TRANS-Ural region, 2007. 294 p.

[18] Kabaldin Yu. G., Kuzmishina A. M. Quantum-mechanical modeling of deformation and fracture of the shear layer during cutting. Vestnik mashinostroeniya, 2016, no. 4, pp. 65–71.

[19] Dreval A. E., M. S. Lugansky built-up edge and the operability of the cutting tool//News of higher educational institutions. Engineering. 2012. no. 12. Pp. 3–7.

[20] Sergiev A. P., Vladimirov A. A., Shvachkin E. G. On the question of physical phenomena in the cutting zone//Federal state Autonomous educational institution of higher education "national research technological University "MISIS", RUSSIAN SCIENTIST. 2017. C.20–30.