# Determination of parameters and efficiency of use of screw supercharger of process lubricant when drawing

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Abstract
The method of parameters calculation of gear-driven screw supercharger for providing the liquid mode of friction when wire drawing with use of dry wire-drawing soap is developed.
Key words: DRAWING, PROCESS LUBRICANT, SCREW SUPERCHARGER, PARAMETERS CALCULATION

Dried and crushed salts of fatty acids (soap) of natural or artificial origin are used in pure form or with functional additives as process lubricant in case of so-called "dry" drawing. Such lubricant in prefocal zone of drawing die is gradually heated, condensed, undergoes thermochemical transformations and is changed from powdery condition into plastic state. In case of "wet" drawing, oils in pure form or with additives or appropriate emulsions are usually used as lubricants. If certain limit of pressure is exceeded, initial liquid lubricant can also gain properties of viscoplastic liquid [1].

Wire passing through a layer of lubricant substance catches it by adhesion force and involves into drawing die according to laws of hydrodynamics. Thus, in the center of deformation, the friction mode, which can be characterized by the corresponding dimensionless indicator [1], is formed:

$$k = \frac{\xi}{R_a}, \qquad (1)$$

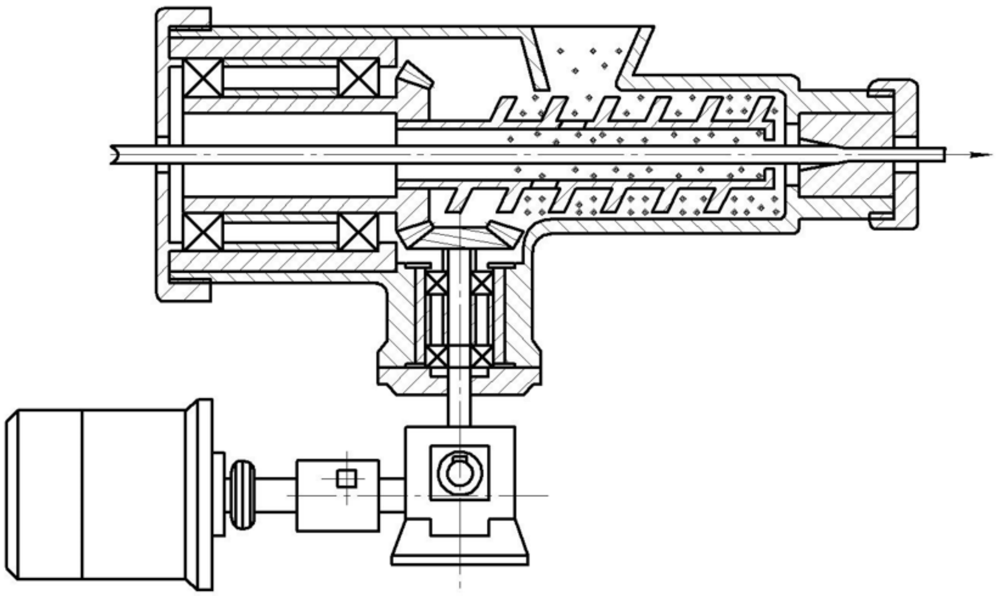
where $\xi$ - thickness of separation lubricant layer; $R_a$ - microrelief height in the deformation center.

In case of $k \geq 3$, lubricant almost completely separates the wearing surfaces of drawing die and wire, and the mode of friction becomes liquid. Experimental and theoretical data demonstrate that drawing in such mode is followed by minimization of friction that leads to reduction of energy consumption for metal deformation by 5 … 15%, increase of die life and also breakage  reduction by 1.5 … 3 times [2, etc.].

However fascinating ability of wire and natural hydrodynamic head of lubricant can be not enough for formation of liquid friction mode.

For intensification of lubricant intake into prefocal zone of monolithic drawing dies, in some cases, the use of gear-driven superchargers is effective. Such devices are arranged in front of working die and fixed hermetically in the last one [1, 2, etc.]. In particular, one of typical designs having proved itself to be positive is screw supercharger (Figure 1) [3, etc.].

At that, the problem of ratio of energy costs for the gear of supercharger working body and economy of energy when drawing after its application is relevant.



1 – electric motor; 2 – reducer and belt drive; 3 – die; 4 – lubricant (soap powder); 5 – body; 6 – screw blades; 7 – drawing die

**Figure 1.** The device for charging of process lubricant when wire drawing

The superchargers charging of viscoplastic liquid, in particular, of soap process lubracant when wire drawing are characterized by complex dependence between kinematic and geometrical parameters of screw, discharge, pressure and temperature, which are formed at the device outlet (and at the inlet of working die). At the same time, pressure and lubricant consumption in a prefocal zone of die must correspond to conditions at the inlet of supercharger.

Consequently, problem is a task of determination of rational parameters of screw supercharger, including characteristics of its gear: power, moment and speed taking into account features of mechanical transmission. Restriction of length of such device with the sizes of equipment of drawing machine can also be significant.

Therefore, the purpose of the whole paper is first of all development of method of determination of characteristics of screw supercharger of viscoplastic process lubricant for providing the liquid mode of friction, and also efficiency evaluation of use of such device when drawing.

Let us consider that the necessary power of gear of the screw supercharger is determined by a formula:

$$N = (1{,}2...1{,}4)\cdot\frac{M_{sc}\cdot\omega_{sc}}{\eta_1\cdot\eta_2}, \qquad (2)$$

where $M_{sc}$ - the moment in the shaft of supercharger; $H{*}m$; $\omega_{sc}$ - angular speed of its rotation, $c^{-1}$; $\eta_1$ - efficiency coefficient of supercharger taking into account use of bevel gear of rotation from the gear to a shaft of screw, countercurrent of lubricant substance and its leak flow in compressions can be accept equal to 0.70 … 0.80; $\eta_2$ - efficiency coefficient of gear, which is formed by efficiency of components of electromechanical gear of screw shaft.

Further comparison of shaft speed of the screw (rpm):

$$n_{sc} = 30\cdot\omega_{sc}/\pi\,. \qquad (3)$$

Rotation frequency of standard electric motors of industrial function ($n_s = 600\ldots3000$ *rpm* and efficiency $\eta_m = 0{,}8...0{,}9$) shows that they differ by several orders of magnitude. It can require the use of the engine (with gearing ratio $i_{sc}$ = 0,5...3), worm reduction gear (with gearing ratio $i_{red}$ of several thousands and efficiency coefficient $\eta_{red}$ = 0,7...0,75) and also belt drive (with gearing ratio $i_{bel} \le 5...7$ and efficiency $\eta_{bel}$ = 0,95...0,96) except for the mentioned bevel gear.

In case of $\eta_2 = \prod_{u=1}^{u}\eta_u$, where $\eta_u$ - $u$-*th* component of electromechanical transmission of shaft rotation of the screw supercharger.

A torque $M_{sc}$ in screw shaft according to data [4] approximately is

$$M_{sc} = 0{,}131\cdot m\cdot p_0\cdot(D_{sc}^3 - d_{sc}^3)\cdot tg\varphi_{av}, \qquad (4)$$

and discharge $Q_{sc}$ of lubricant substance (kg/*s*) in outlet of cylindrical screw supercharger with constant step Hsc (m) according to data [5] is determined:

$$Q_{sc} = 0{,}127\cdot(D_{sc} - d_{sc})\cdot(\mathrm{H}_{sc} - \delta_{sc})\cdot(1 - k_{ab})\cdot\rho_m\cdot\psi\cdot\omega_{sc}, \qquad (5)$$

where $m = 2...6$ - quantity of working steps of the screw; $D_{sc}$, $d_{sc}$ - diameter of the screw in outer generating line and diameter of its shaft respectively, m (Figure 2); $\varphi_{av}$ - average angel with an axis of surface screw of its helical blade in outer generating line and shaft respectively (in order to avoid a material separation from internal surface of device body, it is suggested: $\varphi_{av} \ge 10^0 = 0{,}174$ *radian*):

$$\varphi_{av} = 0{,}5\cdot(\varphi_D + \varphi_d)\,;\ \varphi_D = arctg\frac{H_{sc}}{\pi\cdot D_{sc}}\,;\ \varphi_d = arctg\frac{H_{sc}}{\pi\cdot d_{sc}}\,; \qquad (6)$$

$p_0$ - greasing pressure which at the outlet is developed by the supercharger, and simultaneously, lubricant pressure before the inlet to the drawing die, *N/m²*; $k_{ab}$ - absentee ratio, which characterizes distinction of speeds of lubricant substance stream in a screw shaft and in the field of its external diameter:

$$k_{ab} = 1 - [\cos(2\varphi_{av}) - 0{,}5\cdot f_{lub}\cdot\sin(2\varphi_{av})]; \qquad (7)$$

indicator of internal friction in lubricant layer:

$$f_{lub} = \frac{\tau_{liq}}{p_0}; \qquad (8)$$

$\tau_{liq}$ - shearing stress in a layer of viscoplastic liquid, *N/m²*; $\rho_m \approx 1000$ *kg/m³* - density of slightly compressed soap lubricant [2]; $\psi \to 1{,}0$ - filling coefficient of interturn space of the screw; $\delta_{sc}$ - screw flight thickness in the axial direction by outer diameter, m.

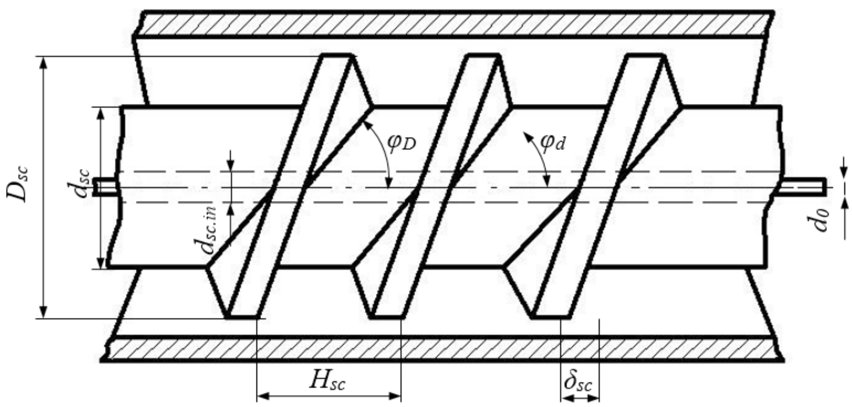



**Figure 2.** Scheme and characteristic sizes of screw

When determining dimensional characteristics of screw supercharger the following factors should be kept in mind.

It is usually accepted:

$$H_{sc} = (0{,}7...0{,}8)\cdot D_{sc} . \quad (9)$$

In this case, working length of screw is determined as follows:

$$L_{sc} = m\cdot H_{sc} < L_{des} , \quad (10)$$

where $L_{des}$ - design limitation length, for example, connected with the sizes of equipment of drawing machine.

In case of determination of $d_{sc}$ , it is necessary to consider presence in screw shaft of an axial hole with diameter $d_{sc.in}$ for passing of die of the maximum size $d_{0.\max}$ , which is characteristic for this machine:

$$d_{\text{sc.in}} = (1{,}2...1{,}4)\cdot d_{0.\max} . \quad (11)$$

Considering this, the value $d_{sc} > d_{sc.in}$ is selected constructively fulfilling condition of absence of self-braking of the moving substance: $d_{sc} \geq$ f ·Hsc and screw shaft durability condition:

$$\sigma_{eq} \leq [\sigma]_{com} , \quad (12)$$

where equivalent stress

$$\sigma_{\text{eq}} = \sqrt{\sigma_{com}^2 + 4\cdot\tau_r^2}$$

of compression and shearing stress of shaft rotation are:

$$\sigma_{com} = \frac{4\cdot P_{sc}}{\pi\cdot(d_{sc}^2 - d_{sc.in}^2)} \quad \text{and} \quad \tau_r = \frac{M_{sc}}{w}$$

respectively; axial force $P_{sc}$ (N) affecting the shaft is approximately determined by a formula [4]:

$$P_{sc} = 0{,}392\cdot m\cdot p_0\cdot(D_{sc}^2 - d_{sc}^2), \quad (13)$$

The moment of resistance of round shaft with through axial hole is

$w = \frac{\pi\cdot d_{sc}^3}{16}\cdot(1 - \frac{d_{sc.in}^4}{d_{sc}^4})$ [5], and considering yield point $\sigma_{\text{y}}$ of material of screw shaft and coefficient of margin of safety under compression $k_{mar} = 2...3$ - permissible stress is $[\sigma]_{com} = \frac{\sigma_y}{k_{mar}}$ .

The value $\delta_{\text{sc}}$ can be determined from bending strength condition of the helical blade of screw in its attachment point to the shaft. In this regard, similar to data [5] with an assumption that one flight of the screw can be assimilated to circular plate fixed on the internal contour of shaft, the maximum bending moment is determined by a formula:

$$M_{ben} = \frac{P_{sc}\cdot(D_{sc} - d_{sc})\cdot\left[1{,}9 - 0{,}7\cdot a^{-4} - 1{,}2\cdot a^{-2} - 5{,}2\cdot\ln a\right]}{32\cdot(1{,}3 + 0{,}7\cdot a^{-2})}, \quad (14)$$

where $a = D_{sc}/d_{sc} = 1{,}5...3{,}0$, and according to [6]:

$$\delta_{sc} \geq \sqrt{\frac{6\cdot M_{ben}}{[\sigma]_{ben}}}, \quad (15)$$

and the allowed stress in case of bending considering coefficient of margin of safety $k_{marben}$ can be accepted as

$$[\sigma]_{ben} = \frac{\sigma_y}{k_{marben}}$$

for corresponding steel.

At that, according to recommendations [4], it is necessary to provide fulfillment of the following condition in order to avoid slipping in an internal surface of the device body of the material moved with screw supercharger:

$$S_b > S_{fl} , \quad (16)$$

where the area of internal surface of the supercharger body along the length of one flight is $S_b = \pi\cdot D_{sc}\cdot(H_{sc} - \delta_{sc})$ ; area of one side of surface of one flight of the screw is

$$S_{fl} = \frac{1}{4\pi}\cdot(\pi\cdot \mathrm{D_{sc}}\cdot l_{\mathrm{D}} - \pi\cdot d_{sc}\cdot l_d + H_{sc}^2\cdot\ln\frac{\mathrm{D}_{sc} + 2\cdot l_{\mathrm{D}}}{\mathrm{d_{sc}} + 2\cdot l_{\mathrm{d}}} ;$$

$l_D, l_d$ - length of development of screw lines on a surface and screw shaft respectively: $l_D = D_{sc}/\cos\varphi_{\mathrm{D}}$; $l_d = d_{sc}/\cos\varphi_{\mathrm{d}}$, and angels $\varphi_D$ and $\varphi_d$ are determined by formulas (6).

For implementation of constant condition of consumption of lubricant substance in system "screw supercharger – drawing die" in addition to expression (5) and taking into account expression (1) for the liquid mode of friction, discharge of $Q_{\text{PL}}$(kg/s) of process lubricant in die has been determined:

$$Q_{PL} = V_0\cdot\rho_{PL}\cdot\frac{\pi}{4}\cdot\left[(d_{0.\max} + 2\cdot\xi)^2 - d_0^2\right] \approx \pi\cdot\rho_{PL}\cdot V_0\cdot d_{0.\max}\cdot\xi = 3\cdot\pi\cdot\rho_{PL}\cdot V_0\cdot d_{0.\max}\cdot R_a \quad (17)$$

where $V_0$ - drawing speed; $\rho_{PL}$=1300...1400 *kg/m³* – lubricant density after its passing into the center of deformation [2].

In practice of drawing, the discharge $q$ of process lubricant is usually determined by *kg/ton* of the stretched metal with density $\rho_{met}$. For such evaluation of calculation results for formula (17), it is possible to determine productivity $Q_{met}$ (kg/s) of drawing machine:

$$Q_{met} = \frac{\pi \cdot d_0^2}{4} \cdot V_0 \cdot \rho_{met}, \qquad (18)$$

Comparison of expressions (17) and (18) gives the following result:

$$q_{PL} = \frac{12 \cdot 10^3 \cdot R_a \cdot \rho_{PL}}{d_0 \cdot \rho_{met}} \text{ (kg/t)}. \qquad (19)$$

Calculations by formula (19) show results close to practical ones.

Further, comparing equalities (5) and (17) after transformations, expression for calculation of angular speed of screw shaft has been obtained:

$$\omega_{sc} = \frac{74{,}2 \cdot V_0 \cdot d_0 \cdot R_a \cdot \rho_{PL}}{(D_{sc} - d_{sc}) \cdot (H_{sc} - \delta_{sc}) \cdot (1 - k_{ab}) \cdot \rho_m}. \qquad (20)$$

The analysis of formulas (2), (4), (13) and (14) shows that determination of rational parameters of screw supercharger is connected with technological conditions of drawing. At that, one of the basic values for formation of the friction mode close to liquid in drawing die is pressure $p_0$ generated by screw supercharger in prefocal zone of die.

Determination of characteristics, which allow concretizing the value of the given formulas, must be development of the real materials.

**Conclusions**

The method of calculation of parameters of screw supercharger for providing the liquid mode of friction when drawing with dry soap process lubricant has been developed. It is shown that the key value defining characteristics of the device is lubricant pressure developed by the supercharger in prefocal zone of drawing die.

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