Control of influence of a thread on a bending of screws

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Abstract. The influence of the threads and the bending of screw on their moments of inertia of the cross section considered. This problem is actual since existing methods exclude from calculations the influence of supporting the thread, using as the basic geometrical parameter such as the internal diameter of the thread (diameter of cavities). Fundamental difference of a bend of the screw from a bend of a smooth rod consists that moment of inertia of the screw is a variable. It is shown that the change in cross-section moment of inertia along the length of the screw are essential and have periodic character. Analytical interrelation of the bending of the screw and the decreasing of moment of inertia of its cross section is established and equation describing this phenomenon is suggested. The greatest decrease of the moment of inertia occurs in the middle of the screw length, and the lowest - at its ends. Function and approximate coefficients for the main types of thread are proposed, which take into account this change.

1. Introduction
The pipeline fittings equip many installations and aggregates in chemical, oil-extracting and oil-processing industry, in metallurgy and power industry.
One of the most important classes of pipeline fittings are the shutoff valves — the devices used to periodic or one-time turning on, or shutdown of the pipeline or valves.
The screw-nut transfer is widely applied in gates of pipelines. Theoretical and experimental researches on the causes of failures or inefficiencies of mechanisms of gates under dynamic loading have shown that one of the weaknesses are the screws of mechanism of pipeline gates.
During the operation, the screws of pipeline gates are subjected to considerable forces and moments. If the screw length exceeds the diameter of more than eight times, then calculation of the longitudinal stability is necessary for these screws. When determining the constructional characteristics of the screws there is a problem to define of the influence of thread on their strength and rigidity parameters [1].
The existing methods exclude from calculations effect of support of a thread as use in calculations as the critical geometrical parameter - diameter of an internal thread of screw or use empirical relationships so-called resulting moment of inertia of the screw [2, 3].

2. Formulation of problem
Figure 1 shows three arbitrary cross sections of the screw. It can be seen that this section has a complex configuration, which cannot be described by elementary functions.
Therefore, to determine the moments of inertia of the cross section of the screw we have conducted a numerical experiment using the combined methods of calculations based on the software "SolidWorks2011" (Table 1).

![Different cross-sections of the screw: a) perpendicular; b) on the line of the helix of the thread; c) arbitrary.](image)

**Figure 1.** Different cross-sections of the screw: a) perpendicular; b) on the line of the helix of the thread; c) arbitrary.

### 3. Theory

Table I shows that the function describing the change of the moments of inertia along the length of the screw are clearly the periodic nature and can be approximated by type $J(z) = J_o + a \cdot \sin(\omega z + \varphi)$, which for the definition of the coefficients can be expressed as:

$$J(z) = J_o + a \cdot \sin\left(\frac{\pi z}{b} + \varphi\right)$$  \hspace{1cm} (1)

where $a$, $\varphi$, $\omega$ and $J_o$, approximation coefficients, $b = \pi / \omega$. Function coefficients (1) are presented in Table 2 and 3.

Table 2 shows when you increase the thread pitch, amplitude and initial phase of harmonic functions (1) are increased, and the average value of the moment of inertia decreases and the angular frequency is the same for different types of thread.

**Table 1.** Changes the moments of inertia along the length of the screw, mm$^4$

| Thread type | 0.3 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 | 2.4 | 2.7 | 3.0 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| M10 Jx      | 250.9 | 227.6 | 235.7 | 264.6 | 273.8 | 250.9 | 227.6 | 235.7 | 264.6 | 273.8 |
| Jy          | 250.1 | 273.6 | 265.1 | 236.6 | 227.0 | 250.1 | 273.6 | 265.1 | 236.6 | 227.0 |
| M20 Jx      | 5481.9 | 5341.1 | 5308.9 | 5428.7 | 5536.2 | 5481.9 | 5341.1 | 5308.9 | 5428.7 | 5536.3 |
| Jy          | 5357.5 | 5497.4 | 5530.1 | 5410.6 | 5302.6 | 5357.5 | 5497.4 | 5530.1 | 5410.6 | 5306.0 |
| TR10 Jx     | 290.8 | 288.4 | 296.6 | 303.6 | 299.6 | 290.8 | 288.4 | 296.6 | 303.6 | 299.6 |
| Jy          | 301.2 | 303.1 | 294.9 | 288.3 | 291.4 | 301.2 | 303.1 | 294.9 | 288.3 | 291.4 |
| TR20 Jx     | 5912.9 | 5962.4 | 5940.9 | 5973.6 | 5954.4 | 5912.9 | 5962.4 | 5940.9 | 5973.6 | 5954.5 |
| Jy          | 5902.0 | 5970.8 | 5932.3 | 5901.6 | 5916.3 | 5962.4 | 5970.8 | 5932.0 | 5901.3 | 5916.3 |
| U10 Jx      | 313.5 | 328.7 | 323.4 | 304.2 | 297.7 | 313.5 | 328.7 | 323.4 | 304.2 | 297.7 |
| Jy          | 314.4 | 297.7 | 303.8 | 323.1 | 328.1 | 314.4 | 297.7 | 303.8 | 323.1 | 328.1 |
| U20 Jx      | 6081.5 | 6287.4 | 6236.0 | 5988.6 | 5891.6 | 6081.5 | 6287.4 | 6236.0 | 5988.6 | 5891.6 |
| Jy          | 6121.5 | 5899.7 | 5960.8 | 6208.8 | 6292.3 | 6121.5 | 5899.7 | 5960.8 | 6208.8 | 6292.3 |
Table 2. Approximation coefficients for different types of thread with a diameter of 20 mm

| Coefficients      | Metrical | Trapezoidal | Buttress |
|-------------------|----------|-------------|----------|
|                   | thread pitch, h, mm |
|                   | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| $a$, mm$^4$       | 25 | 58 | 125 | 5 | 15 | 38 | 94 | 160 | 225 |
| $J_0$, mm$^4$     | 6918 | 6113 | 5425 | 7120 | 6485 | 5936 | 7175 | 6600 | 6100 |
| $\varphi$, mm     | 0.06 | 0.11 | 0.17 | 0.18 | 0.4 | 0.68 | 0.04 | 0.06 | 0.08 |
| $\pi / \omega$, mm| 0.23 | 0.45 | 0.77 | 0.23 | 0.45 | 0.77 | 0.23 | 0.45 | 0.77 |

Table 3. Coefficients for different threads with the same thread pitch of 3 mm

| Coefficients      | Metrical | Trapezoidal | Buttress |
|-------------------|----------|-------------|----------|
|                   | diameter of thread, d, mm |
|                   | 10 | 20 | 30 | 10 | 20 | 30 | 10 | 20 | 30 |
| $a$, mm$^4$       | 25 | 125 | 570 | 8 | 38 | 90 | 17 | 225 | 900 |
| $J_0$, mm$^4$     | 250 | 5425 | 31340 | 296 | 5936 | 32830 | 314 | 6100 | 33400 |
| $\varphi$, mm     | 0.17 | 0.17 | 0.17 | 0.68 | 0.68 | 0.68 | 0.05 | 0.05 | 0.05 |
| $\pi / \omega$, mm| 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 |

Table 3 shows that the angular frequency of the harmonic function (1) does not depend on the diameter and thread type.

The initial phase of function (1) is constantly for the screw thread with the same type and the same thread pitch of and is not changed when the diameter changed.

Figure 2 shows the variation of the axial moment of inertia of the screw with thread TR20 and a thread pitch of 3 mm, built by the formula (1) (solid line) and tabular values of table 1 (dashed line).

Figure 2. The variation of the axial moment of inertia of the screw TR20×3: the formula (1) - solid line; the table values - dotted line.

The analysis of the Figure 2 allows making a conclusion about high accuracy of approximating the actual table values by formula (1).

Further, we study the influence of bending on the geometrical characteristics of the cross-section of the screw.
The longitudinal compressive forces in power screw jacks, screw presses, and the spindles of pipeline gates can achieve big values, when the screws may lose longitudinal stability, as a result, the bending deflections reach high values, and the screw material is experiencing of plastic deformations [4, 5].

As a result of numerical experiment, using a 3D-modeling package SolidWorks-2011, it was found that if the screw is bent, then its moment of inertia in all axial cross sections decreases proportional to the bending deflection (Figure 3).

The results of computer researches of a bending screw TR20×3 and $l = 1000 \text{ mm}$ are given in Table 4.

![Figure 3. The cross-sections of the screw cavity of the threads: a) straight screw; b) bending screw.](image)

Table 4. Change of the moment of inertia, mm$^4$, in different sections of screw with the thread TR20×3, length $L = 1000 \text{ mm}$, depending on the deflection $Y$

|      | Section A-A | Section B-B | Section C-C |
|------|-------------|-------------|-------------|
| 0    | 5954.45     | 5954.45     | 5954.45     |
| 1    | 5928.12     | 5930.06     | 5948.75     |
| 2    | 5896.54     | 5910.48     | 5936.36     |
| 3    | 5860.37     | 5892.23     | 5920.68     |
| 4    | 5840.43     | 5878.29     | 5910.22     |
| 5    | 5808.26     | 5858.59     | 5901.31     |
| 6    | 5770.12     | 5835.17     | 5891.05     |
| 7    | 5745.45     | 5815.86     | 5886.16     |
| 8    | 5710.26     | 5798.36     | 5879.24     |
| 9    | 5688.38     | 5779.62     | 5869.45     |
| 10   | 5659.24     | 5758.35     | 5860.45     |

4. Experimental results

Analysis of the data showed that the fundamental difference between the bending of the screw from bending smooth rod is that the cross-sectional moment of inertia of the screw is variable. It is shown that the change of the cross-section moments of inertia along the length of the screw is significant and
has the periodic in nature. An analytical relationship of the bending of the screw and reducing the cross-section moment of inertia and proposed the equation describing this phenomenon. The greatest decrease of the cross-section moment of inertia occurs in the middle of the screw and least at its ends. The adequacy of the developed models is confirmed by the results of experimental researches conducted in limited company "Livgidromash" under the leadership of Professor V. M. Ryazantsev [6]. This phenomenon is due to the fact that during bending of the screw in the stretched region of the threads of fibers are diverged. Moreover, if in the direct screw of the cross-section gets most of the thread, and then in a distorted screw in cross-section gets a smaller part of the thread, thereby decreasing the cross-section moment of inertia of the screw. The numerical experiment and processing of the obtained results allowed us to propose a convenient approximation of the dependence of changes in cross-section moments of inertia of the screw along its length. The use according to formula (1) more accurately determines the various parameters of screw mechanisms, such as the deflection of screws under transverse bending or characteristics to ensure their stable position of equilibrium at buckling.

5. Discussion of results
Analysis of the data leads to the conclusion that although the experimental and calculated values are close enough; however, the approximation coefficients «a» for various cross-sections differ significantly. Comparison of experimental and calculated data of changes the moment of inertia in different cross-sections is shown in Figure 4. It is proposed to use in the calculations the average value, for example, at \( l = 300 \text{ mm} \) (see Figure 4, middle line). It can be concluded that the screw is less resistance to bending than a smooth rod the same size and, as a function describing the change of the moment of inertia of half the length of the screw, we propose to use (2):

\[
J(z, y) = J_0 - a \cdot z \cdot y
\]  

(2)

where \( a, \text{ mm}^2 \), \( J_0, \text{ mm}^4 \) - approximation coefficients, \( y \) - deflection, mm.

Figure 4. The results of the researches of screw with thread TR20×3.

6. Conclusions
Thus, the functions describing the change of the cross-section moments of inertia of the along the length of the screw are proposed, it is shown that they are periodic in nature. The analytical relationship of the bending of the screw and reducing the cross-section moment of inertia installed and the equation (2) is proposed to account for this phenomenon. Developed method may be useful for a more accurate calculation of the power screw mechanisms.
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