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Force Conditions of Pressing Light-Alloy Drill Pipes with Spiral Ribbing

A. E. Afanas'ev*, V. R. Kargin, and B. V. Kargin*****
Samara State Aerospace University, Moskovskoe sh. 34, Samara, 443086 Russia
**e-mail: alexander.afanasiev@alcoa.com*
***e-mail: vrkargin@mail.ru*
****e-mail: kargin163@gmail.com, bkargin@mail.ru*

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Abstract—The equation for calculating the pressing force of drill pipes with spiral ribbing is proposed from the Perlin procedure based on the balance of active and reactive forces. The cross-section of a spiral pipe is presented in a form of a smooth pipe with a screw arrangement of metal fibers and outer spiral edges. A component taking into account the energy spent for the screw motion of metal is added to the formula. It is shown that the compacting force, which is found according to the modernized formula, is 28% larger than for a smooth pipe with the equal area. It is revealed that an increase in the angle of ascent of the rib spiral leads to an increase in force compared with that for longitudinally edged pipes.

Keywords: light-alloy drill pipe, spiral ribbing, pressing force

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INTRODUCTION

Light-alloy drill pipes with spiral ribbing over the outer surface, which are fabricated by the hot pressing method, find a broad application in drill technique. Due to the presence of screw ribbing, they substantially decrease the contact interaction area of a drill column with well walls, thereby decreasing the clamp appearance. Ribbing also promotes the flow turbulization of the washing liquid in a well-bottom zone and improves its washing, which favorably affects the drilling performance [1].

A promising method of producing pipes with an outer spiral ribbing is pressing with screw metal outflow [2–14]. Various process variants are possible in this case. According to one of them [3–5], pipes with outer screwlike ribs can be fabricated by pressing into the pressing die, the cross-section of which is similar to that of the rifle weapon barrel. The thread imparts the rotation motion to the pipe metal when it leaves the pressing die. The pressing die and a needle remain immobile during the process. Lubrication of the needle surface allows the pipe to rotate around it. In another variant, in order to intensify twisting of the billet metal before the input into screw channels of the pressing die, the needle is rotated in the direction coinciding with the metal twisting direction in screw channels of the pressing die [8].

It is established that the most rational method to press the pipes with an outer spiral ribbing is the method of twisting ribs immediately in the pressing die channel.

To substantiate the selection of the rational pressing technology of light-alloy drill pipes with an outer screw ribbing, we should know the force and torque, since the character of varying these parameters depends directly on the angle of ascent of the rib spiral, notably, its increase causes an increase in plastic shears in a plane perpendicular to the pipe axis and, correspondingly, the forces [14].

The purpose of this study was to develop analytical equations in order to analyze force conditions of pressing the spiral-ribbed pipes allowing for the screw metal outflow.

COMPUTATIONAL PROCEDURE

Currently, in order to calculate the compacting force, the Perlin formula is most often used. This formula is based on the power balance method of active and reactive forces [15–17]:

$$P = R_{\mathrm{pd}} + T_{\mathrm{cw}} + T_{\mathrm{pd}} + T_{\mathrm{pl}}, \tag{1}$$

where R_{pd} is the normal force across the pressure pad necessary to perform the main plastic deformation of pressing without allowing for the friction forces; T_{cw}, T_{pd}, and T_{pl} are the normal forces across the pressure pad appearing on the working surface of the container and a needle, matrix mirror, and parallel land, respectively.

This formula is most convenient for analyzing the compacting force of screw-ribbed pipes, since it is presented in a form of the sum of components of reactive forces, each of which reflects the influence of separate factors on quantity P. Let us correct this formula as applied to pressing conditions of the pipes with a screw metal outflow.

The cross section of spiral pipes is a complex figure formed by the conjugation of ribs and a smooth pipe part. The problem of finding the torque and force is not solved analytically because of the complexity of its contour. Therefore, the spiral pipe can be presented as consisting of several elements such as a smooth pipe with a screw arrangement of metal fibers and N outer spiral ribs with analytical solutions known for them. Then component R_{pd} can be written as a sum of forces separately for a smooth pipe (R_{pdp}) and ribs (R_{pdr}), i.e.,

$$R_{\text{pd}} = R_{\text{pdp}} + NR_{\text{pdr}}. \tag{2}$$

To take into account the torsional strain, additional component R_{scr} should be introduced into formula (2). Then

$$R_{\text{pd}} = R_{\text{pdp}} + NR_{\text{pdr}} + R_{\text{scr}}. \tag{3}$$

Finally, the dependence for determining the total compacting force of spiral pipes will take the form

$$P = R_{\text{pdp}} + NR_{\text{pdr}} + R_{\text{scr}} + T_{\text{cw}} + T_{\text{pd}} + T_{\text{pl}}. \tag{4}$$

When pressing spiral pipes, billet metal is divided into local volumes in a pressure zone according to the number of rib channel in a pressing die. Tangential metal flow is observed in local volumes adjoining them. In connection with this fact, the deformed state when forming the ribs in the limits of the local volume is considered planar to the first approximation, while the local volume is considered a rectangular strip with $F_{\text{n.r}}$, which is determined from the relationship

$$F_{\text{n.r}} = K_{\text{rib}}\frac{F_{\text{c}}}{N}. \tag{5}$$

Here, F_{c} is the cross-section surface area of a container and K_{rib} is the pipe ribbing coefficient [19]:

$$K_{\text{rib}} = \frac{NF_{\text{r}}}{F_{\text{p}}}.$$

To calculate R_{pdr}, we used the known Perlin formula derived for pressing a rectangular rib from a rectangular local volume [15]:

$$R_{\text{pdr}} = 1.1\frac{\alpha_{\text{pd}}}{\sin\alpha_{\text{pd}}}F_{\text{n.r}}S_{\text{dr}}\ln\lambda. \tag{6}$$

Here, α_{pd} is the calculated angle of the matrix channel, λ is the elongation ratio, and S_{dr} is the average deformation resistance in the compacting zone:

$$S_{\text{dr}} = \sqrt{S_{\text{db}}S_{\text{de}}},$$

where S_{db} and S_{de} are the deformation resistance of the billet metal at the input into the compacting zone and at the output from it.

According to the data [4], formulas for determining R_{pdp}, T_{cw}, and T_{pd} in the case of compacting the smooth pipe part with an immobile angle have the following form:

$$\begin{gathered}
R_{\text{pdp}} = \left[1.1\frac{F_{\text{c}}(1-K_{\text{rib}})}{\cos^2(\alpha_{\text{pd}}/2)} - \frac{\pi d_{\text{c}}^2}{4\cos^2(\alpha_{\text{ne}}/2)}\right]S_{\text{dr}}\ln\lambda, \\
T_{\text{cw}} = \pi\left[L_{\text{bil}} - (0.6 + 0.27/\sqrt{\lambda})(D_{\text{bil}} - d_{\text{c}})\right] \\
\times (D_{\text{bil}}f_{\text{cw}} + d_{\text{c}}f_{\text{ne}})S_{\text{db}}, \\
T_{\text{pd}} = \left[\frac{\pi(D_{\text{bil}}^2 - d_{\text{c}}^2)}{4\sin\alpha_{\text{pd}}} - \frac{abN}{\sin\alpha_{\text{pd}}}\right]f_{\text{pd}}S_{\text{dr}}\ln\frac{D_{\text{bil}} - D_{\text{c}}}{D_{\text{c}} - d_{\text{c}}}.
\end{gathered} \tag{7}$$

Here, D_{bil} and L_{bil} are the billet diameter and length after pressing, respectively; D_{rp} and d_{rp} and the outer and inner diameters of the ready pipe, respectively; f_{cw}, f_{ne}, and f_{pd} are the friction coefficients on the working surface of a container, a needle, and pressing die mirror, respectively; and a and b are the rib length and thickness, respectively;

$$\alpha_{\text{ne}} = \arcsin\left(\frac{d_{\text{rp}}}{D_{\text{bil}}}\sin\alpha_{\text{pd}}\right).$$

To analytically evaluate component R_{scr} when performing torsional compaction, we used the method of power balance of active and reactive forces. The power necessary to form the screw outflow equal to the product of the external torque (M) on the desired angular rotation velocity (ω) of the pipe at the pressing die output was equated to the power transferred by a compression ram, which is defined by the product of a normal force across the pressure pad (R_{scr}) on the pressing speed (v_{p}); i.e.,

$$R_{\text{scr}}v_{\text{p}} = M\omega, \tag{8}$$

From here,

$$R_{\text{scr}} = M\frac{\omega\lambda}{v_{\text{of}}}, \tag{9}$$

Using the ratio between the angular and forward speed,

$$\omega = \frac{2\pi}{B}v_{\text{of}}, \tag{10}$$

we finally derive

$$R_{\text{scr}} = M\lambda\frac{2\pi}{B}. \tag{11}$$

Here, B is the spiral ribbing step equal to

$$B = \pi D_{\text{rp}}/\tan\psi,$$

where ψ is the helix angle.

The plastic twist resistance (M_{res}) is maximal for a larger part of the billet compacting zone; therefore, Calculated compacting forces of spiral pipes with outer ribbing

Parameterp	Rib helix angle ($\psi°$)			
	0°	15°	30°	45°
$R_{\text{scr}}/R_{\text{pdp}}$	0	0.02	0.06	0.11
$T_{\text{pl}}(\psi)/T_{\text{pl}}(0)$	1.00	1.06	1.24	1.65
$P(\psi)/P(0)$	1.00	1.02	1.04	1.09

torque $M = 0$. When moving to the pressure zone output, plastic twist resistance of metal decreases while the torque moment applied to the billet from the side of screw channel increases. Then the situation appears when the billet is subjected to plastic twist in a certain cross section. This instant corresponds to condition $M = M_{\text{res}}$.

In connection with this fact, the torque moment necessary to twist the pipe to a specified angle can be calculated using known equations depending on the cross-section geometry and deformation resistance of metal at the pressure zone output. Let us represent the torque moment as the sum of moments necessary to turn the smooth part of the pipe and ribs, i.e.,

$$M = M_{\text{p}} + \sum_{i=1}^{N} M_{\text{r}i}, \tag{12}$$

where i is the number of ribs.

Values of M_{p} and $M_{\text{r}i}$ are determined from expressions [18]

$$\begin{aligned} M_{\text{p}} &= F_{\text{pcs}} R_{\text{av}} t S_{\text{de}}, \\ M_{\text{r}i} &= 1/4\, a_i b_i^2 S_{\text{de}}, \end{aligned} \tag{13}$$

where F_{pcs} is the pipe cross-section without ribs, R_{av} is the average pipe radius, and t is the pipe wall thickness.

When deriving formulas for calculating T_{pl} allowing for intense sliding of billet metal relative to tool screw channels, let us admit that the twist deformation occurs preferentially in the parallel land region, and

$$T_{\text{pl}} = T_{\text{plpd}} + T_{\text{plne}}, \tag{14}$$

where T_{plpd} and T_{plne} are friction forces appearing on surfaces of the parallel lands of a pressing die and a needle, respectively.

According to the figure data, the total outflow velocity of the particles of the elementary layer under the screw outflow with angular velocity ω equals

$$\mathbf{V} = \mathbf{V}_{\text{of}} + \mathbf{V}_0, \tag{15}$$

where $V_0 = \omega d/2$ is the circular velocity.

For a pipe with the outer spiral ribbing

$$V = V_{\text{of}} \left(\cos \frac{d}{D_{\text{cir.r}}} \psi \right)^{-1}, \tag{16}$$

where d is the current diameter and $D_{\text{cir.r}}$ is the diameter of the circle circumscribed relative to outer pipe ribs.

Since the total outflow velocity varies over the rib height, decreasing to the rotation center according to the linear law, when calculating T_{pl} we used average values of the helix angle. For a pipe with an outer spiral ribbing, we can consider that the average outflow velocity equals

$$V_{\text{of.av}} = \frac{V_{\text{of}}}{\cos[0.5\psi(1 + D_{\text{c}}/D_{\text{cir.r}})]}. \tag{17}$$

Applying the equation of equality of active and reactive power for compacting the pipe with outer spiral ribbing from a round hollow billet, we derive the following equation:

$$\begin{aligned} T_{\text{pl}} v_{\text{pl}} &= (2a + b) N l_{\text{scr}} S_{\text{de}} F_{\text{plpd}} \\ &\times \frac{V_{\text{of}}}{\cos[0.5\psi(1 + D_{\text{c}}/D_{\text{cir.r}})]} \\ &+ (\pi D_{\text{c}} - N) l_{\text{scr}} S_{\text{de}} F_{\text{plpd}} \frac{V_{\text{of}}}{\cos[\psi D_{\text{c}}/D_{\text{cir.r}}]} \\ &+ \pi d_{\text{c}} l_{\text{scr}} S_{\text{de}} F_{\text{plne}} \frac{V_{\text{of}}}{\cos[\psi d_{\text{c}}/D_{\text{cir.r}}]}, \end{aligned} \tag{18}$$

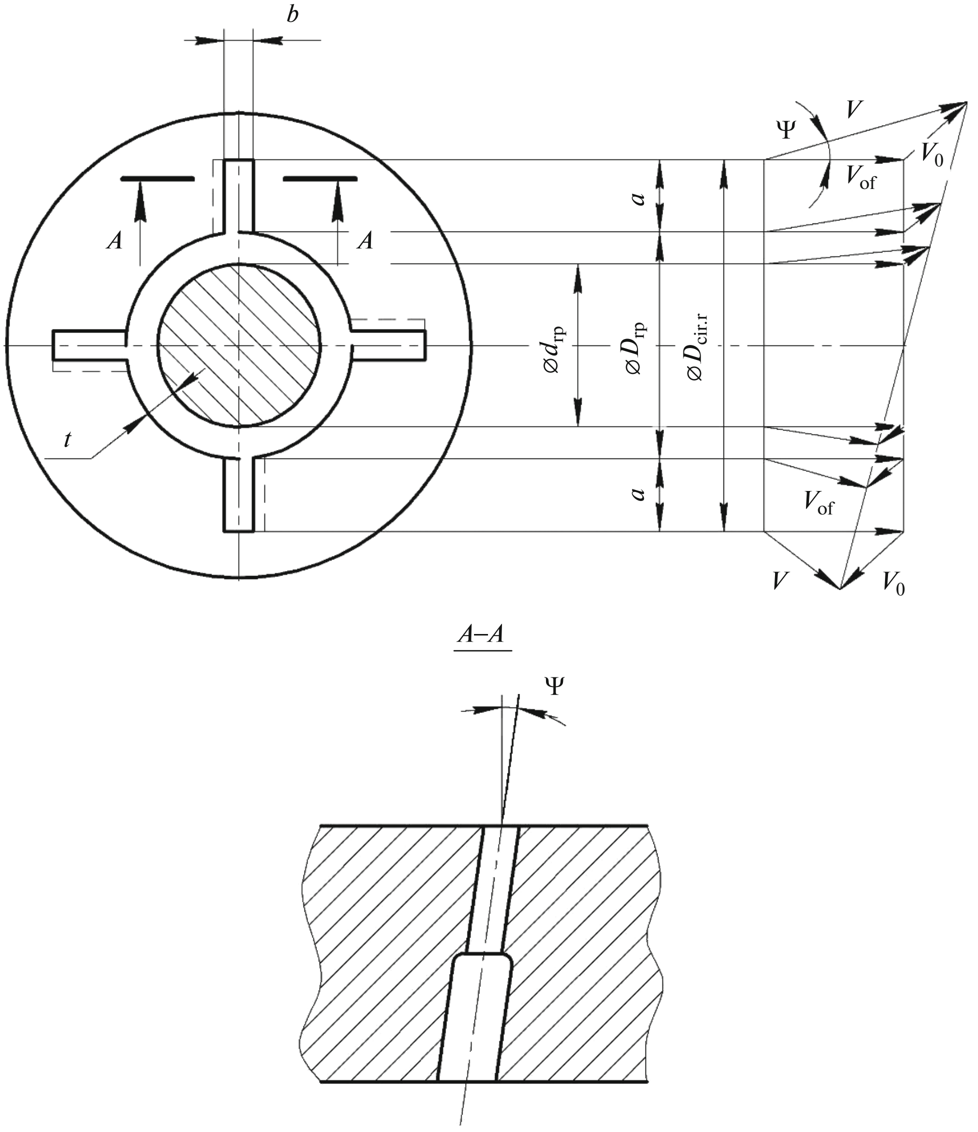
where l_{scr} is the screw segment length; f_{plpd} and f_{plne} are friction coefficients over the parallel land of the pressing die and a needle, respectively; and v_{comp} is the compacting velocity.

Finally, we can write

$$\begin{aligned} T_{\text{pl}} = \lambda l_{\text{scr}} S_{\text{de}} \Bigg\{ \Bigg[& \pi D_{\text{c}} \frac{N}{\cos[\psi D_{\text{c}}/D_{\text{cir.r}}]} \\ & + \frac{(2a + b)N}{\cos[0.5\psi(1 + D_{\text{c}}/D_{\text{cir.r}})]} \Bigg] f_{\text{plpd}} \\ & + \frac{\pi d_{\text{c}}}{\cos[\psi D_{\text{c}}/D_{\text{cir.r}}]} f_{\text{plne}} \Bigg\}. \end{aligned} \tag{19}$$

RESULTS AND DISCUSSION

To analyze our Eq. (4), we calculated force compacting conditions of a drill pipe made of aluminum alloy D16 with three spiral ribs by a direct method on an immobile needle with outflow velocity $V_{\text{of}} = 2$ m/min. We accepted the following values of parameters in our calculations: $D_{\text{cir.r}} = 200$ mm, $D_{\text{rp}} = 140$ mm, $d_{\text{rp}} = 100$ mm, $b = 30$ mm, $K_{\text{rib}} = 0.32$, $\lambda = 11.6$, container diameter is 370 mm, conicity angle of a pressing die is 75°, sizes of a hollow billet are ∅362 × 130 × 720 mm, and compacting pressure is 440°C. Values of friction coefficients and deformation resistance are taken based on recommendations [15]: $f_{\text{cw}} = f_{\text{pd}} = 0.5$; $f_{\text{ne}} = f_{\text{plne}}$, $S_{\text{db}} = 38$ MPa, and $S_{\text{de}} = 64$ MPa. The results of calculations are presented in a table.



Schematic diagram of metal flow during compaction of the pipes with outer spiral ribbing.

It follows from the analysis of our data that the total compacting force allowing for the ribbing contour according to formulas (2), (6) and (7) is 28% higher than the compacting force of a smooth pipe equal by the area [15]. Components R_{scr} and T_{pl}, which are determined from Eqs. (11) and (19), increase due to an increase in the total outflow velocity and surface friction in screw tool channels, which also increases the total compacting force.

We can derive the formula for calculating the compacting force of longitudinally ribbed pipes at $\psi = 0$, $B = \infty$, $R_{scr} = 0$, $T_{pl}(\psi) = T_{pl}(0)$, and $P(\psi) = P(0)$. Value of P calculated according to the proposed procedure for the pipe under consideration differs in limits of 8% of the experimentally found force determined at the moment the basic compacting stage begins by means of the pressure on a plunger in a master cylinder of a horizontal hydraulic press with a force of 50 MN.

CONCLUSIONS

The good convergence of calculated and experimental values allows us to recommend the derived analytical equations for engineering calculations of compacting forces of spiral pipes with both outer and inner ribbing and for starlike spiral profiles at $d_{rp} = 0$ as well.

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