THE STUDY OF SUCKER ROD GASKET LOADS IN THE CASE OF PROGRESSING CAVITY PUMPING SYSTEMS

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Abstract
The present paper examines the case of a quasi-vertical well which bares loads of static nature and also features axial extension and torsional loads with unique sucker rod section. The axial extension and the torsion of the sucker pump gasket lead to a compound load; maximum values manifest in the polished rod section. Furthermore, vibrations are also produced in the sucker pump gasket during operation of the PCP pump (fig. 1).
Keywords: sucker rod, progressing cavity pump, gasket load

1. Introduction

The role of the sucker pump gasket is to transmit the rotational motion from operating system to the pump rotor. Furthermore, the sucker pump gasket must also support the loads generated by the pressure of the extracted fluid.

In the case of PCP production, the sucker pump gasket is subjected to the following loads:

a. extension, produced by sucker rod weight and fluid pressure on the pump rotor;
b. torsion, manifests under the pressure of the motor moment transmitted from the starting system via the polished rod (determined by the functional principle) and influences the PCP rotor;
c. bending, produced by the action of the centrifugal forces which manifest upon sucker pump gasket rotation and is determined by the trajectory of the drill hole (it does not manifest in the case of quasi-vertical wells);
d. transversal and coiling longitudinal oscillations, generated by the imperfections of well components (sucker pumps, extraction pipes, progressive cavity pumps), and by the starting system (operating vibrations).

The manifestation and amplitude of these loads are determined by well configuration (all previously mentioned loads are present in the case of inclined wells and, more so, have a dynamic character).

2. The study of compound loading (axial extension and torsion)

Applying the theory of maximum tangential tensions (T_τ):

$$\sigma_{ech} = \sqrt{\sigma_{tr}^2 + 4\tau^2} \leq \sigma_a \quad (1)$$

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where:
σ_{tr} represents axial extension tension (traction), [MPa];
τ - tangential coiling tension (torsion), [MPa];
σ_a - admissible tension, [MPa];

$$\sigma_a = \frac{\sigma_c}{c_s} \quad (2)$$

σ_c - yield strength of sucker rod material. Sucker rods are categorized in five classes according to specific resistance, in conformity with API Spec 11B.

Axial extension tension (traction), σ_{tr} which manifests in sucker rods is determined by actual weight $F_t$and by the pressure exercised on the rotor by the pumping fluid F_p.

$$.\sigma_{tr} = \frac{F_t + F_p}{A} \quad (3)$$

A – cross-sectional area of the sucker rods in the area where the loads are highest (polished rod).

Axial extension tension (traction) determined by actual weight is:

$$F_t = H_1 \cdot q_p \left(1 - \frac{\rho_f}{\rho_o}\right) \quad (4)$$

H_1 is the depth of pump installation;
q_p– sucker rod individual weight (is dependent on the steel grade);
ρ_o– steel density;
ρ_f– produced fluid density;

$$\rho_f = \rho_p(1 - f) + \rho_a f \quad (5)$$

ρ_p– produced oil density;
ρ_a – water density;
f – the fraction of impurities in the extracted fluid (water).

The axial extension tension due to the pressure forces acting on the pump rotor is:

$$F_p = \left(A_{stator} - A_{prajini}\right) \rho_f \; g \; H_{tp} \quad (6)$$

A_{stator} is the cross-sectional area of the stator cavity (table 1);
$A_{prajini}$ – the cross-sectional area of the sucker rods;
g – gravitational acceleration;

H_{tp}– total pumping height (pump pressure at pump-out):

$$H_{tp} = H_d + H_l + H_f \qquad (7)$$

H_d– dynamic pressure dependent on the dynamic level of the well and on fluid density;

H_l – pump head pressure dependent on the diameter and length of the mixing line, on the viscosity of the fluid and fluid flow, and also on ambient temperature. It can be determined via calculation or can be directly measured by manometer outfitted at the pump head. According to the calculation, pressure at the pump head is:

$$H_l = \frac{10\, p_l}{\gamma_a} \qquad (8)$$

with p_l pressure at the pump head, *MPa*

γ_a– the specific weight of water, N/m^3

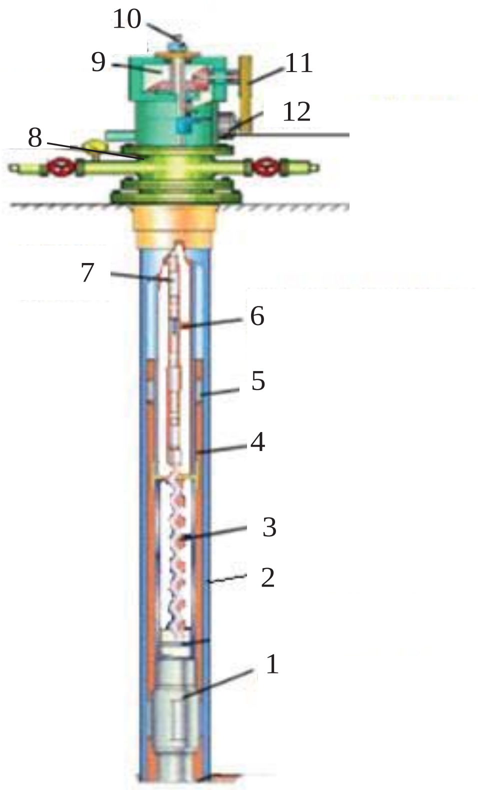
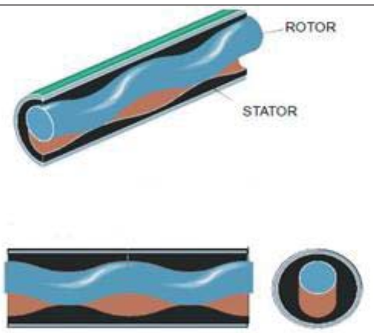
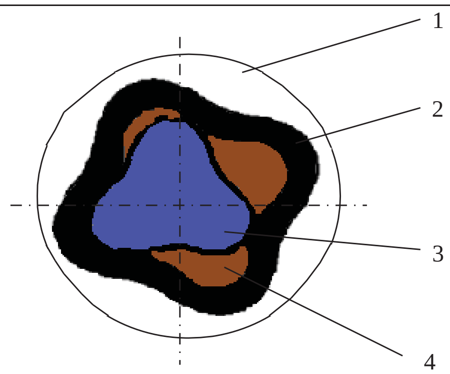


Fig 1. **The PCP system**: 1 – anchor; 2 – casing; 3 – PCP; 4 – tubing; 5 – tubing centralizer; 6 – sucker rod centralizer; 7 – sucker rod; 8 – wellhead; 9 – reducer; 10 – polished rod; 11 – belt transmission; 12 - motor

Table 1. **Geometry of the PCP**

PCP 1 / 2	PCP 3 / 4
	 1,2 – stator; 3 – rotor; 4 – producted fluid.
Cross-sectional area of the stator cavity: $$A_{stator} = \frac{\pi\, D^2}{4} + 4\, D\, e$$ *D* – diameter of the rotor; e – excentricity of the pump	Cross-sectional area of the stator cavity: $$A_{stator} = \frac{\pi\, D_{ms}^2}{4}$$ D_{ms} - the average diameter of the stator

H_f– pressure drop in the production pump columns (via friction), is dependent on tubing diameter, fluid viscosity, well flow and pump installation depth.

Pressure loss in the annular flow space formed by the inside diameter of the extraction pipes and the individual outer diameter of the sucker rods (equal to the diameter of the rod) is calculated using the following relation:

$$H_f=\lambda_{ech} \frac{H_{fix}}{D_{ech}} \frac{v_m^2}{2\,g} \quad (9)$$

H_{fix} represents pump installation depth;

D_{ech}– the equivalent diameter of a pipe where, for the same flow, the same pressure drop occurs as in the given annular space and is calculated:

$$D_{ech} = 4\,R_h \quad (10)$$

with R_h the hydraulic radius, which is determined as the ratio between the flow section area and the perimeter of watering,

$$R_h = \frac{\pi}{4}\left(D_{i\,t}^2 - d_p^2\right) \frac{1}{\pi\,\left(D_{i\,t} + d_p\right)}$$

$$R_h = \frac{\left(D_{i\,t} - d_p\right)}{4} \quad (11)$$

From (10) and (11) results a diameter equal to:

$$D_{ech} = \left(D_{i\,t} - d_p\right)$$

v_m– the average flow speed of the liquid in the annular space between the rod and the extraction pipe column:

$$v_m = \frac{4\,Q}{\pi\,\left(D_{i\,t}^2 - d_p^2\right)\,86400} \quad (12)$$

$D_{i\,t}$ is the interior diameter of the tubing;

d_p – the diameter of the pumping rod;

Q – pumped flow;

λ_{ech} – equivalent hydraulic resistance coefficient. Is determined on the basis of Reynolds' number (to determine the flow regime of the fluid in the well):

$$Re_{ech} = \frac{v_m\,D_{ech}}{\nu} \quad (13)$$

ν is the kinematic viscosity of the pumped fluid;

a) $Re_{ech} \leq 2300$ – laminar flow; the equivalent hydraulic resistance coefficient will be:

$$\lambda_{ech} = \frac{64}{Re_{ech}} \quad (14)$$

b) $Re_{ech} > 2300$ – turbulent flow; the equivalent hydraulic resistance coefficient is determined according to the Darcy-Weissbach relation.

$$\lambda_{ech} = 0{,}3164\ Re^{-0{,}25} \quad (15)$$

The tangential coiling tension τ has maximum value at the upper part of the pumping rods, in the polished rod:

$$\tau = \frac{M}{W_p} \quad (16)$$

W_p– the polar resistance module of the pumping rod body section;

$$W_p = \frac{\pi\,d_p^3}{16} \quad (17)$$

M– moment at the polished rod;

$$M = M_{pump} + M_{fr} \quad (18)$$

M_{pump} is the torsion moment at the PCP rotor. The necessary moment at the pump rotor depends on the mechanical yield of the pump as well as the content of solids in the pumped fluid (the fluid is abrasive). As the percentage of sand increases, so will the friction between rotor and stator increase proportionally, and, as a result, the moment necessary at the pump rotor will also increase.

M_{fr}– the torsion moment due to the friction between the sucker rod gasket and the extraction pipes and the pumped fluid. Is dependent on:

a) the deviation and trajectory of the drill hole geometry,
b) the dimension of the extraction pipes and pumping rods,
c) connector and centering types,
d) pumped fluid viscosity,
e) sand content in the pumped fluid,
f) sucker rod gasket revolution.

On the other hand, taking into consideration the data on pump operation, the moment at the polished rod is:

$$M = 955\ \frac{P}{n} \quad (19)$$

where P is the power developed by the starting system at the polished rod and n the pump operation revolution.

$$P = P_{abs}\,\eta_1\,\eta_2\,\eta_3 \quad (20)$$

P_{abs} is the power absorbed from the electric grid (corresponding to the operation of the pump at installation depth):

$$P_{abs} = \sqrt{3}\,U\,I\cos\varphi \quad (21)$$

$U = 380$ V – represents electric tension;

I – absorbed current;

$\cos\varphi$ – power factor of the power unit, usually around 0.83;

$\eta_1 = 0{,}83 \ldots 0{,}86$ – effectiveness of the electric motor;

$\eta_2 = 0{,}96 \ldots 0{,}98$ – effectiveness of the revolution reductor;

$\eta_3 = 0{,}96$ – effectiveness of the belt transmission.

3. Study on sucker rod gasket vibrations

In order to ensure a normal functioning of the PCP installation, the resonance phenomenon must be checked. During operation, the following vibrations occur in the sucker rods:

a) axial (longitudinal) vibrations;
b) coiling (torsional) vibrations;
c) bending (transversal) vibrations.

a) **Axial (longitudinal) vibrations** are due to friction between the rotor and the pump, and because of manufacturing flaws. For the study of these vibrations it is considered that the sucker rod gasket is a continuous system with uniform section (the attenuation phenomenon is not taken into consideration), with the upper head of the gasket being fixed and the lower one being mobile. Specific vibrations are:

$$p_n = \frac{2\,n-1}{2}\;\frac{\pi\,v}{L} \qquad (22)$$

p_n vibration corresponding to the actual vibration type of magnitude *n* = 1,2, …..;

v – the speed of the elastic deformation in the gasket

$$v = \sqrt{\frac{E}{\rho}} = 5172\ {}^{m}/_{s} \qquad (23)$$

E is the elasticity module of steel;

L – the length of the sucker rod gasket.

Critical revolution (of the sucker rod gasket which leads to vibrations) is determined via the equaling of the specific vibration of the sucker rod gasket with the vibration specific to the appropriate gasket revolution:

$$p_{cr} = \frac{\pi\,n_{cr}}{30} \qquad (24)$$

Form (23) and (24) in (22), results that critical revolution is directly dependent on the functioning revolution of the sucker rod gasket and inversely proportional to the length of the gasket:

$$n_{cr} = \frac{77580\,(2\,n-1)}{L} \qquad (25)$$

b) **Coiling (torsional) vibrations**; is determined under the assumption that the sucker rod gasket is fixed at the head end (at the polished rod) and the lower head (rotor) is free. In motion, the sucker rod gasket vibrates transversely due to dynamically unbalanced masses. Actual torsion vibrations of the sucker rod gasket are:

$$p_n = \frac{2\,n-1}{2}\;\frac{\pi\sqrt{v_1}}{L} \qquad (26)$$

p_n– specific torsion vibration, of *n* magnitude;

$$v_1 = \frac{G}{\rho} \qquad (27)$$

$G = 8{,}1 \cdot 10^{10}\ \frac{N}{m^2}$– the module of transversal elasticity for steel.

Critical revolution is determined via the following relations (22) and (27) in relation (26):

$$n_{cr} = 48184\,\frac{(2\,n-1)}{L} \qquad (28)$$

c) **Bending (transversal) vibrations**

Specific transversal vibrations of *n* magnitude are, in this case, as follows:

$$p_n = \left(\frac{n\,\pi}{I}\right)^2 \sqrt{\frac{E\,l}{\rho\,A}} \qquad (29)$$

$I = \frac{\pi\,d^4}{32}$ is the inertia moment of the sucker rod

A –cross-sectional area of the sucker rod;

l – sucker rod length;

Critical revolution is obtained from (29) and (26):

$$n_{cr} = 120908\,\frac{n^2}{l^2}\,d \qquad (30)$$

4. Conclusions

1. The axial extension tension (traction) depends on: the flow pumped, fluid characteristics produced, the depth of attachment of the PCP, the seal geometry of sucker rods, tubing and a PCP';
2. The tangential coiling tension depends on: sucker rod geometry and the electrical grid power input, corresponding to the depth of fixed pump operation;
3. Calculation of vibration gasket sucker rod (axial, torsional, bending) is important to avoid operation in resonance, phenomenon harmful.

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