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RESEARCH ARTICLE

RESEARCH OF INFLUENCE OF PUMP-COMPRESSOR PIPES' FLUCTUATIONS ON SEALING ELEMENT'S PACK-OFF IN WELL

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ABSTRACT

In this article it is learnt oscillatory motion of pump-compressor pipes during the packer setting in empty column and at liquid presence. Galerkin's method in calculus of variations was used in order to study this process. Forms of pipe fluctuations in emptiness and its movement in liquid are defined. Attenuation coefficient for the first mode has been set.

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INTRODUCTION

Implementing of well packing in difficult technical and geological situations needs particular attention to packer descent, reliable sealing, which is heavily influenced by pump-compressor pipes' fluctuations connected with packer. It should be noted that in inoperative well (for well restoring) packer is moved down in well in which there's no water. It is known that fluctuations from dynamic impact change the mechanical characteristics of rubber sealing elements. Thereby, let's learn fluctuations in the system "Pump-Compressor pipes-Packer".

Let's consider the first case (figure1, a) when liquid is absent in well.

By way of the mechanical model we use Guck's law.

In this case, landing of packer (connected to the end of the pump-compressor pipes moving down in well) is described by the equation of the motion taking into account gravitation force by Guck's law.

Let's consider, that the top of the pipe rigidly fixed and there're packer details with mass m hung at the bottom end.

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The length of pipe-compressor pipe is – ℓ and the square is S, Young's modulus-E, material's density-ρ.

Task's formulation. After pipe separation fluctuations appear near the equilibrium position, which is accepted by pipes unloaded by mass m. Let's express deviation from this position by u (x, t) and count in positive direction from axis X.

Equation of pipe's longitudinal fluctuations

$$ES \cdot \frac{\partial^2 u(x,t)}{\partial x^2} - \rho S \frac{\partial^2 u(x,t)}{\partial t^2} = 0 \qquad \text{..................(1)}$$

$0 < x < \ell$

We get limit conditions at x=0 from appropriate condition c→ (where c-spring rigidity, e.g. rope hedge at the top of the tower):

$$u(o,t) = 0 \qquad \text{..........................(2)}$$

For $x = \ell$ we get

$$\frac{\partial u(x,t)}{\partial x} = 0 \qquad \text{.......................(3)}$$

Let's find Initial conditions having considered pipe position before descent.

Pipe gravitation mg causes its stretching. Let's assume that at the moment of packer descent all transition processes related to fading deformation (packer reached needed depth in well).

Then from fluctuation equation (1) it follows

$\frac{\partial^2 u(x,o)}{\partial x^2} = 0$ or $\frac{\partial u(x,o)}{\partial x} = c_1$

e.g. the force acting in any section of the pipe is the same. After integration by x we'll find

$u(x,o) = c_1 x + c_2$

Let's define constant c_1 and c_2 from the next conditions: offset at point x=0 is equal zero u(0,0)=0; tensile force acting in section of the pipe x= ℓ, is equal to the weight of pipe above the packer:

$ES\frac{\partial u(\ell,\partial)}{\partial x} = mg$ From here $c_1 = \frac{mg}{ES}$; $c_2 = 0$.

So, at t=o

$u(x,0) = \frac{mg}{ES}x$ -Initial offset ……………..(4)

$\frac{\partial u(x,0)}{\partial t} = 0$ -Initial speed ………………(5)

Task's solution. Let's take $u(x,0)$=U(x)cos(ωt+α). We get boundary-value problem of own values for U(x).
Its solution for c=∞ gives

$\omega_n = \frac{2n-1}{2\ell}\cdot\pi\sqrt{\frac{E}{\rho}},$

$U_n(x) = sin\frac{\pi(2n-1)}{2\ell}x\,,\quad n = 1,2,3,\ldots$ ....(6)

Common solution (1) with limit (2), (3) looks like

$u(x,t) = \sum_{n=1}^{\infty} B_n sin\frac{(2n-1)\pi\cdot x}{2\ell}\cdot\cos\,(\omega_{nt} + \alpha_n)$ ....(7)

Substitute (7) to initial conditions (4), (5)

$\sum_{n=1}^{\infty} B_n sin\frac{(2n-1)\pi\cdot x}{2\ell}\cdot\cos\alpha_n = \frac{mg}{ES}\cdot x\,,$

$\sum_{n=1}^{\infty} B_n\cdot\omega_n\cdot sin\frac{(2n-1)\pi x}{2\ell}\cdot sin\alpha_n = 0$ ……………(8)

To define B_n and α_n multiply both parts in equalities (8) to $U_p(x)$ and integrating by x from 0 till ℓ.

$\sum_{n=1}^{\infty} B_n cos\alpha_n\int_0^{\ell}\sin\left(\frac{2n-1}{2\ell}\cdot\pi x\right)\sin\left(\frac{2p-1}{2\ell}\cdot\pi x\right)dx = \int_0^{\ell}\frac{mg}{ES}\cdot xsin(\frac{2p-1}{2\ell}\cdot\pi x)dx$ …………….(9)

$$\sum_{n=1}^{\infty} B_n\cdot\omega_n\cdot sin\alpha_n\int_0^{\ell}\sin\left(\frac{2n-1}{2\ell}\cdot\pi x\right)\sin\left(\frac{2p-1}{2\ell}\cdot\pi x\right)dx$$

By virtue of that

$$\int_0^{\ell}\sin\left(\frac{2n-1}{2\ell}\cdot\pi x\right)\sin\left(\frac{2p-1}{2\ell}\cdot\pi x\right)dx = \begin{cases}0 & at\ n\neq p\\ \frac{\ell}{2} & at\ n = p\end{cases}$$

System (9) becomes

$$\begin{cases}B_p cos\alpha_p = 2\frac{mg}{ES}\cdot\frac{(-1)^{p+1}}{(\frac{2n-1}{2}\cdot\frac{\pi}{\ell})^2}\\ B_p\omega_p sin\alpha_p = 0,\quad p = 1,2,\ldots\end{cases}$$

Find a solution

$\alpha_p = \pi(p+1);\qquad B_p = 2\frac{mg}{ES}\cdot\frac{1}{(\frac{2p-1}{2}\cdot\frac{\pi}{\ell})^2}$

From here we get

$u(x,t) = \sum_{n=1}^{\infty}\frac{2mg}{ES}\cdot\frac{(-1)^{p+1}}{(\frac{2n-1}{2}\frac{\pi}{\ell})^2}\cdot\sin\,(\frac{2n-1}{2}\cdot\pi\frac{x}{\ell})\cdot\cos(\omega_n t + \alpha_n)$ ……(10)

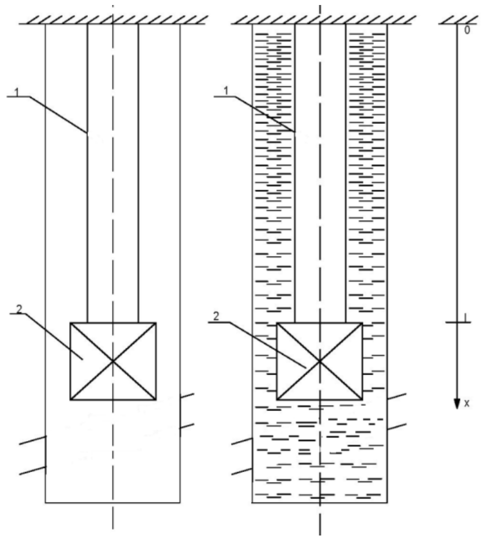
Let's have a look at the second case (figure 1, b). Packer landing (descent to well) is carried out to well where liquid and pump-compressor pipes with packers commit longitudinal fluctuations in liquid.

Estimate attenuation coefficient in first point if bar cross-section e.g. pump-compressor pipes, circle with radius –r, material density – ρ, Young modulus – E.

Friction force in liquid is proportional to the square of pipe's lateral surface.

Task's solution. It's possible to write equation of pipe's fluctuation in the way

$\rho S\cdot\frac{\partial^2 u(x,t)}{\partial t^2} - ES\frac{\partial^2 u(x,t)}{\partial x^2} = f(x,t)$ …………(11)



a) b)

Figure 1. Calculation scheme 1. Pump-compressor pipe. 2. Packer a) Empty well; b) Filled well

where $f(x,t) = -2\pi r\eta \frac{\partial^2(x,t)}{\partial t}$ - friction force of pipe's lateral surface to liquid, η – friction coefficient.

According to Galerkin's method we find the solution in the way

$$u(x,t) = \sum_{q=1}^{S} a_q(t)\psi_q(x) \quad \text{……………..(12)}$$

After transformations described in methodical instructions, from equation (1) we get

$$\sum_{q=1}^{S}(T_{pq}\frac{d^2a_q}{dt^2} + H_{pq}\cdot\frac{da_q}{dt} - U_{pq}a_q) = 0,\ p = 1,2,\dots,S \quad \text{...(13)}$$

where T_{pq}, U_{pq} are found next way:

$$T_{pq} = \int_0^l \beta(x)\psi_p(x)dx$$

$$U_{pq} = \int_0^l \psi_p(x)\frac{\partial}{\partial x}(\gamma(x) - \frac{\partial\psi_q(x)}{\partial x})\cdot dx \quad \text{……………(14)}$$

and

$$H_{pq} = 2\pi r\eta\int_0^l \psi_p(x)\,\psi_q(x)dx \quad \text{… … … … … ..(15)}$$

If the starting point of OX axis coincides with fixed end of pipe, then

$$\psi(0) = 0, \quad \frac{\partial\psi}{\partial x}\Big| x = e \quad \text{……………..(16)}$$

Solution. Let's take $\psi_1(x) = sin\frac{\pi x}{2l}$ - first form of pipe's fluctuation in emptiness (well is not filled by liquid).
Substituting $\psi_1(x)$ to (3) we get:

$$T_{11} = \rho S\int_0^l sin^2\frac{\pi x}{2l}dx = \frac{\rho Sl}{2} \quad \text{………………(17)}$$

$$U_{11} = -ES\frac{\pi^2}{4l^2}\int_0^l sin^2\frac{\pi x}{2l}dx = -\frac{ES\pi}{8l}$$

$$H_{11} = \frac{2\pi r\eta l}{2} \quad \text{…………………(18)}$$

The equation (2) will take the form

$$\frac{\rho Sl}{2}\cdot\frac{d^2a_1}{dt^2} + \frac{2\pi r\eta l}{2}\cdot\frac{da_1}{dt} + \frac{ES\pi^2}{8l}\cdot a_1 = 0 \quad \text{… … … … … … … ….(19)}$$

Look for the solution in the form $a_1(t) = A_1e^{\lambda t}$, then

$$\lambda^2 + \frac{2\eta}{2\rho r}\cdot\lambda + \frac{E\pi^2}{4\rho l^2} = 0 \quad \text{…………………..(20)}$$

$$\lambda_{1,2} = -\frac{\eta}{\rho r} \pm \omega\sqrt{1 - \frac{\eta^2 l^2}{\pi^2 E\rho r^2}} \quad \text{……………………(21)}$$

where $= \frac{\pi}{2l}\sqrt{\frac{E}{\rho}}$.

Solution's analysis. First factor of the equation (10) – amplitude of fluctuation's n-th harmonic, which is occurred in the pipe after descent; the second – displacement distribution along OX axis at n-th harmonic; the third – change of the displacement in time.

With the growth of n number, amplitude harmonic declines proportionally n^{-2}.

In empty well it is set:

- At given initial conditions the movement of pipe is defined, basically, by the fluctuation at first natural frequencies;
- Fluctuations at even harmonics (n=2q) occur in antiphase with fluctuations of odd which have initial phase is equal to zero;

In filled well it is set:

- The movement of pump-compressor's pipes in liquid will be oscillatory if $\eta = \frac{\omega\rho}{r}$;
- Attenuation coefficient for the first mode is approximately equal to $\frac{\eta}{\rho r}$.

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