Research The Elastic-Fixed Well Sealant Element Indication Under External Pressure Action

Aslanov Jamaladdin Nuraddin
Department of Oil and Gas Equipment
Azerbaijan State Oil and Industry University
Azadliq str. 27, Baku, Azerbaijan, Az1010
tribo72@mail.ru

Huseynli Zenfira Seydi
Department of Oil and Gas Equipment
Azerbaijan State Oil and Industry University
Azadliq str. 27, Baku, Azerbaijan, Az1010
huseynli_z@rambler.ru

Introduction

In the oil and gas industry, elastic-fixed sealant element (rubber) is often used in gas well packer equipment for hermetic seal well, so the research of the dynamic behavior of this element represents practical interest.

Keywords—the circular sealing element, the dynamic behavior, hermetic seal, sealant element

Statement of a question.

Plug valves, which are the main components of the fountain fittings, are realized by sealing between metal-metal surfaces in straight valves, adjustable throttles and their flange connections. Since the main unit of the Christmas tree is its connecting structures, their efficiency will be included in the criterion for the effectiveness of the Christmas tree. When selecting parts and assemblies of connecting structures in accordance with the design, operating parameters and the required properties of the socket into which they are installed, its performance can be increased many times over. The goal is to create physical models of joints of connecting structures in accordance with the required property. One of the important tasks here is to ensure the absence of "leaks" in the sealed joint zone in accordance with the requirements for the nodes, ensuring operational reliability and durability[4,5,6,7,8].

The main task of the seal between the required contact surfaces is to determine the criteria, which is the selection of the parameters of the sealing parts that perform the required technical functions.

The most general case of elastic fastening can be reflected with help of boundary conditions:

$$F-M=\alpha_2 W+\alpha_{22}\frac{\partial W}{\partial r} \quad (1)$$

where: F and M are accordingly the shearing force and the bending moment at the edge of the sealing element;

W and $\frac{\partial W}{\partial r}$- deflection (deformation) and angle of the edge rotation;

α_{ij} - coefficient of fastening elasticity.

In the axisymmetric case, which we will research for F_2 great concreteness of the obtained results, we have [1]:

$$F=-D\frac{\partial}{\partial r}\cdot\nabla^2 W \quad M=-D\left(\frac{\partial^2}{\partial r^2}+\frac{\gamma}{r}\cdot\frac{\partial}{\partial r}\right) \quad (2)$$

the equation of the sealing element motion under the action of an external pressure $(P_0\cdot l^{-i\omega t})$ in the form [1]:

$$D\nabla^2\nabla^2\cdot W-Ph\omega^2 w=P_0 \quad (3)$$

Methods for solving the stated problem

We\`ll write in the sum form of a particular solution of the inhomogeneous equation and the general solution of the homogeneous equation [2]:

$$W=-\frac{P_0}{\rho h\omega^2 W}=P_0 \quad (4)$$

where k is the wavenumber of bending waves, defined by

$$k=\sqrt[4]{\rho h\omega^2}/D \quad (5)$$

Taking into account that the Bessel functions $J_0(kr)$ and I$I_0(kr)$ are the eigenfunctions of the operators

$$(\nabla_r^2+k^2)\cdot J_0(kr)=)\ (\nabla^2-k^2)\cdot I_0(kr)=0 \quad (6)$$

We write the values of F and M b in the form:

$$F=ADk^3 I_0(kr)-BDk^3(I_0(kr)$$

$$M=D^2k^2A\left[J_0(kr)+\frac{1-\gamma}{kr}\cdot J_0(kr)\right]+ \quad (7)$$

$$Dk^2B\left[-I_0(kr)+\frac{1-\gamma}{kr}\cdot J(kr)\right]$$

Using the boundary conditions (1), we obtain the following system of algebraic equation:

$$A\{\alpha_{11}J_0(kR)+I_0(kR)[Dk^3+\alpha_{12}k]\}+$$

$$+BA\{\alpha_{11}J_0(kR)+I(kR)[-Dk^3+\alpha_{12}k]\}=\frac{P_0\alpha_{11}}{\rho h\omega^2}$$

$$A\left\{[\alpha_{21}+Dk^2]+I_0(kR)\left[\alpha_{22}k+Dk^2+\frac{1-\gamma}{KR}\right]\right\}+$$

$$+B\left\{J_0(kR)[\alpha_{21}-Dk^2]+I(KR)\left[\alpha_{22}k+Dk^2\frac{(1-\gamma)}{KR}\right]\right\} = \frac{P_{0\alpha_{21}}}{\rho h\omega^2} \quad (8)$$

Thus, the solution of the problem is obtained in closed form without any expansions in eigenfunctions :

$$W(r,t) = (\frac{P_0e^{-iat}}{\rho h\omega^2}\cdot\left\{-1+\frac{\Delta_1 J_0(kr)+\Delta_2 \dot{I}_0(kr)}{\Delta}\right\}$$

$$W(r,t) = (\frac{P_0e^{-iat}}{\rho h\omega^2}\cdot\left\{-1+\frac{\Delta_1 J_0(kr)+\Delta_2 \dot{I}_0(kr)}{\Delta}\right\}$$

where

$$\Delta_1 = \begin{vmatrix} \alpha_{11}\{\alpha_{11}J_0(kR)+\dot{I}_0(kR[Dk^3+\alpha_{21}k]\} \\ \alpha_{22}\left\{J_0(KR)[\alpha_{21}-Dk^2]+\dot{I}(kR)\left[\alpha_{22}k+Dk^2\frac{1-\gamma}{kR}\right]\right\} \end{vmatrix};$$

$$\Delta_2 = \begin{vmatrix} \{\alpha_{11}J_0(kR)[Dk^3+\alpha_{21}k]\}\,\alpha_{11} \\ \left\{[\alpha_{21}+Dk^2]-J_0(kR)+\dot{I}_0kR\left[\alpha_{22}k+Dk^2\frac{1-\gamma}{KR}\right]\right\}\alpha_{21} \end{vmatrix} \quad (9)$$

$$\Delta = \begin{vmatrix} \alpha_{11}J_o(kR)+[-Dk^2+\alpha_{12}k]\dot{I}_0(kR) \\ \alpha_{11}J_o(kR)+[-Dk^2+\alpha_{12}k]I_0(kR) \\ \left\{[\alpha_{21}+Dk^2]J_o(kR)+\left[\alpha_{22}k+Dk^2\frac{(1-\gamma)}{kR}\right]\dot{I}_0(kR)\right\} \\ \left\{[\alpha_{21}-Dk^2]J_o(kR)+\left[\alpha_{21}k+Dk^2\frac{1-\gamma}{kR}\right]\dot{I}_0(kR)\right\} \end{vmatrix}$$

Now we have the opportunity to study various special cases of elastic fastening of the circular sealing element edge, which are most often found in engineering practice

$$\alpha_{12}=\alpha_{21}=0\,;\ \alpha_{22}=\infty\,;\ 0<\alpha_{11}<\infty \quad (10)$$

It is easy to see that the compliance of the support in this case is connected with the shearing forces. Another possible case of elastic pinching, which we will call the second type of fixation, is expressed by the conditions:

$$\alpha_{12}=\alpha_{21}=0;\ \alpha_{11}=\infty;\ 0<\alpha_{22}<\infty \quad (11)$$

In this case, the compliance of the supports is related to the bending moment. The stiffness coefficients of the sealing element can be expressed through their mechanical and geometric parameters in a known manner [3]:

First we consider an elastic fastening of the first kind. For $\sigma_{12}=\alpha_{21}=0, \alpha_{22}=\infty$ the solution can be represented in the form

$$W(r,t) = \frac{P_0e^{-i\omega t}}{\rho h\omega^2}\cdot\left\{-1+\frac{\dot{I}_0(kR)J_0(kR)-\dot{I}_0(kR)J_0(kR)}{\dot{I}_0(kR)J_0(kR)-\dot{I}_0(kR)J_0(kR)+\frac{2Dk^2}{\alpha_{11}}\cdot\dot{I}_0J_0}\right\} \quad (12)$$

$$W(r,t) = \frac{P_0e^{-i\omega t}}{\rho h\omega^2}\cdot\left\{-1+\frac{\dot{I}_0(kR)J_0(kR)-\dot{I}_0(kR)J_0(kR)}{\dot{I}_0(kR)J_0(kR)-\dot{I}_0(kR)J_0(kR)+\frac{2Dk^2}{\alpha_{11}}\cdot\dot{I}_0J_0}\right\} \quad (12)$$

For strength calculations the value of the reaction force, arising in elastic fastening introduces a special interest. In accordance with the boundary conditions, this quantity is

$$F=-\alpha_{11}W(R,t) \quad (13)$$

After the transformations, we obtain

$$F=-\frac{P_0\alpha_{11}e^{-i\omega t}}{\rho h\omega^2}\left\{-1+\frac{\frac{J_0(kR)}{\dot{I}_0(kR)}-\frac{J_0(kR)}{\dot{I}_0(kR)}}{\left[\frac{J_0(kR)}{\dot{I}_0(kR)}-\frac{J_0(kR)}{\dot{I}_0(kR)}+\frac{2Dk^3}{\alpha_{11}}\right]}\right\} \quad (14)$$

This ratio can be written in a dimensionless form

$$f(\Omega)=\frac{E1D}{\beta\left[\frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}}-\frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}}\right]\Omega+\Omega^4} \quad (15)$$

where $f(\Omega)=\frac{ED}{P_0\alpha_{11}R^4}$ is a dimensionless quantity characterizing the strength of the reactions;

□=kR - dimensionless excitation frequency;

$\beta=\frac{d_{11}R^3}{2D}$ - dimensionless stiffness parameter of the support.

Analysis of results

A particular dependence of the quantity modulus f(□) gives a resonance curve; reverse value f(□) has a transmitting character in strength. We explore in detail the frequency dependence of f(□) for various parameters characterizing their fixation rigidity. An important feature of this type of boundary conditions is the appearance of a low-frequency resonance, caused by the compliance of the support. However, as the rigidity of the fastening increases, this resonant frequency increases, reaching, at $\beta\to\infty$ the lower frequency of the clamped disk. The physical appearance of low-frequency resonance can be explained by the existence of a special oscillation shape at which the deformations of the disk are small, and it oscillates almost like a rigid mass, and the elasticity of the system is due to the compliance of the sealing element. If the support is sufficiently soft, then for low frequencies the expansion

$$\frac{J_{0(\Omega)}}{\dot{I}_{0(\Omega)}}-\frac{J_{0(\Omega)}}{\dot{I}_{0(\Omega)}}=-\frac{2}{\Omega}-\frac{2}{\Omega}=-\frac{4}{\Omega} \quad (16)$$

This implies that the dimensional record of the reaction force will have the form

$$F=-\frac{2P_0Re^{-t\omega t}}{\frac{2\rho hR\omega^2}{\alpha_{11}}} \quad (17)$$

This formula corresponds to the elastic oscillations of a solid disk on a sufficiently compliant spring, which is confirmed by previous arguments. Finally, we`ll analyze the overall frequency characteristics of the system. It is convenient to consider the case of small

$\beta(\beta\sim1)$ and the case of large ($\beta \gg 1$) those the case of small and high stiffness of the seal. It is interesting to note here that the resonances alternate with the anti-resonances whose position does not depend on the rigidity parameter β. Indeed, the denominator turns to infinity only at frequency values, when

$\dot{I}_0(\Omega) = 0$; $\Omega = \mu_k$; $k = 1{,}2{,}3.$

At these values, the frequencies f (Ω)=0 and are anti-resonances. The values of the dimensionless frequency μ_K, at which F = 0 are given below

Table 1-The value of K and μ_K

k	.1	2	3	4	5	6	7	8	9
μ_k	.3,832	7,016	10,17	13,32	16,47	19,61	22,76	25,90	29,05

Resonances of the system are determined by a complex transcendental equation

$$\frac{J_{0(\Omega)}}{\dot{I}_{0(\Omega)}} - \frac{J_{0(\Omega)}}{\dot{I}_{0(\Omega)}} = -\frac{\Omega^2}{\beta} \quad (18)$$

The solution of this equation depends essentially on the parameter □ β. If β is small, then the first resonance is very low-frequency and can be found by expanding the Bessel functions into series. Thus, we obtain

$$\Omega^* = \sqrt[4]{4\beta} \quad (19)$$

he remaining roots of this equation can also be found, since at small β the resonances are very close to the anti-resonances and can be found by the formula

$$\Omega_k = \mu_k + \delta_k$$

where $\delta_k/\mu_k \ll 1$; μ_k - the value of the anti-resonances given in the table. From the approximate formulas and from the correct calculation it is seen that the natural frequencies increase asymptotically approaching the corresponding frequencies of the clamped disk. Another practically possible variant of the elastic fastening of the edge is the fixation, when the boundary conditions are satisfied

$$-M = \alpha_{22} W_r^{|}\ ;\ \alpha_{22} < 0. \quad (20)$$

It can be obtained from the general case by passage to the limit, taking

$$\alpha_{12} = \alpha_{21} = 0;\ \alpha_1 = \infty;\ 0 < \alpha_{22} < \infty \quad (21)$$

and substituting in (1)

$$W(r,t) = \frac{P_0 e^{-i\omega t}}{\rho h \omega^2} \cdot \left\{-1 + \frac{\Delta_1 V_0(kR) + \Delta_2 J_0(kR)}{\dot{I}_0(kR) J_0(kR) - \dot{I}_0(kR) J_0(kR) + \frac{2Dk^2}{\alpha_{11}} \dot{I}_0 J_0}\right\} \quad (22)$$

where

$$\Delta_1 = \dot{I}_0(kR) \cdot \left(\alpha_{22} + \frac{D(1-\curlyvee)}{R}\right) k - Dk^2 J_0(kR)$$

$$\Delta_2 = -J_0(kR) \left(\alpha_{22} + \frac{D(1-\curlyvee)}{R}\right) k - Dk^2 J_0(kR)$$

$$\Delta_3 = [J_0(kR)\dot{I}_0(kR) - \dot{I}_0(kR) - J_0(kR)]\left[\alpha_{22} + \frac{D(1-\mu)}{R}\right] k - J_0(kR)\dot{I}_0(kR)\ 2Dk^2$$

Here, the characteristic value of the determining reactive bending moment in the pinch is the angle of rotation of the section in the seal. This value is dimensionless, therefore, the dimensionless parameters introduced will be:

$$r = R;\ \frac{\partial W}{\partial r} = \varphi(\boldsymbol{\Omega});\ \Omega = kR \quad (24)$$

$$\gamma = -\frac{\alpha_{22} R}{2D} + \frac{1-\curlyvee}{2};\ \varphi_0 = \frac{P_0 R^3}{2D}$$

Thus, we obtain

$$\varphi(\Omega) = \frac{\varphi_0\left(\frac{J_{0(\Omega)}}{J_{0(\Omega)}} + \frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}}\right)}{\gamma\Omega^2\left(\frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}} + \frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}}\right) + \Omega^3} \quad (25)$$

A feature of this particular characteristic is that there is no low-frequency resonance even with a small value of the solid parameter. At low frequencies, the frequency characteristic is:

This circumstance reflects the mechanical meaning of the boundary condition (21), related with deformation of the sealant. The fact is that the boundary conditions are formulated in such a way that no oscillations are possible without its bending, and consequently the rigidity of the fastening can not be a source of a special self-form of oscillation, in which the sealer moves like a rigid disk. In other words, this circumstance can be reflected as follows. For separate values of the elasticity parameter, i.e. for $\gamma = -\frac{1-i}{2}$ and for $\gamma = \infty$ are accordingly, under the condition of free support and rigid pinching conditions. Although the first case is much low-frequency second, nevertheless the lowest frequency does not drop to zero, as in the previous case, In this case, the anti-resonances are determined by the equation

$$\frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}} + \frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}} = 0 \quad (26)$$

and resonances

$$\frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}} - \frac{\dot{I}_{0(\Omega)}}{J_{0(\Omega)}} = \frac{\Omega}{\gamma} \quad (27)$$

The correct solution of this frequency equation, in which the value of the first resonance is represented as a function of the stiffness parameter of fixation γ. It is important to note that the dimensionless elastic-fixing parameter $\alpha_{22}R/2D$ adds additive to the parameter ($(1-\gamma)/2$, which characterizes the sealant material. Consequently, the parameter

$\gamma = -\left(\frac{\alpha_{22}R}{2D} + \frac{1-^{\gamma}}{2}\right)$ (28)

can take both positive (for small α_{22}) and negative values. This shows that with free support, the quantity $(1-^{\gamma})/2$ forms, as it were, an additional elasticity due to the antiplastic effect.

The most interesting, but very difficult for research because of the greater number of parameters affecting the frequency characteristics is the general case, taking into account the compliance of the support at the same time to displacement and to bending.

We consider the elastic fastening variant, which is described by the following boundary conditions:

$F = \alpha_{11}W;$ (29)

$-M = \alpha_{22}\frac{\partial W}{\partial r}$ (30)

$W(r,t) = \frac{P_0 e^{-i\omega t}}{\rho h\omega^2}\left\{-1 + \frac{\Delta_1 V_0(kr)+\Delta_2 J_0(kr)}{\Delta}\right\}$ (31)

$$\Delta_1 = \begin{vmatrix} \alpha_{11} & 0 \\ 0 & k\left[\alpha_{22}+\frac{D(1-^{\gamma})}{R}\right]\dot{\mathrm{I}}_0(kR) - Dk^2 J_0(kR) \end{vmatrix};$$

$$\Delta_2 = \begin{vmatrix} 0 & \alpha_{11} \\ k\left[\alpha_{22}+\frac{D(1-^{\gamma})}{R}\right]\dot{\mathrm{I}}_0(kR) + Dk^2 J_0(kR) & 0 \end{vmatrix} \quad (32)$$

$$\Delta = \begin{vmatrix} \alpha_{11}J_o(kR) + Dk^3(kR) & \alpha_{11}J_o(kR) - Dk^3(kR) \\ k\left[\alpha_{21}+\frac{D(1-^{\gamma})}{R}\right] & J_0(kR) - Dk^2 J_0(kR) \\ -Dk^2 J_0(kR) + k\left[\alpha_{22}+\frac{D(1-^{\gamma})}{R}\right] & \dot{\mathrm{I}}_0(kR) \end{vmatrix}$$

As can be seen, in this case the frequency response depends on three dimensionless parameters, γ, β.

The problem becomes simpler if we confine ourselves to investigating only the natural frequencies, which are functions of only two parameters characterizing the compliance of the fastening. The equation of frequency is written in dimensionless form

$-\frac{\dot{\mathrm{I}}_{0(\Omega)}\dot{\mathrm{I}}_{0(\Omega)}}{J_{0(\Omega)}J_0(\Omega)}\cdot\frac{\Omega^2\gamma}{\beta} + \left[\frac{\Omega^3}{\beta} - \frac{\gamma}{\Omega}\right]\left[\frac{\dot{\mathrm{I}}_{0(\Omega)}}{J_{0(\Omega)}} - \frac{\dot{\mathrm{I}}_{0(\Omega)}}{J_{0(\Omega)}}\right]$ (33)

In this case, there is a characteristic low frequency, which can be low if the parameter β is small. It is for small β that the solution of the frequency equation can be represented in the form

$\Omega^* = \sqrt[4]{4\beta\left(\frac{\gamma+1}{\gamma+4}\right)}$ (34)

CONCLUSIONS

1. With the dynamic behavior of a circular borehole seal under the influence of external pressure, a low-frequency physical resonance arises due to a special form of oscillation.

REFERENCES

1.Timoschenko SP, Voinovsky-Krigers S. Plates and shells. M.State publishing house Physics - mathematics- literature. 1963, p. 696

2.V.T.Mamedov, S.R. Qurbanov The impact of the relatively ion compression rubber to functions sealing elements of well bore packers. ICSSW-2015, English International Conference on Soft Computing, Computing with and Perceptions in System Analysis. Decision and Control, Edited by R.A. Aliyev, I.B.Turksen, J.Kasprzuk, Dedicated to Professor Lutfizadeh, Antalya, Turkey September 3-4, 2015, p.p. 397-399

3.Mamedov V.T., Aslanov J.N. Calculation of stress-strain state of sealing arrangement from rubber comproition materials using in oilfileld equipment. p.p.78-81 European Science and Technology [Text]: Materials of the XII International Research and Practice Conference. Minch, December 29th-30th, 2015. Publishing office web Veriag Waldkraiburg-Munich-Germany, 2015-352 p.

4. Асланов Дж. Н. «Внедрение на закрывающие устройства новой модели резиновых матричных уплотнителей». Журнал: Оборудование. Технологии. Материалы. № 3, Баку, 2020

5. Aslanov Jamaladdin Nuraddin, Sultanova Axira Bahman. Forecasting of Improved Straightforward Valves Technical Condition Using Fuzzy Inference Models. IFAC-Papers OnLine, Volume 51, Issue 30, 2018, Pages 12-14.

Available online at www.sciencedirect.com

6. V. T. Mamedov, G. A. Mamedov, J. N. Aslanov; Stress-Strain State of Reinforcing Rubber Membranes at Large Deformations, Journal of Applied Mechanics and Technical Physics №2, 2020, Pp(152-157).

7. IUPAC, Compendium of Chemical Terminology, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "Shear modulus, G". doi:10.1351/goldbook.S05635

8.Aslanov Jamaladdin Nuraddin, Sultanova Axira Bahman, Habibov Ibrahim

Abalfaz. Model Design for Predicting the Efficiency of Improved Valve Constructions During Statistical Data Based Exploitation. IFAC-Papers On Line, Volume 52, Issue 25, 2019, Pages 547-550