Analysis Method of Sucker Rod Centralizer Spacing in Three-dimensional Hole

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Abstract. The usage rate of sucker rod centralizer more and more broad with the development of a sucker rod pump, adding sucker rod centralizer is very effective to reduce the impact of rod and tubing wear, increase the sucker rod and tubing service life, reduce the frequency of maintenance and the production cost. Starting from the actual borehole parameters, comprehensively considering bending stress condition of sucker rod string in the three-dimensional hole, analyzing of the axial load of sucker rod and lateral loads, and use the lateral deformation of the sucker rod equal annular space between tubing and sucker rod as the basic principle of centralizer allocation, to calculate and analysis of the spacing configuration of the stabilizer. The example analyzed shows that optimization design of sucker rod centralizer spacing has a certain reference value.

Introduction

Sucker rod pumping system is one of the most widely used oil pumping methods at home and abroad. The friction and wear between sucker rod and tubing is always an important issue needs resolution during the rod pumping system works steadily. It will cause sorts of downhole accidents indirectly, result in oil well stop production, increase oil well maintenance times and repair costs and directly affect the oil well production benefit [1-3]. In view of the eccentric wear of the rod tube, oil workers at home and abroad have made a lot of theoretical research, and achieved certain results. Various measures for preventing side wear have emerged. The installation of the stabilizer on the sucker rod string is a widely accepted method for oil field, which has low cost and good effect. Sucker rod centralizer is very effective to reduce the impact of rod and tubing wear, increase the sucker rod and tubing service life and reduce the frequency of maintenance and the production cost.

At present, the optimum locating positions and intervals of the rod centralizers lacking of support theory to guide and carry out concrete basis, most wells are configured by experience to design the locating positions and intervals of the rod centralizers, in addition to observing wear during the workover, to position centralizer at badly worn. This paper from the actual borehole parameters, comprehensively considering bending stress condition of sucker rod string in the three-dimensional hole, analyzing of the axial load of sucker rod and lateral loads, and use the lateral deformation of the sucker rod equal annular space between tubing and sucker rod as the basic principle of centralizer allocation, to calculate and analysis of the spacing configuration of the stabilizer.

Axial load of a sucker rod

Axial force at the bottom of a sucker rod. A sucker rod is limited at the bottom by a variety of load included the force acting on the plunger by the weight of the liquid W_L , the force produced by liquid inertia W_{Lau} , the buoyancy of well liquid and the sucker-rod string W_f , the friction between the liquid column and the tubing W_{tL} , the friction force between the piston and the bush W_{bp} and the friction force of well fluid through the subsurface pump W_{pL} during the up and down stroke.

Axial force at the bottom of a sucker rod during the up stroke W_{ub}

$$W_{ub} = W_L + W_{Lau} + W_{tL} + W_{bp} \quad (1)$$

Axial force at the bottom of a sucker rod during the down stroke W_{db}

$$W_{db} = W_f + W_{bp} + W_{pL} \quad (2)$$

Axial force on top of a segment of a sucker rod between two centralizers. Assuming that the rod string centralizer has been installed, calculating the axial force on top of a segment of a sucker rod between two centralizers. The axial force of the segment rod string included the segment rod string dead weight W_{rd} , inertial load W_{ad} , the buoyancy of the segment rod string W_{fd} and the friction force between the segment rod string and liquid column W_{rL} . Due to the load of sucker rod string is not the same during the up and down stroke, so the axial force on top of a segment of a sucker rod between two centralizers is calculated according to the up and down stroke.

The unit load of a segment of a sucker rod between two centralizers during the up stroke q_{ud} is

$$q_{ud} = (W_{rd} + W_{ad} - W_{fd}) / l \quad (3)$$

Axial force on top of a segment of a sucker rod between two centralizers during the up stroke W_{us} is:

$$W_{us} = W_{xd} + q_{ud}l = W_{xd} + (W_{rd} + W_{ad} - W_{fd}) / l \quad (4)$$

Where: W_{xd} is axial force at the end of a segment of a sucker rod, at the first cross axial force is W_{ub} .

The unit load of a segment of a sucker rod between two centralizers during the down stroke q_{dd} is:

$$q_{dd} = (W_{rd} - W_{ad} - W_{fd} - W_{rL}) / l \quad (5)$$

Axial force on top of a segment of a sucker rod between two centralizers during the down stroke W_{ds} is:

$$W_{ds} = W_{xd} - q_{dd}l = W_{xd} - (W_{rd} - W_{ad} - W_{fd} - W_{rL}) \quad (6)$$

Where: W_{xd} is axial force at the end of a segment of a sucker rod, at the first cross axial force is W_{db} .

Horizontal load of a sucker rod

Fig.1 shows the three-dimensional space curve of a sucker rod between two centralizers. Well the principal normal direction of hole is n and the vice-normal direction of hole is m . The oblique plane where the principal normal direction of the surface is called the dogleg, oblique plane where the vice-normal direction of the surface is orthogonal with the dogleg plane, and corresponding m is orthogonal with n .

Fig.1 Three-dimensional space curve of a sucker rod

General variation angle. Given by the formula (Lu-binski) [4]

$$\cos \beta = \cos \theta_1 \cos \theta_2 + \sin \theta_1 \sin \theta_2 \cos(\varphi_2 - \varphi_1) \quad (7)$$

Where: θ_1 , θ_2 , φ_1 , φ_2 is respectively the well angle and azimuth angle of the two end points of

sucker rod between two centralizers in three dimensional well eyes.

Vice-normal vector of hole section m is [3]

$$m = m_1 i + m_2 j + m_3 k \quad (8)$$

Where:

$$\begin{cases} m_1 = \sin \theta_2 \cos \varphi_2 \cos \theta_1 - \sin \theta_1 \cos \varphi_1 \cos \theta_2 \\ m_2 = \sin \theta_1 \sin \varphi_1 \cos \theta_2 - \sin \theta_2 \cos \varphi_2 \cos \theta_1 \\ m_3 = \sin \theta_1 \sin \varphi_1 \sin \theta_2 \cos \varphi_2 - \sin \theta_2 \sin \varphi_2 \sin \theta_1 \cos \varphi_1 \end{cases} \quad (9)$$

Principal normal vector of hole section n is [3]

$$n = (m_2 t_3 - m_3 t_2) i + (m_3 t_1 - m_1 t_3) j + (m_1 t_2 - m_2 t_1) k \quad (10)$$

Where:

$$\begin{cases} t_1 = \sin \theta_1 \sin \varphi_1 + \sin \theta_2 \sin \varphi_2 \\ t_2 = \sin \theta_1 \cos \varphi_1 + \sin \theta_2 \cos \varphi_2 \\ t_3 = \cos \theta_1 + \cos \theta_2 \end{cases} \quad (11)$$

Horizontal load in the direction of principal normal F_{nl} is [3]

$$F_{nl} = 2F_2 \sin(\beta/2) + W_{rd} l \sin((\theta_1 + \theta_2)/2) \sin((\theta_1 - \theta_2)/2) / \sin(\beta/2) \quad (12)$$

Horizontal load in the direction of vice-normal F_{ml} is [3]

$$F_{ml} = W_{rd} l \sin(\beta) \sin(\theta_2) \sin(\theta_1) \sin(\varphi_2 - \varphi_1) \quad (13)$$

In summary: horizontal load of a sucker rod between two centralizers F_H is

$$F_H = \sqrt{F_{nl}^2 + F_{ml}^2} \quad (14)$$

Lateral deformation of a sucker rod between two centralizers

In the three-dimensional well, lateral deformation of a sucker rod is produced by the axial tension and dead weight of a sucker rod. The calculation of the lateral deformation of a sucker rod in three dimensional wells is given by the following formula [5]

$$\delta = \left(\frac{F_H l^3}{384EI} \right) \left(\frac{24}{u^4} \right) \left(\frac{u^2}{2} - \frac{u \cosh u - u}{\sinh u} \right) \quad (15)$$

Where: $u = \sqrt{\frac{Fl^2}{4EI}}$, F is Axial tension of the segment rod string, E is material elastic modulus; I is the cross-section moment of inertia of sucker rod.

Calculation of two sucker rod centralizers spacing

According to the maximum deformation of the sucker rod between the two stabilizer, the spacing of the sucker rod stabilizer is designed. Its design criteria are

$$\varepsilon = \frac{f(d_t - d_r)}{2} \quad (16)$$

Where: f is the deformation ratio coefficient, d_{it} is the diameter of tube, d_r is the diameter of sucker-rod.

When $\delta < \varepsilon$ increased l , then decreased l . Thus we can established one element nonlinear equation as following (17) and the numerical calculation method is used to solve the nonlinear equation.

$$\left(\frac{F_H l^3}{384EI} \right) \left(\frac{24}{u^4} \right) \left(\frac{u^2}{2} - \frac{u \cosh u - u}{\sinh u} \right) = \frac{f(d_t - d_r)}{2} \quad (17)$$

Application example

A sucker-rod pumping pump depth is 1660m, submergence depth is 30m, plunger diameter is 22mm, length of stroke is 2.1m, pumping speed is 4/min. Combination of sucker rod is $\phi 16\text{mm} \times 332\text{m} + \phi 19\text{mm} \times 830\text{m} + \phi 22\text{mm} \times 498\text{m}$. The density of well liquid is 0.85t/m^3 , dynamic viscosity of the well fluid is 0.065pa.s , dimension of inner diameter of tubing is 63mm. Using the MATLAB software to optimize design of sucker rod centralizer spacing. Calculation results of centralizer spacing in Table 1, Calculation results of centralizer location in Table 2, Arrangement of the centralizer in Fig.2.

Table 1 Calculation results of centralizer spacing

serial number	1	2	3	4	5	6	7	8
m	13.5	24.5	22.5	20.5	21	19	19	19.5
serial number	9	10	11	12	13	...	45	46
m	17	17	18	17	17.5	...	45	79
serial number	47	48	49	50	51	52	53	54
m	76	61	71.5	82.5	73.5	46	43	63.5

Table 2 Calculation results of centralizer location

serial number	1	2	3	4	5	6	7	8
m	1646.5	1622	1599.5	1579	1558	1539	1520	1500.5
serial number	9	10	11	12	13	...	45	46
m	1483.5	1466.5	1448.5	1431.5	1414	...	776	697
serial number	47	48	49	50	51	52	53	54
m	621	560	488.5	406	332.5	286.5	243.5	180

Fig.2 Arrangement of the centralizer

From the Table 1 and the Table 2 we can figure out that there are 54 centralizers. The centralizer distribute closely because the force of sucker rod which at the end of a segment of a pump is larger and the trajectory curve of the borehole is larger. The upper centralizer distribute less because the force of sucker rod which at the top of a segment of a pump is little and the trajectory curve of the borehole is

close to a straight line. Example analysis shows that the result of optimum design of sucker rod centralizer spacing has a certain reference value.

Conclusions

This paper from the actual borehole parameters, comprehensively considering bending stress condition of sucker rod string in the three-dimensional hole, analyzing of the axial load of sucker rod and lateral loads, and use the lateral deformation of the sucker rod equal annular space between tubing and sucker rod as the basic principle of centralizer allocation, to calculate and analysis of the spacing configuration of the stabilizer. The example analyzed shows that optimization design of sucker rod centralizer spacing has a certain reference value.

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