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The Structure Parameters Optimization of Variable Direction Joint During Extracting Casing in High-Inclination Directional Well

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Abstract

During extracting casing in high-inclination directional well, the existence of variable direction joint (VDJ) can enhance the build-up ability of washover string. And it can increase the compatibility between washover head and casing to some extent. However, too large or too small bending angle of VDJ will result in that the washover head cuts the upper and bottom parts of casing. Therefore, it is necessary to design reasonable bending angles for casing damage wells with different borehole curvature. In this paper, through the geometrical and mechanical analysis on the washover string with VDJ, a build-up rate calculation model and an axial force calculation model are established respectively. Moreover, through establishing the finite element model of washover tubing-ball-casing combination, the contact stress distribution is obtained. Under the critical condition of casing breaking when the contact stress exceeds the yield stress, the reasonable bending angle of VDJ matching with different casing damage well is designed. We can conclude that the research results play an important significance for in assuring the safe extracting casing.

Key words: Variable direction joint; Safe extracting; Parameters optimization; Casing damage well

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INTRODUCTION

During extracting casing[1-2] in high-inclination directional well, the phenomenon of washover head cutting casing in the high-inclination portion will always happen because the hardness of washover tubing is greater than that of casing. At last, it results in the fish falling, which decreases the operating efficiency with no doubt. In order to enhance the compatibility between the washover head and casing, one or more VDJ whose can generate a bending angle itself under the effect of axial compressive force is combined with washover string. And the hardness of whole washover string will be decreased under the effect of bending angle. Unfortunately, how VDJ affects the build-up rate and axial force of washover string haven't been mentioned in the recent literatures. Furthermore, these literatures don't include the research on the compatibility between VDJ and casing damage well. In this paper, through the geometrical and mechanical analysis on the washover string with VDJ, a build-up rate calculation model and an axial force calculation model are established respectively. Moreover, casing damage is analyzed with the numerical method. Finally, the reasonable angles of VDJ matching with different casing damage well are obtained. And the structure parameters of VDJ are successfully optimized. There is no doubt that the research results provide a theoretical basis for safe extracting casing.

1. VDJ STRUCTURE

The VDJ used for extracting casing in high-inclination directional well is composed of internal and external tubes. There are some keys around the outer wall of internal tube. Besides, the same number of keyways which matches with these keys is on the inner wall of external tube. And there exists some space between the key and keyway. Under the effect of axial compressive force, the internal tube will be close to the external one. Finally, the key and keyway mesh with each other in a range of circumferential angle. Now, a bending angle in VDJ is generated. The effects of bending angle mainly includes: On the one hand, it can enhance the build-up ability of washover string. As a result, the trajectory of washover well can match with that of casing damage well preferably. The phenomenon of washover head cutting casing in the high-inclination portion can be avoided. On the other hand, it decreases the hardness of whole washover string, which enhances the ability of string passing well portion with small curvature. The VDJ structure is as shown in Figure 1.

(a) Whole Appearance (b) Key and Keyway Meshing (c) Inner Structure

Figure1
The VDJ Structure

2. THE EFFECT OF VDJ ON AXIAL FORCE

VDJ can generate bend itself under the effect of axial compressive force. So it will make the build-up ability of washover string change. And a new well trajectory will be generated during extracting casing. In this situation, the axial force born by washover string changes. Therefore, it is necessary for the washover string to make mechanism analysis and establish an mechanical model.

2.1 The Effect of VDJ on Washover String Build-Up Ability

During extracting casing in high-inclination directional well, VDJ is always used in conjunction with the centralizer in order to avoid string vibration caused by key and keyway meshing with each other. The structure of washover string with VDJ is as shown in Figure 2. Based on the theory of "three points determining one circle"[3-5], the effect of VDJ on string build-up ability are analyzed.

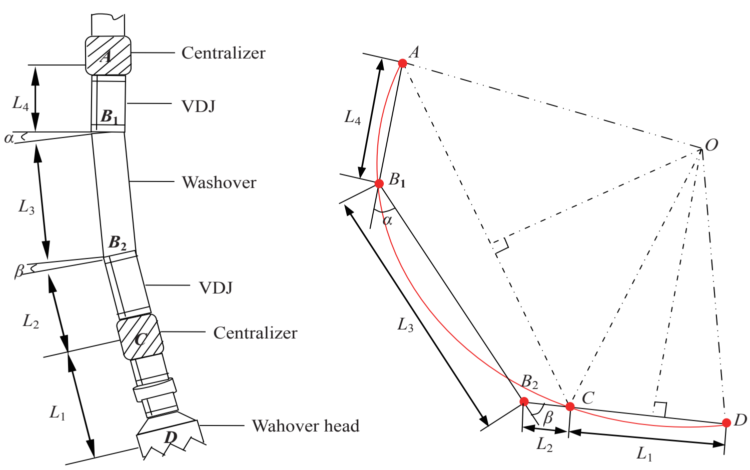


Figure 2
The Build-Up Ability of Washover String With

The model for calculating build-up rate is:

$$k = \frac{360\left[\alpha L_4 + \beta\left(L_3 + L_4\right)\right]}{\pi\left(L_1 + L_2 + L_3 + L_4\right)\left(L_2 + L_3 + L_4\right)}. \quad (1)$$

Where, k represents the build-up rate of washover string, °/30 m.

Based on the Equation (1), the build-up rates of washover string with different composite structures can be obtained when the values of α, β, L_1, L_2, L_3 and L_4.

2.2 Establishing Axial Force Model for Washover String With VDJ

It is well known that VDJ can increase the build-up rate of washover string. As a result, a new well trajectory is genetated. When establishing the calculation model, some assumptions should be indicated: (a) In the vertical portion, the new trajectory generated by washover string is the same with that of casing damage well. However, the both are different in the bending portion. (b) VDJ only changes the build-up ablity of washover string. And it hasn't any effect on the change of azimuthal angle. (c) the bend of washover tubing between two centralizers has no effect on the build-up ability. The new inclined angle at any well depth x_j can be expressed by:

$$\begin{cases} y_j = 0,\ x_j \le L \\ y_j = \dfrac{360\left[\alpha L_4 + \beta\left(L_3 + L_4\right)\right]}{\pi\left(L_1 + L_2 + L_3 + L_4\right)\left(L_2 + L_3 + L_4\right)}\left(x_j - L_1\right),\ x_j > L. \end{cases} \quad (2)$$

For the sake of the convenient calculating axial force, the numerical method[6-8] is used. Along the well trajectory, the washover string is divided into 1, 2, 3, ······, m+1 nodes from well head to bottom. The numbers of up and down nodes of unit j are j and j+1 respectively. The value of $q_{e,j}$ and axial force at node j can be calculated based on:

$$q_{e,j} = q_j + \rho_{\text{in}} g A_{\text{in},j} - \rho_{\text{out}} g A_{\text{out},j}. \quad (3)$$

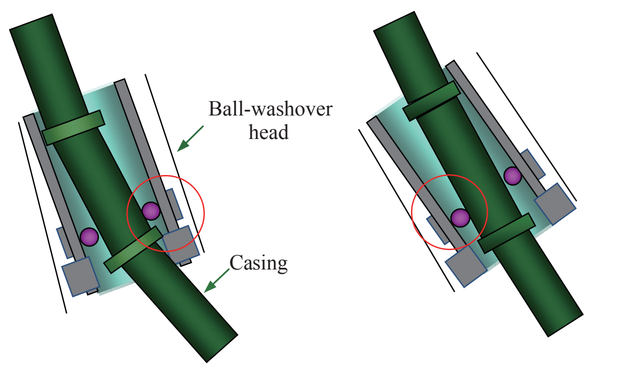
$$\begin{cases} F_{e\tau,j+1} = F_{e\tau,j} + \left(q_{e,j} - f_{l,j} N_j\right)\Delta l_j - f_{l,j}\left(N_1^j + N_2^j + N_3^j\right),\ x_j \le L \\ F_{e\tau,j+1} = F_{e\tau,j} + q_{e,j}\Delta l_j \left\{\dfrac{360\left[\alpha L_4 + \beta\left(L_3 + L_4\right)\right]\left(x_j - L\right)}{\pi\left(L_1 + L_2 + L_3 + L_4\right)\left(L_2 + L_3 + L_4\right)}\right\} - f_{l,j}\left(N_1^j + N_2^j + N_3^j\right),\ x_j > L, \\ F_{\tau,j} = F_{e\tau,j} - P_{\text{in},j} A_{\text{in},j} + P_{\text{out},j} A_{\text{out},j} \end{cases} \quad (4)$$

$$\begin{cases} F_{e\tau,j-1} = F_{e\tau,j} - \left(q_{e,j} - f_{l,j} N_j\right)\Delta l_j,\ x_j \le L \\ F_{e\tau,j-1} = F_{e\tau,j} - q_{e,j}\Delta l_j \left\{\dfrac{360\left[\alpha L_4 + \beta\left(L_3 + L_4\right)\right]\left(x_j - L\right)}{\pi\left(L_1 + L_2 + L_3 + L_4\right)\left(L_2 + L_3 + L_4\right)}\right\} - f_{l,j}\left(N_1^j + N_2^j + N_3^j\right),\ x_j > L. \\ F_{\tau,j} = F_{e\tau,j} - P_{\text{in},j} A_{\text{in},j} + P_{\text{out},j} A_{\text{out},j} \end{cases} \quad (5)$$

Where, L is length of vertical well portion, m; q_j is the weight of per unit washover tubing length at node j, N/m; $A_{\text{in},j}$ and $A_{\text{out},j}$ are the inner and outer section area, m^2; $F_{e\tau,j}$ is the equivalent axial force of washover tubing at node j, N; $f_{l,j}$ is the friction coefficient between washover string and well wall, dimensionless; $F_{\tau,j}$ is the actual axial force of washover tubing at node j, N; N^j_1 is the friction resistance between the casing above node j and the inner wall of washover tubing, N; N^j_2 is friction resistance at centralizers above node j, N; N^j_3 is the total friction resistance of each new contact point generated by washover tubing between two centralizers above node j, N.

3. STRUCTURE PARAMETERS OPTIMIZATION FOR VDJ

During extracting casing in high-inclination directional well, too large or too small bending angle of VDJ will generate a new trajectory that is different from casing damage well's. As a result, upper and bottom parts of casing will be cut by washover head. The washover cutting casing is as shown in Figure 3. Therefore, in order to assure safe extracting casing, designing the bending angle of VDJ and making the bending angle match with casing damage well with different borehole curvature are needed.

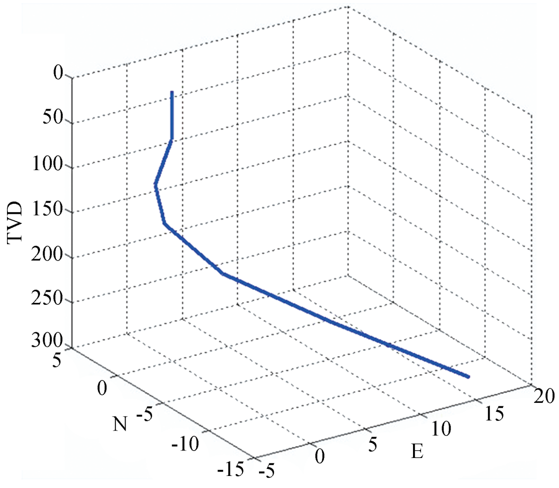


(a) Cutting upper casing (b) Cutting bottom casing

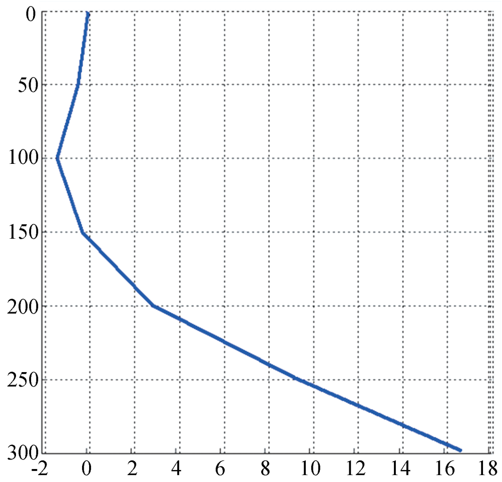
Figure 3
The Washover Head Cutting Casing

3.1 Analysis on Casing Breaking

We taking a high-inclination directional casing damage well for example. The casing damage points are located in 200 m, 250 m and 300 m well depth. And the extracting and replacing casing construction is needed. The trajectory of casing well is shown in Figure 4. During extracting, the washover string combination is washover head + 1 centralizer + 1 VDJ (1.6°) + 1 washover tubing + 1 VDJ (1.6°) + 1 centralizer + *n* washover tubing. And the other basic parameters are given in Table 1. Based on Equations (2)-(4), the zero-hook-load axial force of washover string with VDJ at 300 m casing damage points are obtained. Then, using the finite software Comsol multiphysics, the contact stress born by casing can be simulated. And the simulation result is shown in Figure 5.



(a) 3-D well trajectory

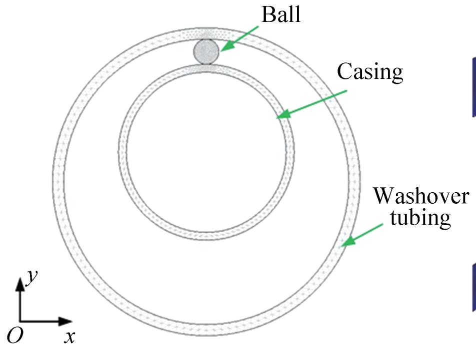


(b) Vertical Projection

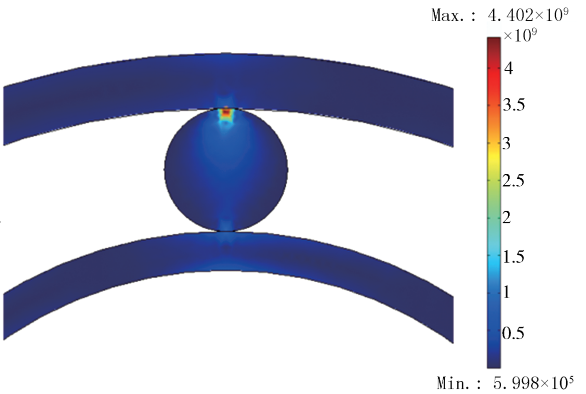
Figure 4
The Trajectory of Casing Damage

Table 1
The Basic Parameters

Item	Numerical value
Casing inner/outer diameter	0.1271/0.1397 m
Washover tubing inner/outer diameter	0.2266/0.2445 m
Ball diameter	0.02 m
Casing/washover tubing per unit length quality	20.83/53.57 kg/m
Casing/washover tubing/ball MOE	2.06×10^{11} Pa
Washover head/centralizer/VDJ/washover tubing length	0.455/1.014/0.95/10 m
Casing yield strength	431 MPa
Workover fluid density	1690 kg/m^3
Wellbore diameter	0.33 m



(a) Geometrical model



(b) Contact stress

Figure 5
The Contact Stress Born by Casing

As shown in Figure 5, we can obtain that the maximum contact stress is 4,400 MPa, which far exceeds the yield stress of casing 431 MPa. Now, the casing will generate an unrecoverable plastic deformation during extracting. As the time of extracting operation advances, the plastic deformation increases gradually. And the casing is cut by washover head at last.

3.2 The Design for Reasonable Bending Angle of VDJ

With the method of casing breaking analysis, three frequently-used washover string combination in the site are selected (Table 2). The maximum contact stress born by casing under different bending angles (0°-2.0°) of VDJ are simulated. The simulation results are shown in Figures 6-8. Under the critical condition of casing breaking when the contact stress exceeds the yield stress, the reasonable bending angles matching with casing damage well with different curvatures are designed.

Table 2
Three Washover String Combination

Parameter	Description
Washover string structure	I: washover head + 1 centralizer + 1 VDJ + 1 washover tubing + 1 VDJ + 1 centralizer + n washover tubing II: washover head + 1 centralizer + 1 VDJ + 1 washover tubing + 1 centralizer + n washover tubing III: washover head + 1 washover tubing + 1 centralizer + 1 VDJ + 1 washover tubing + 1 centralizer+ n washover tubing
Ending angle of VDJ	0°-2.0°

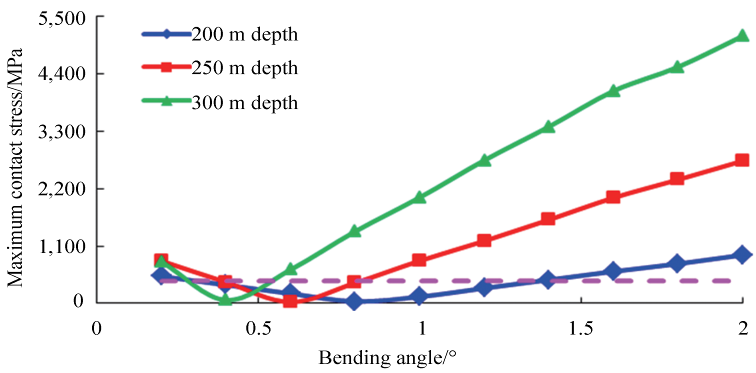


Figure 6
The Maximum Contact Stress at Different Bending Angles (I String)

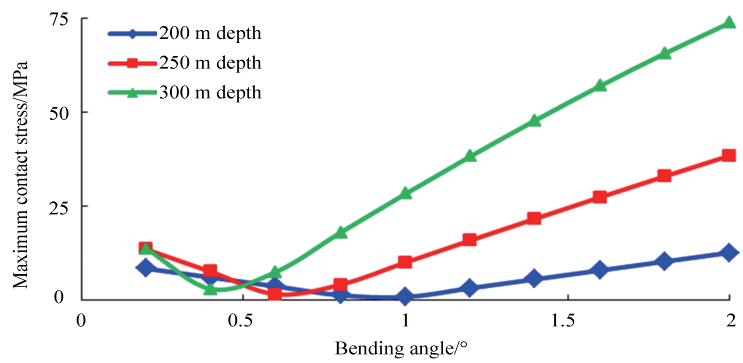


Figure 7
The Maximum Contact Stress at Different Bending Angles (II String)

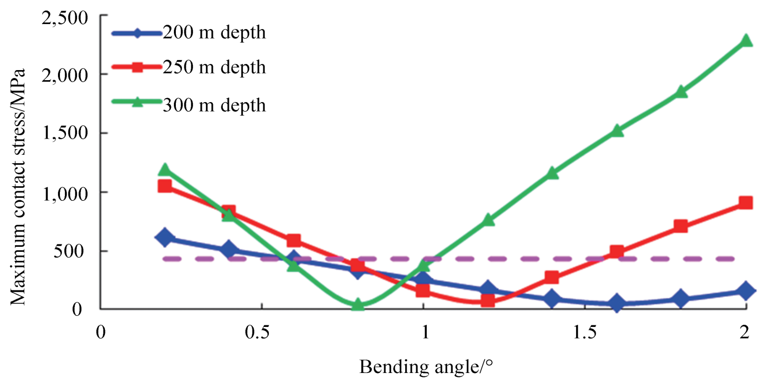


Figure 8
The Maximum Contact Stress at Different Bending Angles (III String)

As shown in Figures 6-8, we can obtain that: (a) The build-up ability of three washover string combination is I > II > III. Now, we can conclude that the more VDJ and the smaller distance between VDJ and washover head will result in a greater build-up ability. (b) The maximum contact stress born by casing will increase first and then decrease at different casing damage point. There exists an optimal bending angle of VDJ, which makes the contact stress equal to zero. Now, the new well trajectory generated by washover string is the same with that of casing damage well. (c) When the maximum contact stress is smaller than the yield stress (the pink curve), the casing breaking doesn't happen. So, there exists a reasonable range of bending angle to satisfy a safe extracting casing operation.

Table 3
The Design Results of Bending Angles

String structure \ Bending angle \ Casing damage point	200 m	250 m	300 m
String I	0.3°-1.38°	0.39°-0.84°	0.39°-0.51°
String II	0.31°-1.57°	0.44°-0.82°	0.44°-0.58°
String III	0.6°-2.0°	0.77°-1.58°	0.77°-1.02°

CONCLUSION

(a) Taking VDJ affecting the build-up ability and axial force of washover string, a build-up rate calculation model and an axial force calculation model are established respectively in this paper. There is no doubt that the research results enrich the string mechanism theory.

(b) A finite model for analyzing casing breaking is established. And the contact stress of washover tubing-ball-casing combination is obtained with the numerical method. Moreover, how the casing breaks is analyzed.

(c) Under the critical condition of casing breaking when the contact stress exceeds the yield stress, the bending angle of VDJ matching with casing damage well with different curvature are designed. There indeed exists a reasonable range of bending angle, which can satisfy a safe extracting casing operation.

(d) The research results of VDJ bending angle provide a theoretical basis for selecting VDJ numbers and string assembly design.

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