THE NONLINEAR DYNAMIC CHARACTERISITICS ANALYSIS AND ITS APPLICATION ON SUCKER ROD STRIINGS IN 3D CURVED WELLBORES

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Summary An innovative sucker rod strings dynamic characteristics analysis method was proposed. The effect of the initial displacement on the dynamic characteristics and the double nonlinear of sucker rod strings was taken into account. The crunode iterative method was used to solve the dynamic finite element equation of sucker rod strings in 3D curved wellbore, and the dynamic characteristics of sucker rod strings was analyzed. This method has been used successfully in the oilfields.

INTRODUCTION

Sucker rod string is a super thin beam, and has contact nonlinear and geometrically nonlinear characteristics with reciprocating motion in 3D curved wellbore. At present, the finite difference equations of sucker as well as mostly finite element model were based on the hypothesis of the axis of sucker rod coincide with the wellbore[1-2]. But this is not appropriate to the 3D curved wellbore since the trajectory of borehole was not straight or inclined anymore. Generally, the mechanical behaviors of sucker rod strings in 3D curved well are significant different from that in conventional vertical well. The differences between them are mainly due to the variation of curvature and torsion of wellbore trajectory. It makes the super-thin rod strings with reciprocating motion in wellbore endure the couplings among axial force, torsion and flexure, and the features of geometrical nonlinearity and contact nonlinearity of rod strings are exhibited. In this paper, a new dynamic model of sucker rod strings was established and solved by using finite element method. This new method can embody the features of geometrical nonlinearity and contact nonlinearity, and the couplings among axial force, lateral deformation and flexure of super-thin rod strings in actual 3D curved wellbores. With the time-domain straggling of the kinetic process for sucker rod strings by the Newmark method, the 3D dynamic finite element equation was circularly solved by using the crunode iterative method. And the dynamic characteristic was analyzed, this innovative method has been used successfully in the dynamometer card forecast and diagnosis of sucker rod strings. The reasonable parameters of sucker-rod string were obtained and the measurement data in the oilfields was used to verify the accuracy of the method in this paper.

DYNAMIC MODEL OF RODSTRING

Considered the high-order terms caused by the initial displacement of sucker rod stings, the incremental equation of strain within the spatially curved borehole can be written compactly in matrix form as

$$\boldsymbol{u} = \boldsymbol{N}\boldsymbol{d} \tag{1}$$

$$\boldsymbol{\varepsilon} = \overline{\boldsymbol{B}}\boldsymbol{u}^e \tag{2}$$

$$\delta\boldsymbol{\varepsilon} = \delta\boldsymbol{\varepsilon}_L + \delta\boldsymbol{\varepsilon}_N \tag{3}$$

Where $\boldsymbol{N}$ is the shape function matrix, $\overline{\boldsymbol{B}}$ is the strain-displacement transformation matrix which is contain the nonlinear factors.
The expression for total energy in the sucker rod strings element is given by

$$\begin{aligned}V = {} & \frac{EA}{2}\int_0^L (\frac{\partial u_x}{\partial x})^2 \mathrm{d}x + \frac{GI_x}{2}\int_0^L (\frac{\partial \theta_x}{\partial x})^2 \mathrm{d}x + \frac{EI_z}{2}\int_0^L (\frac{\partial \theta_z}{\partial x})^2 \mathrm{d}x + \frac{EI_y}{2}\int_0^L (\frac{\partial \theta_y}{\partial x})^2 \mathrm{d}x \\ & + \frac{EA}{2}\int_0^L (\frac{\partial u_x}{\partial x})^3 \mathrm{d}x + \frac{EA}{2}\int_0^L \frac{\partial u_x}{\partial x}\theta_y^{\,2} \mathrm{d}x + \frac{EA}{2}\int_0^L \frac{\partial u_x}{\partial x}\theta_z^{\,2} \mathrm{d}x \\ & + \frac{3EI_z}{2}\int_0^L \frac{\partial u_x}{\partial x}(\frac{\partial \theta_z}{\partial x})^2 \mathrm{d}x + \frac{3EI_y}{2}\int_0^L \frac{\partial u_x}{\partial x}(\frac{\partial \theta_y}{\partial x})^2 \mathrm{d}x + \frac{3EI_x}{2}\int_0^L \frac{\partial u_x}{\partial x}(\frac{\partial \theta_x}{\partial x})^2 \mathrm{d}x \\ & + \frac{(E-G)I_x}{2}\int_0^L \frac{\partial \theta_x}{\partial x}\theta_y \frac{\partial \theta_z}{\partial x}\mathrm{d}x - \frac{(E-G)I_x}{2}\int_0^L \frac{\partial \theta_x}{\partial x}\theta_z \frac{\partial \theta_y}{\partial x}\mathrm{d}x\end{aligned} \tag{4}$$

Where $u_x, u_y, u_z, \theta_x, \theta_y, \theta_z$ are the deformation of six orientations of degree of freedom respectively. The couplings among axial force, torsion and flexure are embodied in Equation 4.
The finite element equation of sucker rod strings dynamic characteristics can be expressed as

$$[\boldsymbol{M}]\{\ddot{\boldsymbol{U}}\} + [\boldsymbol{C}]\{\dot{\boldsymbol{U}}\} + [\boldsymbol{K}]\{\boldsymbol{U}\} = \{\boldsymbol{F}\} \tag{1}$$

Where $[\boldsymbol{M}]$ $[\boldsymbol{K}]$ and $[\boldsymbol{C}]$ represent the mass, stiffness, and damping matrixes, respectively[3-4]. The stiffness matrix takes the complicated couplings among axial force, torsion and flexure into considered. The initial displacement and the contact nonlinear were also contributed to the stiffness and force matrix. The dynamic contact between tube and rod strings was treating with a direct constraint procedure. Thus, the dynamic characteristics of sucker rod strings would be

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described in more detail and more accurate by using the crunode iterative method solved the 3D dynamic finite element equation.

DYNAMIC CARD FORCAST AND DIGNOSE

The classical empirical formula can not give a reasonable boundary condition when rod pumps used in directional well. In this paper, the measured dynamic card was used as boundary conditions, and by means of the innovative method above the dynamic characteristics of sucker rod strings was analyzed. While the boundary condition is the measured ground or down hole dynamic card, the diagnosis or forecast of sucker rod strings will be obtained, its accuracy were confirmed by comparing the numerical results and the measured data. Then the optimizing design of sucker rod strings was achieved.

CASE STUDY

A case study was conducted for the dynamic character evaluation of the suck rod strings of Guan129 well in the ChangQin Oilfield. The length of rod in Guan129 well is 2292.00 meters, the maximum diameters of sucker rod string is 19 millimeter, the slenderness ratio approximated to 100000:1. The wellbore trajectory and deviation angle and direction angle variation was shown in figure1 and figure 2. It indicates the complicated character of 3D curved borehole trajectory. By using the innovation numerical solution method and the measured ground dynamic card (fig.3), the downhole dynamic card would be deduced. And the comparison between simulated result and measured data were shown in figure 4. Similarly, the forecasting dynamic card is obtained with the measured down-hole dynamic card, as shown in figure 5. Then the dynamic properties of sucker rod strings were analyzed, as shown in figure 6. The local three-dimensional configuration of sucker-rod in actual wellbore is shown in figure 7. The dynamic characteristics of rod strings in wellbore was described, as shown in figure 8.

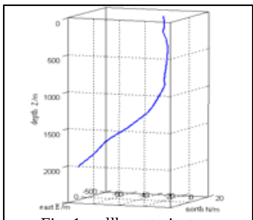
Fig. 1 wellbore trajectory

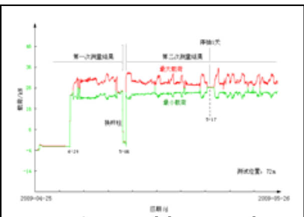
Fig. 3 measured dynamic card

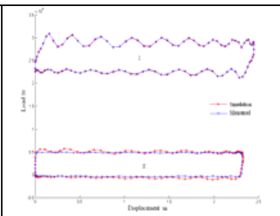
Fig. 4 dynamic card diagnosis

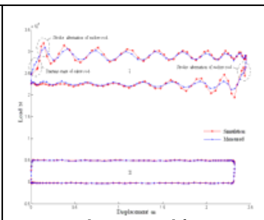
Fig.5 dynamic card forecast

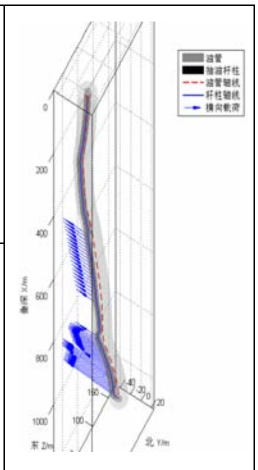
Fig. 8 dynamic properties

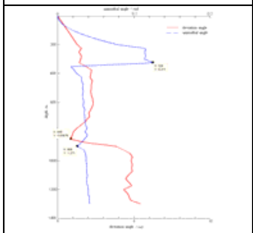
Fig. 2 angle variation

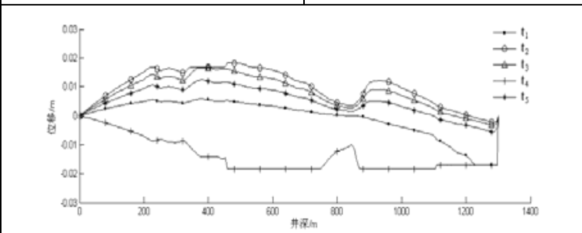
Fig. 6 dynamic configuration

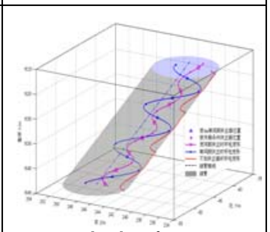
Fig. 7 local configuration

CONCLUSIONS

A new sucker rod dynamic model which is considered the features of geometrical nonlinearity and contact nonlinearity are exhibited. The initial displacement of sucker rod strings which is caused by the constraint of 3D curve wellbore is also taken into considered. The crunode iterative method combined with the direct constraint method were used to solve the super-thin sucker rod strings dynamic process for the first time. Then the 3D spatial configuration and dynamic character was calculated exactly. Case study on dynamic character of sucker rod strings of Guan129 well in ChangQin Oilfield was proposed, the dynamic card diagnosis or forecast of sucker rod strings was obtained.

References

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