Analysis on the Critical Speed of Drilling String in Deep Water without Riser

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Abstract. According to logging data of the field, while drilling in the deep water without riser, rules of motion and stress distribution of drilling string is really complicated without the constraint of riser because of the comprehensive action of working load, environmental load, movement of platform, whirl of drilling string and so on. Especially with the increase of water depth, the drill string will vibrate severely when the speed reaches the critical value, which easily causes the dynamic failure of the drill string. Based on rotor dynamics theory, this paper has established the mechanics calculation model of nonlinear support drill string without riser to analyze the influences of bearing stiffness, water depth and section size of drill string on critical speed of drilling string. The result shows that critical speed of whirl of drilling string is decreased with the increase of wall thickness; critical speed of whirl of drilling string is decreased with the increase of the length of string in water; critical speed of whirl of drilling string is increased with the increase of the stiffness of bearing. According to the results, reasonable speed of drilling string has been given to prevent resonance. The results can be used as reference for deepwater drilling operations without riser.

1. Introduction

Compared with using riser system, riserless drilling technology can effectively solve the various problems caused by using riser system and also can shorten the construction cycle which has remarkable economical benefit. It has been listed as a new technology in the petroleum industry in twenty-first Century [1-3]. Compared with the traditional marine drilling technology, the characteristics of riserless drilling technology is that it can solve the top strata instability of deepwater riser, reduce the risks of shallow and solve other potential deepwater drilling problem without protection of riser while drilling. It can drilling deepwater top hole with lower cost, faster drilling speed, safer operation and smaller environmental impact. Moreover, not only can it safely explore complex seabed surface, but also can extend the depth of surface casing, reduce the number of casing
and optimize the well body mechanism [4-5]. The practice shows that, riserless drilling technology can be used to drill deeper wells with using RMR technology under the ideal condition.

With the rapid development of marine deepwater oil and gas drilling and the strengthening of marine environment protection, riserless drilling technology will be used more widely in the world as its technology becomes more and more matures. Breihan [6] and Jellison et al [7], had studied the design, inspection, operation process and so on of feeding tube column in deep water. DeWayne et al [8-9], had studied the calculation method of the longitudinal vibration load for the casing string during feeding tube column of deepwater riserless drilling under the action of platform heave motion. According to the characteristic of the jet installation of the deepwater riserless pipe, Gao Deli, Zhang Hui [10] et al, established the static model of the pipe string of the process in domestic. Solving the model by using the method of weighted residuals, they had gotten the rules of deformation and stress distribution of pipe string in consideration of the action of environmental load, the structure of drilling string, offset of drilling ship and other factors. Considering the influence of sea surface wind speed, tidal current velocity and other factors, Han Tao, Lian zhuanghua et al [11], solved mechanics model of riserless drilling string by using the method of weighted residuals. Su Kanhua, Wan Wei et al [12], analyzed the dynamic response of drill string which was exposed to seawater under drilling platform motion and wave flow force during riserless drilling.

Figure 1. The logging curve of salvage operation of LH29-2-1 well.
For example, it is the logging curve of LH29-2-1 well for the salvage operation and cutting casing of 13-3/8”, as shown in Fig 1. From the picture, it can be drawn that, the depth of water of LH29-2-1 wall is 780m, when the speed of drilling string between 60 ~ 70rpm, the torque and hook load of drilling string are relatively small; When the speed of drilling string is between 70 ~ 80rpm, the torque and the hook load of drilling string increase sharply, the drill string violently vibration, and it will cause drilling string to stop. The cause has been analyzed that, the actual speed of the drill string is close to the critical speed of the drill string which causing resonance. Therefore, it is necessary to study critical speed of the riserless drilling.

Accordingly, considering the effect of "gyroscopic effect", the paper has established mechanics calculation model of nonlinear support riserless drilling string which guides the operation of riserless drilling by using the theory of rotor dynamics.

2. Establishment of dynamic modeling of drilling string in deep water

Assuming that the bearing is the connection of drilling string, and the suction module and platform, the dynamic control equations of the rotor tube element and the support have been established, and then the dynamic control equation of riser has been derived, with the combination of the finite element method and Lagrange equation.
\[ M \ddot{U} + (\Omega J + C_N) \dot{U} + KU = F \] (1)

Where \( M \) is the mass matrix, \( \Omega J \) is the drill string rotation matrix, \( K \) is the stiffness matrix, \( \ddot{U} \) is the acceleration matrix, \( C_N \) is the damping matrix, \( \dot{U} \) is the speed matrix, \( U \) is the generalized displacement matrix, and \( F \) is the loading matrix.

Under zero damping and no load conditions, the free vibration equation of structure can resolve as a superposition of many simple harmonic motion. Bringing \( U = \phi \sin(\omega t + \theta) \) into equation (1), the equation is:

\[ -M \omega^2 + J\Omega \omega + K = 0 \] (2)

When \( \Omega \) is equal to \( \omega \), the finite element software is used to analyze the resonance mode shape of drilling string and the each influence factor on the critical speed of drill string.

3. Analysis of influence factors of drilling string on critical speed

It has been analyzed the situation of LH29-2-1 well, water depth is 780m, 6-5/8” drilling string has been used. The elastic modulus of the drilling string of riserless drilling pipe is 2.1E11Pa, the Poisson's ratio is 0.3, the density is 7800kg/m3, and the spring stiffness of the bearing is set to infinity. Outside diameter of 6-5/8” drilling string is 0.1683m, inner diameter is 0.1515m, damping is 0 (Without considering the influence of damping), depth of water is 780m. According to equations before, the first three order critical speed of whirl can be obtained as follows: 95.75rpm, 382.4rpm and 858.7rpm. When the actual speed is close to 80rpm, the vibration of drilling string is violent which is in good agreement with practical situation. The corresponding figure is shown as follows.

![Figure 4. The first three order vibration mode of drilling string.](image-url)
(1) The influence of the length of drilling string in the water on critical speed of whirl
Considering that the spring stiffness of the bearing is set as infinity, outside diameter of 6-5/8” drilling string is 0.1683m, inner diameter is 0.1515m, damping is 0 (Without considering the influence of damping), influences of different lengths of drilling string have been analyzed on critical speed of whirl, as shown in figure 5. The results show that critical speed of whirl will decrease with the length of drilling string increased in deep water during riserless drilling.

![Figure 5. Influence of the length of the drilling string on the critical speed of whirl.](image)

(2) Influence of section size on riserless pipe string on critical whirling speed
When the length of riserless string is 780m, the influence of section size of riserless pipe string has been considered on critical speed of whirl. When outside diameter of drilling string is 0.1683m, the wall thickness of the pipe is taken as 8.24mm, 12.7mm, 19mm, 25.4mm respectively, and the whirl speed of the riserless drilling string has been obtained as shown in Figure 6.

![Figure 6. Influence of the wall thickness of the drilling string on the critical speed of whirl (constant outsider diameter).](image)

When the inside diameter of the drilling string is 0.1515m, the wall thickness of the pipe is taken as 8.24mm, 12.7mm, 19mm, 25.4mm respectively, and the critical speed of whirl of the riserless drilling string has been obtained as shown in Figure 7.
According to the analysis above, the critical speed of whirl will decrease with the increase of wall thickness as outside diameter of drilling string is constant during riserless drilling; the critical speed of whirl will increase with the increase of wall thickness as inside diameter of drilling string is constant. But the change of the wall thickness has little effect on the critical speed of whirl of riserless drilling string.

(3) The influence of bearing stiffness variation on critical whirling speed

Considering that outside diameter of 6-5/8” drilling string is 0.1683m, inner diameter is 0.1515m, damping is 0 (Without considering the influence of damping), and the depth of riserless drilling string is 780m, the influence of the stiffness at both ends of the bearing on the critical speed of whirl of the riserless drilling string is studied as shown in Figure 8. According to the results, the bearing stiffness has a great influence on the critical speed of whirl of the drilling string; with the increase of the stiffness of bearing, the critical speed of whirl of the drilling string will increases. But after the bearing stiffness is reached to 1.8E8N/m, it has little effect on the critical speed of whirl of the drilling string with the increase of it.
with the combination of the finite element method and Lagrange equation. The following rules are obtained.

1. With the increase of the wall thickness, the critical speed of whirl of riserless drilling string decreases; with the length of drilling string in the water increased, the critical speed of whirl of riserless drilling string decreases; with the increase of bearing stiffness, the critical speed of whirl of riserless drilling string increases.

2. When the water depth is more than 500m, the critical speed is reduced, the actual speed of the drilling string is closed to the critical speed which is easy to cause the resonance destruction.

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