

Mechanical Analysis of Drill String Drag and Torque With the Condition of Irregular Borehole

CAI Meng^[a]; WANG Lu^[b]; WANG Peng^{[a],*}; LI Meng^[a]

^[a]Production Engineering & Research Institute, Daqing Oilfield, Daqing, Heilongjiang, China.

^[b]PetroChina Research Institute of Petroleum Exploration & Development, Beijing, China.

*Corresponding author.

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Abstract

With the rapid development of drilling technology, air drilling technology and large displacement well, and horizontal well drilling technology are also known as the main directions of the future drilling development. Compared with conventional drilling mode, air drilling is particular, such as drilling fluid with low density, poor lubrication, large friction coefficient between the drill string and borehole, irregular borehole, well trajectory control difficulty, and so on. Along with the change of drilling condition, the stress of drill string is also changed. However, irregular borehole has a direct impact on the fatigue failure and the stress of drill string. Therefore, it is necessary to analyze drill string stress and influence factors in irregular hole. Based on the previous studies, application of drill string mechanics and statistical regression methods is used to study drill string drag and torque, and it can predict the drilling string stress state with the hole enlargement rate, meanwhile, it also provides a theoretical basis for gas drilling and complex drilling technology.

Key words: Irregular borehole; Drill string; Drag; Torque; Mechanical analysis

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INTRODUCTION

Drilling technology is developing rapidly, such as large displacement wells, large displacement horizontal well. However, there are so many difficult problems in the process of oilfield construction, such as drill string drag and torque is quite difficult to predict in different types of borehole, which directly restricts the drill string limit extended. Drill string drag and torque is the basis of well trajectory and drill string optimization design, especially to the large displacement wells, large displacement horizontal wells and complex wells. However, compared with conventional drilling mode, the drill string drag and torque mainly has the following characteristics in gas drilling: drill string friction drag, lateral force, torque are significantly large between the drill string and borehole; Hole trajectory azimuth drift is serious in gas drilling, and prediction and control of well trajectory is quite difficult. Therefore, it is very necessary to analyze drill string drag and torque in gas drilling. In this paper, on the basis of previous drill string mechanics studies, sensitivity analysis of drill string drag and torque are conducted, which including friction coefficient, rotation speed, which providing the theory basis for gas drilling safety and field extensive application.

1. IRREGULAR BOREHOLE DRILLING STRING DRAG-TORQUE PROBLEM ANALYSIS

Oil and gas well drilling string mechanical analysis is a necessary method to ensure the safety of drilling string operation, at the same time, it is also an important aspect of the bottom hole assembly (BHA) optimization design. Therefore, it is very important to analyze drill string drag and torque under different borehole conditions.

In this paper, the well of Shengshen X is an analyzed object in Shengping structure, southeast of Xujiaweizi faulted basin. Gas drilling is applied in re-drilling intervals which causes hole enlargement. The average hole enlargement rate is 21.34% (max 40%), as shown in Figure 1. Irregular borehole diameter has a great

impact on drilling string drag and torque, which not only increasing the drilling difficulty and the risk of drill string fatigue failure. At the same time, it also brings difficulties to the subsequent operations, such as well cementing. Therefore, it is necessary to predict drill string drag and torque in irregular wellbore.

2. THE MECHANICAL MODEL OF DRILL STRING DRAG-TORQUE

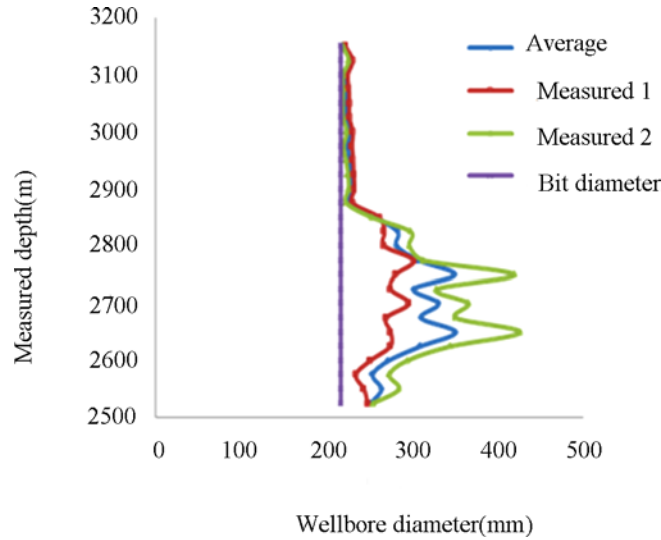


Figure 1
Diameter Measurement Curve Gas Drilling Well

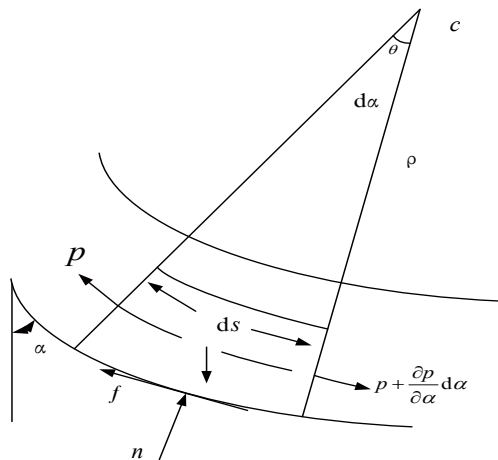


Figure 2
Drill String Mechanics Model

The mechanical model of drill string is established, as shown in Figure 2. The drill string is simplified as soft pipe contact drill string with one side of the borehole wall, and its cross-sectional can endure tensile, compressive load. ds is an element of drill string, P is the drill string axial tension, N ; q is drill string weight of

per unit length, N/m ; n is normal force per unit length of drill string, N/m ; ρ is curvature radius, m ; α is deviation angle, $^\circ$; D_w is well diameter, m ; D_c is outer diameter of drill string, m ; μ is friction coefficient between the drill string and borehole. Applying the equilibrium conditions and the frictional laws, equations can be derived, as follows:

$$\begin{cases} P + nR_1 = R_2 q \sin \alpha \\ \frac{dP}{d\alpha} + n\mu R_1 = -R_2 q \cos \alpha \\ R_1 = \rho + \frac{D_w}{2} \\ R_2 = \rho + \frac{D_w}{2} - \frac{D_c}{2} \end{cases} \quad (1)$$

Then the axial force as follows:

$$P = Ae^{\mu\alpha} + \frac{qR_2}{1+\mu^2} [(\mu^2 - 1)\sin \alpha + 2\mu \cos \alpha] \quad (2)$$

Where, A is undetermined coefficients which can be determined by boundary conditions.

Axial force is calculated segments because that borehole curvature radius and drill string line weight is

changing with the well depth. Assuming that there are $N+1$ nodes (N units) on the drill string, then the parameters of unit i are separately ρ_i, L_i, q_i . Then location of node 0 is bit, its boundary condition as follows:

$$\begin{cases} \alpha = \alpha_0 \\ p = p_0 = 0 \end{cases} \quad (3)$$

Axial force of node 1 can be calculated by Formula (2) and boundary condition (3), then p_2, p_3, \dots, p_N is obtained with the same method.

When $\alpha_i = \alpha_{i-1}$, steady inclined or horizontal section i , then

$$p_i = p_{i-1} + q_i L_i \cos \alpha_i + \mu q_i L_i \sin \alpha_i. \quad (4)$$

When $\alpha_i \neq \alpha_{i-1}$, then building section i , then

$$p_i = A_i e^{\mu \alpha_i} + \frac{q_i R_2}{1 + \mu^2} \left[(\mu^2 - 1) \sin \alpha_{i-1} + 2\mu \cos \alpha_{i-1} \right]. \quad (5)$$

Where

$$A_i = \left\{ p_{i-1} - \frac{q_i R_2}{1 + \mu^2} \left[(\mu^2 - 1) \sin \alpha_{i-1} + 2\mu \cos \alpha_{i-1} \right] \right\} \frac{1}{e^{\mu \alpha_{i-1}}}. \quad (6)$$

3. CALCULATION

The calculation model was established above to predict and analyze the drill string drag and torque. Well trajectory as shown in Figure 3. BHA of re-drilling intervals is shown as follows: ($\Phi 215.9\text{mm}$) bit $\times 0.24\text{m}$ + ($\Phi 214\text{mm}$) stabilizer $\times 1.50\text{m}$ + (165mm) MWD $\times 11\text{m}$ + ($\Phi 214\text{mm}$) stabilizer $\times 1.40\text{m}$ + ($\Phi 159\text{mm}$) drill collar $\times 9.11\text{m}$ + ($\Phi 214\text{mm}$) stabilizer $\times 1.40\text{m}$ + ($\Phi 159\text{mm}$) drill collar $\times 258.87\text{m}$ + ($\Phi 127\text{mm}$) drill pipe. In the section of the well hole enlargement (1900-2100m), calculated torque is far from the measured torque, namely torque expansion area. Measured torque changes with the depth of the well, through the statistical analysis of the data, the relationship between borehole diameter enlargement and calculated torque can be determined, and then corrected traditional computing. In the end, the reference range of added torque value is obtained under different borehole diameter enlargement rate, as shown in Figure 6.

On the basis of the model above, comparative analysis drill string torque between measured and calculated. The charts show: irregular borehole plays an important role on the drill string lateral force, torque and drag, at the same time, it is also one of the most important aspects in high frequency alternating stress load in gas drilling drill string failure.

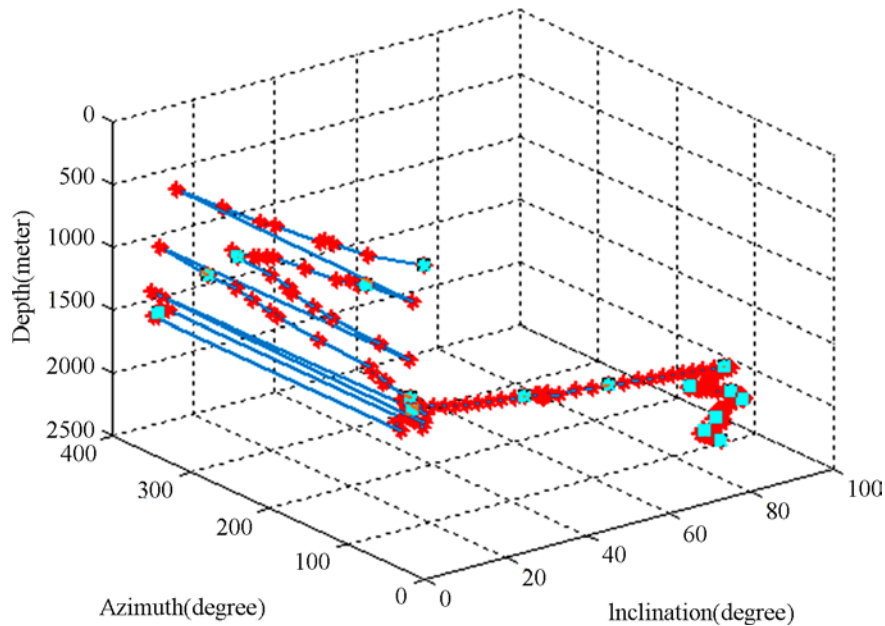


Figure 3
Survey Data 3D Display

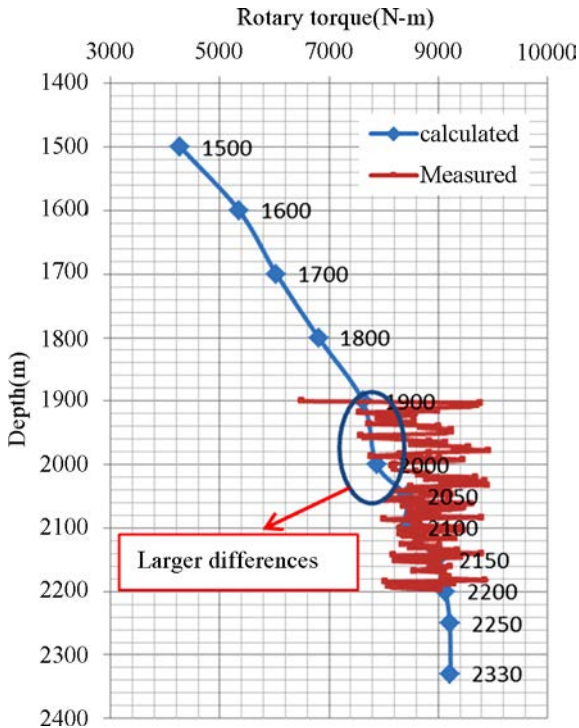


Figure 4
Torque Analysis With Borehole Diameter Enlargement

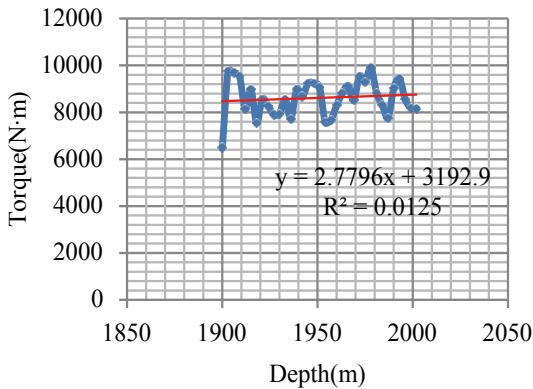


Figure 5
The Measured Torque Linear Regression Curve

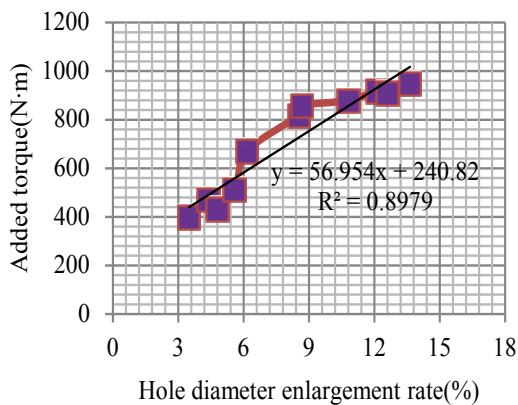


Figure 6
Different Hole Enlargement Ratio Value Torque

4. DRILL STRING DRAG AND TORQUE FACTORS ANALYSIS

There is a direct relationship between the borehole smooth degree and drag and torque of drilling string, and it also has close relation with the drilling conditions. Therefore, it is necessary to analyze the sensitivity analysis of the influencing factors, which provides a theoretical basis for drag and torque prediction and on-site construction. On the basis of given data, the model is more suitable for analysis string drill stress with the condition of irregular borehole, which considering the influence of added torque.

Sensitivity factors of drill string drag and torque are analyzed under the condition of tripping out, which considering the change of the well diameter.

Figures 7 to 9 show that axial force of drill string drag and torque will increase with the increase of friction coefficient. The increased drag for two reasons: (a) the drag is proportional to friction coefficient, and its increasing is caused by friction coefficient increasing; (b) increasing of the friction coefficient will cause the contact force and drag increases. Torque increases because that torque is proportional to friction coefficient. In addition, the axial force increases because that axial force is linear with friction coefficient, and it increases with friction coefficient increasing.

Figures 10 to 12 show that drill string rotation speed increases with the axial drag reduction, and rotation speed also reduces the axial friction coefficient by the theory of composite friction force decomposition. However, the axial drag reduces with the rotation speed increasing, and it gradually decreases (until to zero); meanwhile, the axial force is consequent reducing. Similarly, drill string torque will increase with the increasing of circumferential friction coefficient and drill string rotation speed.

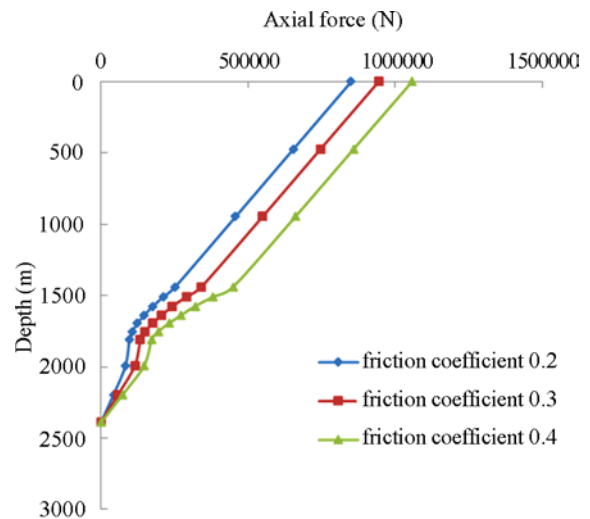


Figure 7
Axial Force for Varying Friction Coefficient

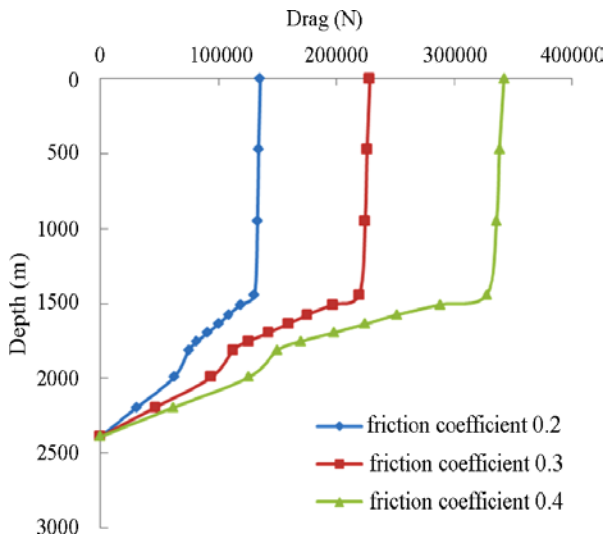


Figure 8
Drag for Varying Friction Coefficient

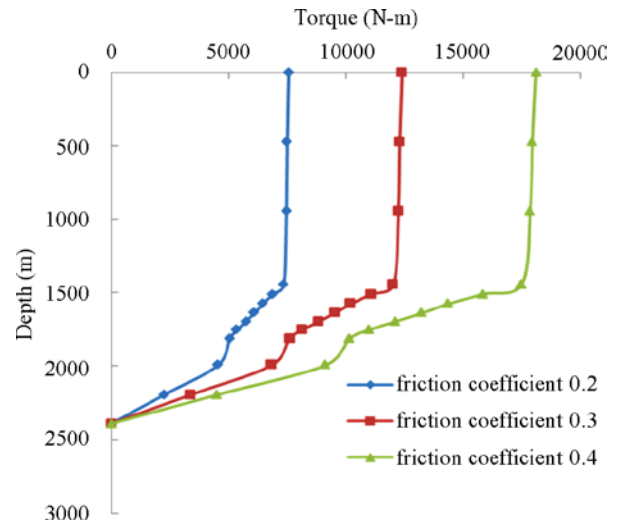


Figure 9
Torque for Varying Friction Coefficient

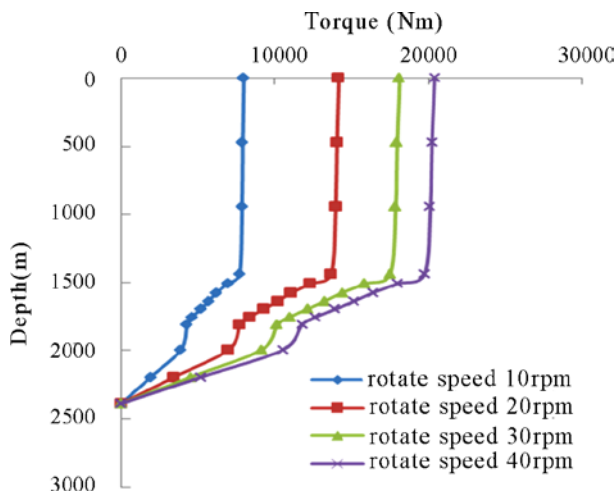


Figure 10
Torque for Varying Rotation Rate

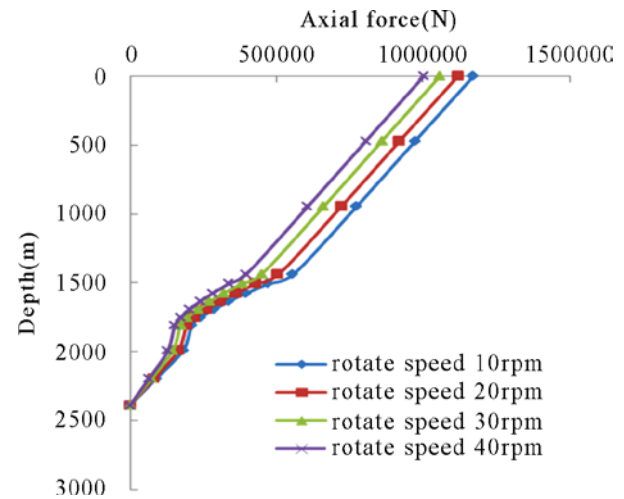


Figure 11
Axial Force for Varying Rotation Rate

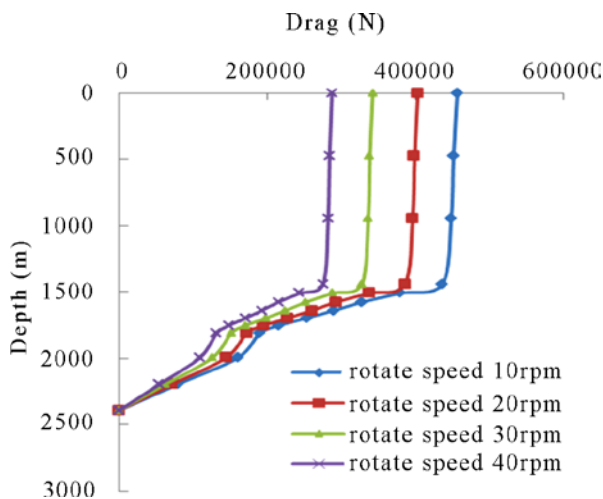


Figure 12
Drag for Varying Rotation Rate

CONCLUSION

(a) Drill string side force increases caused by irregular borehole, and it also increases drill string drag and torque linearly. The mechanics models are corrected by statistical regression method, which is more suitable for actual practice.

(b) Friction coefficient between the drill string and borehole is high. With the increase of friction coefficient of drill string, axial force, friction and torque will increase gradually, and the increase rate becomes large; with the increase of rotating speed of drill string, axial force, friction resistance will decrease rapidly, and torque decrease rate becomes small;

(c) The model can be used to predict drill string drag and torque accurately in the next well section, and it provides scientific basis for drilling safely in horizontal well, extended reach horizontal well.

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