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Analysis of Factors Affecting the String Cross-Through Capability Within Long Horizontal Section in Shale Gas Drilling

WANG Wei[a]; GUAN Zhichuan[a]; GUO Jianjun[b]; XU Yuqiang[a],*; DOU Yuling[c]; WANG Xiaohui[a]

[a] College of Petroleum Engineering, China University of Petroleum (East China), Qingdao, China.
[b] Petroleum Engineering Technology Development Center of Sinopec Shengli Oilfield, Dongying, China.
[c] Drilling Technology Research Institute, Sinopec Shengli Oilfield Service Corporation, Dongying, China.
*Corresponding author.

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Abstract
Along with the further petroleum exploration and development, the conventional oil and gas resources cannot meet the needs of rapid economic development now. Shale gas energy as an important supplement to the existing traditional energy is one of the main successive energy in the future which has very important significance for our country to realize diversified energy security strategy. In the course of drilling and developing horizontal wells in shale gas reservoirs, when it comes to hole trajectory control technology based on guide screw drill in horizontal well drilling with long horizontal section, there are some problems that string extension ability will be limited through horizontal section and low drilling efficiency will happen in later period which is not good for economic and efficient development of shale gas. This article focused on the researches of limit mechanism of the influence factors such as assembly, drill string buckling, weight on bit, well depth profile, and slope, and finally the extension ability in horizontal section was effectively improved by optimizing the well bore profile design and optimizing drilling parameters.

Key words: Drill strings; Horizontal well; Long horizontal section; Shale gas reservoir; Build-up rate

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INTRODUCTION
At present, in the process of the international scope exploration and development of oil and gas resources, the exploration and development of shale gas is becoming a hot spot in domestic area. Domestic shale gas development is still in the initial stage, and the number of shale gas well drilling has a gradually increasing trend. This technology with advantages in increasing borehole drilling and improve oil and gas production have been recognized by more and more society. Believe that with the improvement of shale gas drilling technology, it will become one of an important part in the field of drilling in the future. However, the development of the technology is facing some new challenges. How to improve the string through ability and extension ability in horizontal section of shale gas well is one of them. Due to various restricted factors, shale gas horizontal section could not have unlimited crossing and extensive ability, at the same time, according to the related research, from the economic perspective, horizontal section length should not as long as possible. String through the extensive ability in shale gas horizontal section can affect the efficiency of this type of well drilling and the cost of whole well. Therefore, analysis of the factors influencing the through the extensive ability in shale gas horizontal section is very important for horizontal well drilling design[1-2].

1. INFLUENCE FACTORS OF STRING THROUGH ABILITY IN HORIZONTAL WELL IN SHALE GAS RESERVOIR

String through ability in horizontal well in shale gas reservoir are jointly decided by various factors, and practical considerations is complicated. We consider to limit certain conditions, by changing a few of parameters and through comparative analysis, to speculate the maximum through length in horizontal well in the precondition of drill string not spiral buckling. What follows in this passage are qualitative analysis of influence parameters, and the study of string through the extensive capability by the selecting of the key factor in shale gas horizontal section.

1.1 Influence of Drilling Assembly

Shale gas reservoir horizontal well has the characteristic of long horizontal section (above 1,000 m), so the focus and difficulty of the horizontal well track control is the horizontal section trajectory control. Drilling tool combination closely contact with wall, thus greatly affecting the friction drag and torque of the drill string. In order to guarantee the stability of drilling horizontal section in shale gas horizontal well, the general drill assembly usually contains more stabilizer, drill collar, and aggravated pipes, which makes contact area between the tool and borehole wall, contact force, torque and friction larger. Especially in the inclined section, if the stiffness of drill pipe cannot meet the requirements will exacerbate this influence. Therefore, the rational assembly design can significantly improve the drill string and borehole wall contact situation so as to improve the level of through and extensive ability in shale gas horizontal well section.

Under different working conditions, when the stress of horizontal well drilling string and load level is not the same-under the condition of hoisting, ordinary drill pipe in well head endure maximum axial tension. Under rotary drilling conditions, ordinary drill pipes in well mouth are under maximum torque and larger axial force. Compound pipes in deflecting section are under high alternating bending stress. Under the running in condition and sliding drilling conditions, ordinary drill pipes (slope drill pipe) in high angle holes section and horizontal section are under larger axial pressure. In the process of assembly design, additional drilling torque, friction effects, drill string tensile and torsional strength checking must be considered[3-4].

Therefore, in horizontal well drilling, sliding guide assembly optimization design and drilling parameter optimization have to comply with the following two basic principles:

(a) In the shale gas horizontal section, the rotary drilling has stronger ability of stabilization. Rotary drilling way can transfer drilling pressure in a timely manner to the bottom hole, which help to improve the efficiency of horizontal drilling and horizontal section through and stretch ability.

(b) In shale gas horizontal section the slide drilling is with appropriate deflection ability. Due to the horizontal friction problem is very outstanding, adopting the sliding drilling way to adjust the trajectory is difficult, which requires oriented assembly must have appropriate deflection ability when it comes to the sliding drilling.

1.2 Influence of Wob

Wob effects shale gas horizontal well through and extensive ability by influencing the friction. At the bottom of the horizontal well, excessive friction can cause self-locking, weight on bit hard to be transferred to the bottom hole, and through and extensive ability is restricted in horizontal section. Through proper control of wob, choosing the appropriate bottom hole drilling pressure according to the stratigraphic conditions, it can achieve the effect of resistance reducing and speed increasing, which is advantageous to the horizontal well continue. Wob rising will cause the redistribution of the contact point between drill string and borehole wall, and so the contact force direction will have new changes. According to theoretical analysis, when the drilling pressure increases, the deformation of the drill string and the drill string compression strength increases; the wall between the positive pressure increases rapidly; thus friction increases as well.

In order to analyzing the influence of drilling pressure on the extension better, taking qualified down hole drilling pressure respectively 0 KN, 30 KN and 50 KN and horizontal long 1,000 m and 1,500 m and 1,800 m respectively, friction torque under drilling conditions can be calculated. Figures 1 and 2 are string friction torque forecast analysis under qualified wob different and horizontal section length condition.

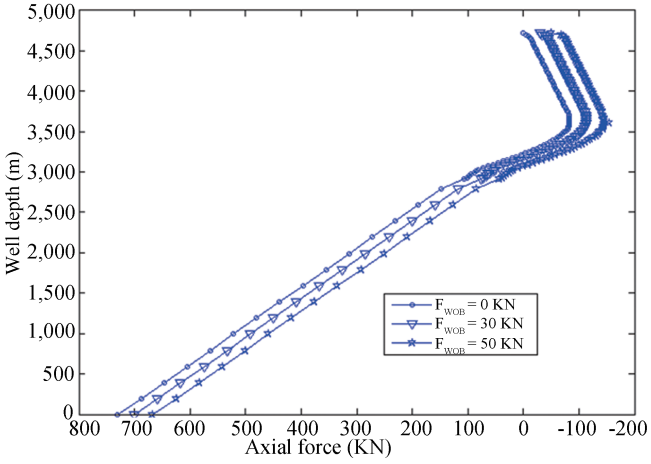

Figure 1
Analysis of Friction and Torque in Different WOB (1,000 m Extension)

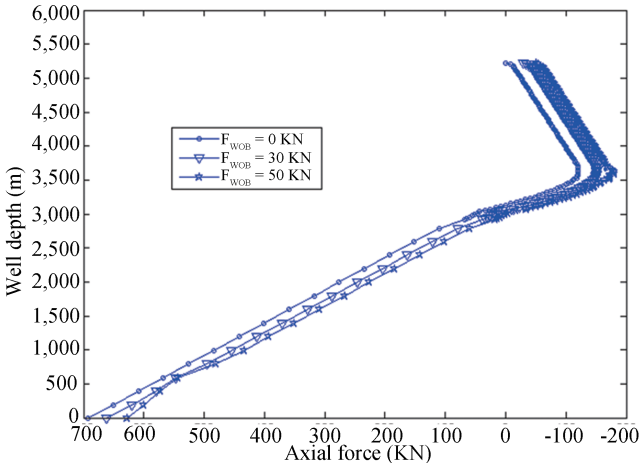

Figure 2
Analysis of Friction and Torque in Different WOB (1,500 m Extension)

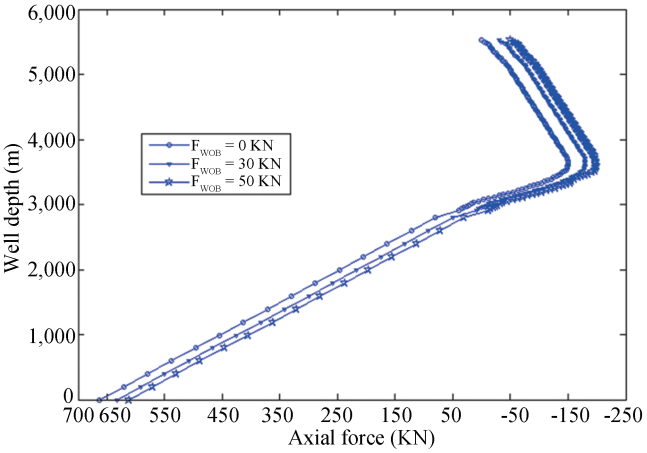

Figure 3
Analysis of Friction and Torque in Different WOB (1,800 m Extension)

As you can see from Figure 1 to Figure 3, with the increase of qualified wob, different levels of long friction torque is increased. Under the same limit wob condition, the longer the horizontal interval, the greater the friction torque. Through calculation, in conditions of limited amount wob: 30 KN, 50 KN, horizontal section level at about 1,800 m long, hole deviation at 60°, helical buckling happens. Drilling pressure at this time will be hard to pass to bit which will even produces self-locking phenomenon. If compound pipe down to Angle 60°, drill string strength checking all meet the requirements, but when it comes to qualification that pipe do not spiral buckling in bending section and horizontal section (sinusoidal buckling allowed), bottom hole pass 30 KN wob and horizontal interval extension length is about 1,800 m or so, the horizontal section level will add about 100 m every 10 KN below of the weight on bit.

1.3 Influence of the Drill String Buckling

In shale gas horizontal well, with the increase of drilling depth, drilling string load also increase, and the drill string are prone to buckling under well, which will affect drill string continue to transfer drilling pressure to down hole, and can even bring to serious drill string "locking", thus affecting the continued extension of highly-displacement well. Linear stability, sinusoidal buckling and spiral buckling state is shale gas horizontal well in each interval experiences before, during, and after buckling deformation pattern, the drill string in underground actual deformation may be in the transition state between the several states. Therefore, reasonable control of the drill string buckling and keeping within the sinusoidal buckling is one of the important factors influencing the horizontal limit extension. The drill string buckling diagram is shown in Figure 4.

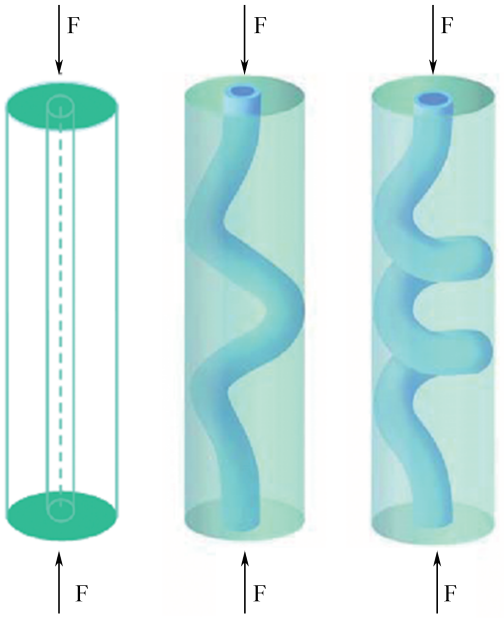

Figure 4
Balanced State of Drill Strings (Line, Sinusoidal and Helical Buckling)

The influence of horizontal well string sinusoidal buckling state on friction and torque between the walls can be ignored because it don't affect the string to continue drilling. But the influence of helical buckling of tubing string state on friction torque is bigger so it can't be ignored. So when the tubing string in helical buckling occurs, the additional effect on friction torque is the key. All kinds of drilling tools of critical buckling load are increased with the increase of angle, and the Angle is larger the buckling critical load growth trend is gradually slow. But all the tool corresponding to the helical buckling of pitch and decreases with the increase of angle and when the angle is bigger helical buckling pitch downward trend gradually decrease. By comparing increased friction value caused by the helical buckling, it can be seen that the friction of the drill collar is the largest, next the aggravating drill pipe, and drill pipe is minimal. With the increase of deviation angle, the friction increasing gradually slower. According to the

actual situation, it can appropriate considered to the deterioration of the critical buckling load is higher drill down to appropriate high angle hole (angle greater than 60° interval, and even into the horizontal section with a certain length), and reduce the slope of drill pipe on the axial stress, which will help to reduce or avoid the lower slope of drill pipe and spiral buckling problems lead to serious friction torque, and help extend horizontal section length[5-7].

1.4 Influence of Well Profile

Shale gas horizontal well bore profile design is the first step of shale gas horizontal well drilling construction, its profile optimization can effectively adjust the well track, reducing friction torque in the process of drilling, reducing the construction difficulty and improve the accuracy of target, so shale gas horizontal well bore profile design should follow the following principles:

(a) Meeting the requirements of reservoir characteristics and geological;

(b) Its shape is advantageous to the reservoir development and trajectory control, before the target distance, slope and the choice of the Angle also should satisfy engineering requirement, horizontal section length should be close to the optimal long;

(c) To ensure that the drilling and tripping operation friction torque is as small as possible;

(d) The drilling depth prediction can be overcome and tools (including formation) made slope uncertainty problems.

Conventional directional well trajectory has types of three-step, multiple target of three, and five sections types. Selecting deflection point location, size of build-up rate and other important parameters according to the design principle and drilling conditions. Through the calculations of two horizontal wells in same oilfield block data in Shengli calculations show that under the premise of limiting other conditions, the horizontal section design has an important influence on friction torque and so on the stable state of drill string and the horizontal section. Through the comparison and calculation, it can be found that the three "straight-diagonal-stabilizing" borehole profile design has certain advantages, which is mainly manifested in that the friction and torque in the rotary drilling hole is much smaller than in building type section, then to drill a convenient and safe well, which make the mechanical properties of drill string is more stable in the process of drilling, thus indirectly promote the horizontal section of the limit extension ability [8-10].

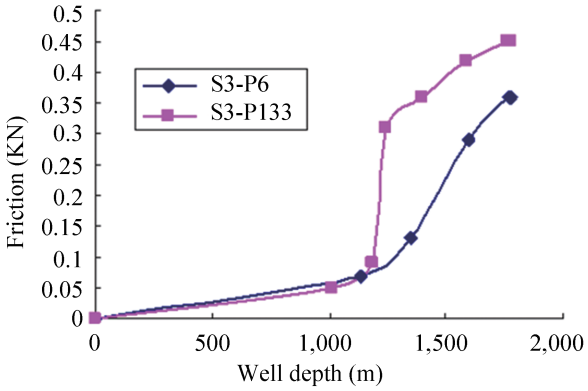

Figure 5
Analysis of Friction Between Different Well Depth

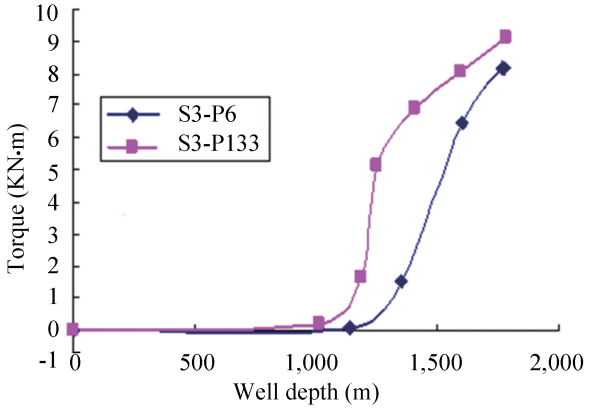

Figure 6
Analysis of Torque Between Different Well Depth

There are two horizontal wells of fault zone tuo7 fault block, whose deflection point are both about 1,000 m, with depth of 1,775.45 m and 1,781.41 m respectively. One of them named which is three-step design, well bore profile is straight-increase-ping. The other one is five sections of the design, with well bore profile of straight-stability-toughening-ping. By computing the friction and torque of the hole drilling tools in rotary drilling conditions, it can be seen from Figure 1 to Figure 2 that three hole plane surface friction and the torque relative to the five sections of the well bore of plane surface is small, and reducing the friction torque is more advantageous to the scene to continue drilling, so the three interval profile can effectively improve the ability of an extension of the horizontal well.

1.5 Influence of Build-Up Rate

Build-up rate is an important parameter in wellbore trajectory design of horizontal wells and it determines

the wellbore trajectory. Well profiles differ, and the mechanical analyses of the whole section are different, and so will the friction and the torque. So the choice of the build-up rate influence not only the mechanical stability of drill strings, but the shape of the bending section which determined by the build-up rate makes a notable impact on tripping up and tripping in. Therefore it becomes an important concern for the delivery of drill pressure of the horizontal segment, and especially the critical extension capacity. The horizontal wells' extension capacities reduce by the increase of the wellbore curvature. It is because by the build-up rate raising, the wellbore curvature increases, and bending degree of the drill string increases. The additional contact force which exists in the bending section will cause the increase of the drill pressure and wall of the well pressure and the friction, and it will be more possible for drill strings to buckle and then influence the delivery of drill pressure and reduce the critical extension capacity. However, it is not that the lower build-up rate, the better will the drill operation be. If the build-up rate is too low, the adjustment tendency will be slow, and then increase the distance of bending segment. As the cost raises, the overlong slide drilling section influences the efficiency of drilling, even causing missing the target. Therefore, when making a wellbore trajectory design, it should consider many kinds of factor and optimize a rational build-up rate.

The following example shows the influence of wellbore build-up rate on the extension capacity of horizontal segment. In order to facilitate comparison and according to the stimulation designed conditions and the established basis curvature K_1, we introduce another three wellbore trajectories ($K_3<K_1<K_2$) of two wellbore build-up rates (K_2, K_3). Related wellbore trajectory profile and parameters map as the Figure 7 showed.

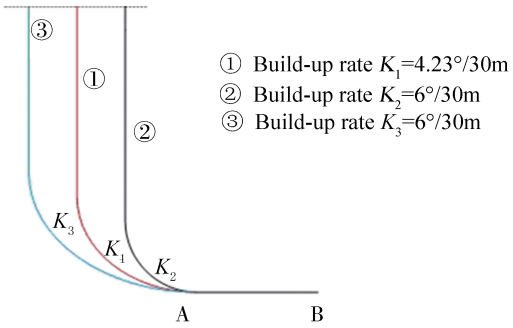

Figure 7
Cartogram of Well Trajectory Design in Different Deflection Rate

Assuming the distance of the horizontal segment is 1,000 m. By calculation we can get the extension capacity and drill string stability analysis results of three different curvatures which report four different working conditions and three different results of predicted friction and torque as follows (from Figure 8 to Figure 11).

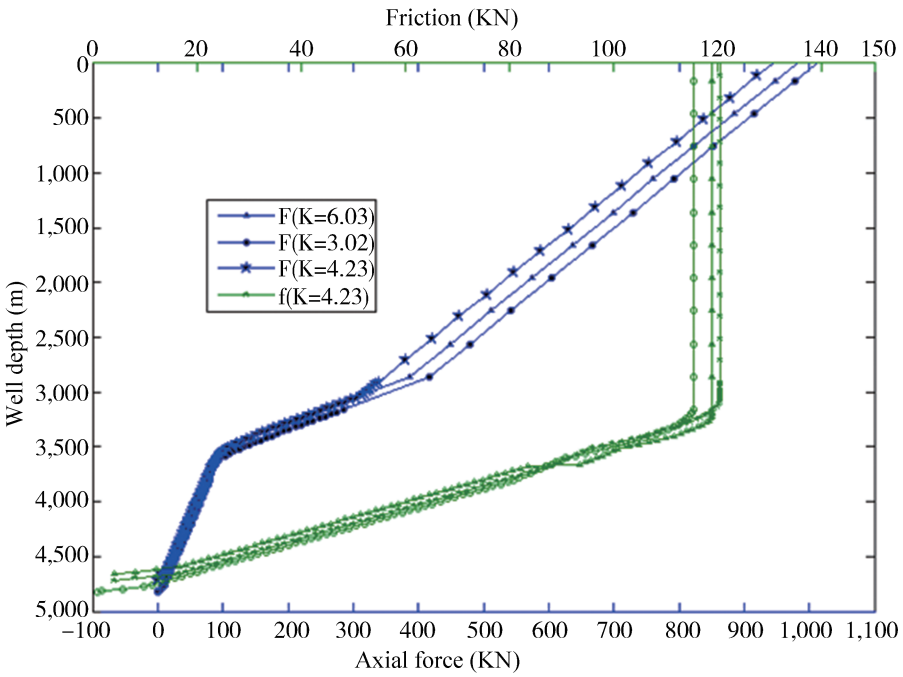

Figure 8
Analysis of Friction and Torque in Different Deflection Rate (Slide)

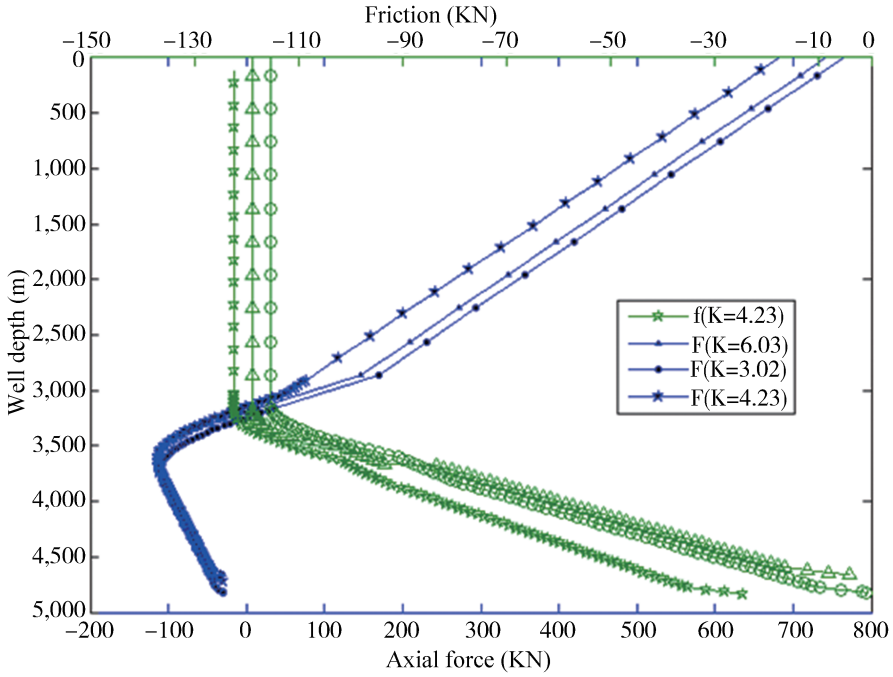

Figure 9
Analysis of Friction and Torque in Different Deflection Rate (Trip)

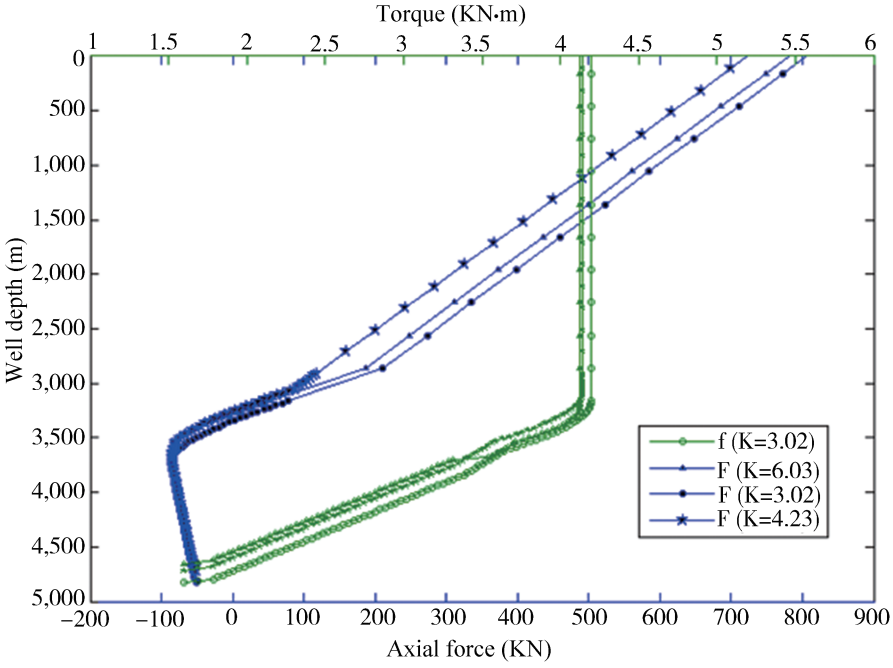

Figure 10
Analysis of Friction and Torque in Different Deflection Rate (Rotary)

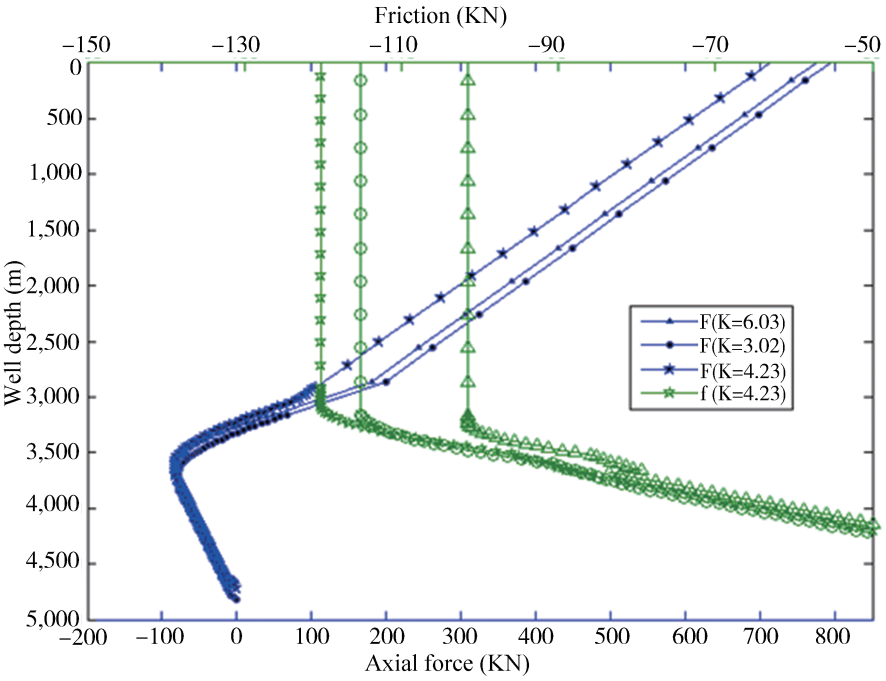

Figure 11
Analysis of Friction and Torque in Different Deflection Rate (Run)

By analyzing Figure 8 to Figure 11, we can get the following results:

(a) The drill strings all conform to intensity check by the change of build-up rates. The total hook load generates small change. The tripping in as a case: The total friction of three build-up rates are 101.52 KN and 110.29 KN and 125.23 KN, and the differences are less than 10%.

(b) The slope is not as small as possible. When building slope from K_1 (4.23) reduce to K_3 (3.02), friction has increased. The increase amplitude is smaller than it of slope. This is because the build-up rate is reduced, which will inevitably lead to deflection point up, borehole length increases, elongated curved segment will increase and borehole contact length and area increase. So the friction resistance increases, which is not conducive to the weight of the drill string delivery and level of through and extension ability.

(c) Under all kinds of working conditions, if build-up rate increases, when the build-up rate increased from K_1 (4.23) to K_2 (6.03), the total friction resistance increase. This is because the bending degree of the big hole increase the contact between the tool and borehole wall; and under the hoisting conditions, the drill string and borehole wall friction has increased on the point of tangency sections. Under running in working conditions, the drill string and borehole wall friction is bigger on the tangent point section which is not good for lift and down of the drill string. Therefore, for the drill string wob transfer and horizontal section through and extension ability, it has disadvantages.

Based on the analysis of the above calculation, when carries on the borehole trajectory design, it is necessary to comprehensively consider various factors, to select the appropriate slope, reduce the frictions. Appropriate build-up rate can be effective to reduce friction, guarantee the stability of the drill string and drilling pressure transfer effectively, thus promotes horizontal section extension.

CONCLUSION

(a) During the actual drilling operation, the emphasis and difficulty of horizontal well trajectory control exists in the horizontal segment. Rational make-up of string design can improve the stress states of drill string notably. Meanwhile, it can reduce friction resistance and raise drill speed, and improve the extension capacity of the horizontal segment by controlling the drill pressure and choosing the rational drill pressure on the basis of formation condition.

(b) The drill string will occur deformation because of the influence of axial force. When the drill string transforms to a spiral, it will be difficult for pressure to deliver to the drill bit. Moreover, if the self-locking phenomenon occurred and made the drill string become unstable, it would make the drill bit stop working. So, controlling the buckling deformation of the drill string within a rational range is an important factor in horizontal well crossing and extension.

(c) According to practical condition of site, we can move the heavy weight drill pipes which have a higher critical buckling load to the highly deviated segment (the segment whose deviation angle is larger than 60°, even part of it entering the horizontal segment).

Reducing the axial pressure supported by the lower slope drill pipe as much as possible, it helps mitigate or avoid the serious friction and torque trouble caused by the spiral deformation of the lower slope drill pipe and contributes to the crossing and extension of the horizontal segment.

(d) The design of wellbore trajectory is an important factor influencing the crossing capacity of the horizontal segment. We should simplify the design of wellbore trajectory as much as possible and optimize the build-up rate to reduce the friction and torque and improve the crossing capacity of the horizontal segment in practical drill operations.

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