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Design and Exploitation Problems of Drill String in Directional Drilling

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Abstract

Drill string design for directional drilling requires accounting for a number of factors. First, types and expected values of loads should be determined. Then, elements of the drill string should be so selected as to enable realization of the plan at specified loads. Some of additional factors, e. g. purchase, exploitation cost, geological conditions in the bore-hole, washing of the bore-hole, stability, trajectory, rig parameters, accuracy of gauges, pumps parameters remain in conflict. Drill pipes are made of rolled pipes, upset and welded with tool joints to 9,5 m long; the shorter ones can be made of hot forged rods. Exploitation requirements, being a result of practical experience supported by theoretical and laboratory analyses should be a part of syllabuses of technical staff educational programs. Apart from designing the string, it is also vital to lower the risk of a drilling failure. The significance of these aspects seems to be unquestionable.

Key words: *Design and Exploitation Problems of Drill String,*

Introduction

Owing to the dependence of efficiency of a project realization on the rational exploitation of pipes, drill string requires much care on the part of the drilling contractor and the crew. Some of additional factors, e.g. purchase , exploitation, geological conditions in the bore-hole, washing of the bore-hole, stability, trajectory, rig parameters, accuracy of gauges, pumps parameters are mutually exclusive. For instance, the requirements for bore-hole washing and pressure pump restrictions may suggest using the 5-1/2” instead of 4-1/2” diameters; however, the price, weight of the pipes and space needed may speak for the smaller ones. Therefore, one should consider in which horizontal drilling conditions, and at what load the external stresses acting on the pipe material may reach the critical level, i.e. is higher than allowable stress values. This should be done to operate the drill string safely and rationally [2]. As to the design drill string aspect, the vertical drilling differs greatly from its directional counterparts, horizontals in particular.

In vertical drilling, the drill string basically consists of drill pipes and drill collars, whereas in horizontal bore-holes there is no need to use traditional bottom hole assembly BHA. Drill pipes in horizontal drilling are used for exerting an axial pressure force on the bit, which is not possible in the case of vertical bore-holes.

Tensile force coming from the drill string suspended at the bore-hole outlet is smaller during drilling than expected from the measured depth (length) MD. This is caused by the fact that the string leans against the wall of the bore-hole, especially at a great deviation angle. In the course of out-tripping, the force is bigger than in vertical bore-holes. Moreover, the rotary torque value in the course of drilling is also higher than in vertical bore-holes. The maximum tensile force is a boundary load in vertical bore-holes, whereas in horizontal bore-holes it is the torsional strength.

Loads calculated on the basis of the value of load suspended at the bore-hole outlet are of top importance to the vertical bore-holes. The influence of friction is often small and accounted for by safety coefficients or marginal on pull MOP. The influence of friction and drag in horizontal bore-holes is so big that that cannot be ignored and thus requires simulations instead of simple calculations of expected load in vertical bore-holes.

The drill string configuration for vertical bore-holes requires an one calculation cycle; in the case of horizontal bore-holes – iterative calculations are needed.

Drill string in the bore-hole

Drill string design for directional and horizontal drilling requires accounting for a number of factors. Owing to the increasing depth of the horizontal bore-holes, the behaviour of the drill string in the bore-hole has to be well understood. A drill string, confined by the walls of the bore-hole can assume one of the shapes of its trajectory, i.e. straight, sinusoidal, unstable sinusoidal or helical.

Lubinski applied the beam-column equations to consider the stresses in drill pipe with tool joints in tension in a two-dimensional constant curvature hole. Tool joint stand-off significantly magnifies bending stresses in drill pipe. The introduction to calculations of torque in Karlic’s paper [6] extended usefulness of analysis for

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practice. Analysis of drill pipes buckling in hole was subject of many works in the last 20 years. The most advanced approach to the behaviour of the drill string in a bore-hole by Mitchell & Miska [5] accounts for a three-dimensional helical buckling of drill string with tool joints with torque in tension.

Drill string fatigue

When rotating the drill string, the bending stress values change, modifying the tensile stress values, basically in a pulsation mode. Pulsating compressive stresses appear only in the shoulder front zones in the API tool joints, where the compressive stresses are evoked by the assembling make-up of threaded connections. Bending stresses exerted by bending moment from curvature of the hole and helical buckling of drill pipes are significantly magnified by tool joint stand-off. On the other hand, one should not ignore such parameters as variable torsional stresses produced by variable drilling resistances and frictions of the pipes against the casing in the course of string rotation and openhole well of a specific curvature. In the course of drilling, the shape of the drill string axis in a directional bore-hole shows to a very dynamic character of stresses. In the first drilling operations during drill string exploitation, microcracks are formed in the drill string material in the places known from fracture mechanics theory as stress concentrators. Their origin may be connected with the technological process of the pipes (non-metallic precipitations, microstructural defects, bottoms of the threaded connection grooves, etc.), exploitation in the widest sense (cuts from the slips in the drilling table, cuts, notches and pits accumulated during handling and drilling), work environment (corrosion pits, hydrogen inducted from sour fluids). Microcracks in steel are a result of a sliding movement of displacements to the loose surfaces or a crack caused by an increased stress in a cyclically reinforced zone or a consequence of coalescence of vacancies. There are a number of metal fatigue hypotheses, stemming out from various assumptions. They can be analyzed on the background of the dominating type of crystalline lattice of the material and resolution level of the observation/analysis. Besides, statistical methods have developed for years. They employ some physical parameters, which depend on the accessibility of measurement data. Drilling field conditions are very specific and difficult for identifying and tracing every single pipe during its lifetime, especially in view of detailed measurement data acquisition and comparison with a history of a given drill string detail. Most drill pipe failures are a result of material fatigue. The amount of fatigue damage which results in exploitation depends upon tensile and torsion load in the pipe at the dogleg, the severity of dogleg and corrosion. Corrosion environment increases the number of stress concentrators and also enhances propagation of cracks, especially at a low frequency of stress/strain variations. To predict crack growth the Forman equation may be used as it is proposed in paper [4]. However, this concept taken from fracture mechanics requires a number of material data, the accessibility of which is still limited. To design a drill string, it is still possible to employ a comparative method for assessing the strength of the drill string in various configurations [1], [4]. No calculation method for drill string durability depending on its construction and drilling conditions has been worked out yet.

Combined Torsional and Tensile Operational Limits

High torsional and tensile loads are met simultaneously specially in extended reach drilling (ERD), when drill string is rotated while pulling out of the hole, which is performed on top drive rigs. In API RP 7G it is recommended that tool joints have a torsional strength of 80% of the pipe's torsional strength. Tool joint make-up torques are presented there [1] and are 60% of the calculated torsional yield strength. Method for plotting a diagram showing the limits for combined torque and tension for rotary shouldered connection is also in API RP 7G. The limits of drill pipe may be calculated from the formula [1]. The following figure presents the limits for combined torsion and tension [2] of a 5x29/16 NC38 tool joint on $3^1/_2$x2,764 S-135 drill pipe diagram (Fig.1).

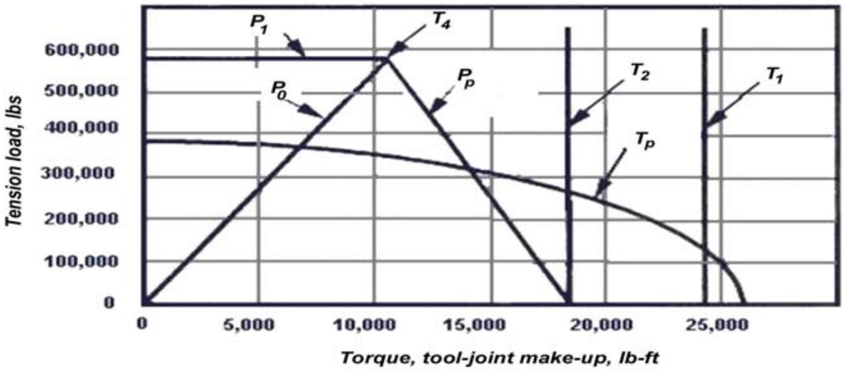

Fig. 1. Torque-Tension Limits diagram for 5x$2^9/_{16}$" NC38 tool joint on $3^1/_2$", 13,30 lb/ft S-135 drill pipe.

The bending stresses discussed above should be included in applied tension for drill pipe (elliptical curve). Applied drilling torque or tool joint make-up torque before tension is applied are on horizontal axis of above diagram. It is recommended that the operational torque be limited to level less than the make-up torque. Conversion factors are: 100 000 lb = 444,8 kN, 1 000 lbxft = 135,6 Nm.

Criteria of plotted diagram are listed below.

Po – tension required to open the shoulder of the box after make-up of tool joint to applied torque and is represented by a sloping line,

P1 – tensile strength of the tool joint pin at 19,1 mm from the shoulder. It is calculated by multiplying the cross sectional area of the pin at the last engaged thread by the yield strength of the tool joint material and dividing by the 1,1 safety margin, as all limit calculations,

T1 – torsional strength of the tool joint box,

T2 - torsional strength of the tool joint pin,

T4 – value of the torque at the point where the pin begins to yield and shoulder stress becomes zero,

Pp – tension required to yield the pin after make-up,

Tp – torsional strength of drill pipe in tension and is represented by elliptical curve.

To assess the bearing capacity (strength at loads acting simultaneously) of the drill string, calculations should be made on the basis of mechanical properties of the material, tool joint geometry, quality of lubricant and criteria of the applied make-up and rotary torques. During all operations, the torque and tension combination should be under the limit curve and limit lines to prevent damage to the drill pipe and tool joint.

Practical tips

Proper initial make-up torque is probably the most important factor affecting the life of the tool joint connections. Selection of the make-p torque and prediction of the drilling torque allows the use of proper diagrams, tables or calculations. Applying of the predetermined make-up torque requires a properly working calibrated torque gauge. Controlled break-in procedures should be consistently applied to every tool joint and drill pipe in factory. For ERD it is useful to apply drill pipes with double-shouldered design tool joints. Good rig practices will help eliminate time consuming trips and other operations because of failures and damages in the future exploitation.

Conclusions

1. Fatigue damage mostly depends upon tensile and torsion load in the pipe at the dogleg, the severity of dogleg and corrosion.
2. Bending stress from helical beam bending moment may be used to calculations of combined stresses in critical points of drilling string in directional, extended reach bore-holes and horizontal drilling. This is achieved at three-dimensional buckling of pipes with tool joints with applied torque.
3. Exploitation requirements, being a result of practical experience supported by theoretical and laboratory analyses should be a part of syllabuses of technical staff educational programs. Apart from designing the string, it is also vital to lower the risk of a drilling failure, it affects on safe work environment and reliability of system. .

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