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Mini Review

A Mini Review of Friction Reduction in Coiled Tubing Drilling with Hydraulic Axial Vibratory Tool

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Abstract

Hydraulic axial vibratory tool is a useful technology to improve the efficiency of axial load transmitting and extend the lateral length in coiled tubing drilling. This paper summarized the research progress of the action mechanism and limitation of the tool. It is hoped that this mini review will trigger further research and development of CT vibratory tools to improve their predictability and reliability.

Keywords: Axial vibratory tool; Coiled tubing drilling; Friction reduction

Introduction

Coiled tubing drilling (CTD) is a technology with wide application prospects and great development potential, especially in the un-swept portions of old oil field development, composite plugs drilling out in shale gas multistage fracturing, underbalanced drilling, and so on. However, as the CT slides forward without rotation during drilling, high friction between the wellbore and tubing would reduce the efficiency of axial load transfer to the bit, slow the rate of penetration down and limit the lateral extension of horizontal wells.

Many technologies are used or considered to tackle the problem of high friction, such as larger CT, rotation, straightening the CT, vibratory tools, tractors and lubricates. However, lager CT would increase the logistical and economic challenges, rotate the CT is still theoretical option, straighten the CT would also increase the risk of fatigue damage, so that vibratory tools, tractors and lubricates are the most common technologies that have been widely used in CT operation. Even though these technologies have some advantages in friction reduction, their disadvantages and operational limitations are still distinctly. For instance, though the tractors could provide large pulling force and easy to handle, their performance are strongly depend on the clean wellbore condition, because that large amounts of rock cuttings and debris would impair the tool performance strongly [1,2]. To the lubricates, if they are been used correctly, they could wet the contact face completely and reduce the friction force significantly. They are also convenient to conduct the experiment and field application without other unnecessary equipment. But the biggest disadvantage is their unreliable and inconsistent performance in the field [3]. The formation damage and large consumption volume of lubricates are also serious problems that need to be considered. To the vibratory tools, they have the advantages of stable, consistent and efficient performance of friction reduction, but the field performance studies regarding vibratory tools are mostly anecdotal or proprietary, rising questions about the predictability and reliability. The main reason is that the action mechanism of vibration generation and propagation along the CT is too complicated to be understood completely.

Hydraulic Axial Vibratory Tool

Significant achievement in hydraulic vibratory application has been reported in recent decades. It has been proven to be an effective and successful method to reduce friction and extend lateral reach in CT operation, such as well intervention, underbalanced drilling, composite plug drilling out, and so on. However, only a few papers study how the tool is specifically modelled for CT operations and how several tools are used for extending the CT reach [4-7], so that this section mainly summarized the research progress of tool structure, vibration generation mechanism and friction reduction mechanism.

Tool structure

Newman [8] once conducted experiment to study the availability of lateral, torsional and axial vibration on friction reduction, the results indicated that the axial vibration is the best among the three-type vibration. At present, there are three types of representative hydraulic axial vibratory tool that have been reported or used, they are Rotary Valve Pulse (RVP) tools, Poppet/Spring Mass (PSM) tools, Fluidic-Flow modulation (FFM) tools, respectively [9] once reported the development and test of a so-called Friction Drag Reducer (FDR). It can be regarded as doubleacting hydraulic cylinder with automatic reverse valves, when drilling fluid is pump through the tool, it is forced oscillate. The full-scale tests have proven the friction reducing efficiency, the friction force during run-in and pullout test was reduced by up to 90% in several tests. Even more, the measured friction reduction reached 94% in one case. But no further development or field application were reported after that.

The second representative axial vibratory tool is Axial-oscillation Generator Tool, which is developed by the company of National Oilwell Varco. It comprises three components: power section, valve system and oscillation system. The power section is a 2:1 positive displacement mud motor, the valve system comprises an oscillation valve and a stationary valve. The PDM drives the oscillation valve to rotate and then the flow area changes from maximum and minimum generating the desired pressure pulses [10].

The third typically axial vibratory tool is the Fluidic-Flow modulation (FFM) tools. The difference from other devices is that the fluid switch is based on the Coanda effect and does not have any moving part. The position valve that rapidly opens and closes to create square pressure waves is the only moving parts [5].

In summary, though their structures are different, the core operation principle of each tool is very similar that they all make full use of the fluid hammer to improve the CTD efficiency, as displayed in Figure 1. These tools all induce a periodic pressure pulse by changing the flow area or flow resistance across the hydraulic vibratory tool. As a result, the periodic flow causes cycle axial excitation force built up and released periodically, this stress cycle induces vibration of coil tubing string which results in a friction reduction between the coil tubing and the wellbore [11,12].

Vibration generation mechanism

The effect of fluid hammer on the axial vibration is a critical problem for the tool performance prediction and structure optimization. At present, the methods for water hammer evaluation can be classified into three categories roughly, i.e., respectively analytical solution or semi-analytical method, simulation with commercial software and numerical method of solving the transient fluid hammer equations.

Based on the classical water hammer models, the analytical or semi analytical models are usually used to calculate the amplitude of the pulse pressure [6,13]. The formula is $\Delta p=\rho c\Delta v$, where ρ is the density of the drilling fluid, c is the wave velocity and Δv is the change in fluid velocity. Obviously, it is a simplified and approximate method that neglect the effect of tool parameters.

Commercial software's are also commonly used to study the fluid hammer, such as OLAG and FLUENT [14,15]. For the transient fluid hammer of valve close suddenly, it is convenient. However, it is extremely too complicate to study the periodic flow with the dynamic change of flow area in CTD, the calculation time and efficiency both are huge challenges in this method.

The third representative method is the numerical solving of the transient hydraulic models, which comprise of mass and momentum equations. Compare with the above two method, it is more convenient to study the characteristic axial vibration and the effect of CT parameters, tool parameters, pumping rate, and downhole pressure on the tool performance [5,7] once investigated the fluid-CT interaction and the competition between axial and lateral vibration with the quasi-steady water hammer model. Then an improved model is proposed with an unsteady friction to study the fluid hammer in CTD [16]. The results indicated that the magnitude of drag force induced by hydraulic vibratory tool is not affected by the frequency of flow area change, it increases exponentially with flow rate while decreases exponentially with minimum flow area ratio.

Therefore, the above study provides a theoretical basis for the generation of axial vibration by the tool, the effect of tool parameters on the axial force is also revealed preliminarily.

Friction reduction mechanism

In order to incorporate the tool effect, a constant axial force and a potential coefficient of friction reduction are usually introduced into the common tubing force analysis models. However, the effects of such operation parameters as the vibration frequency, amplitude, CT size, wellbore parameters, etc. are not considered [5,7]. So that this approach is usually vulnerable to inconsistent results when comparing the pre-planned and post-job CT axial and frictional forces [17,18]. In addition, there are three mainstream views that intend to reveal the friction reduction mechanism of the axial vibratory tool.

Skyles [19] once reported that the friction reduces mainly because that the pipe vibration converts the static friction to kinetic friction, as the kinetic friction coefficient is smaller than static friction coefficient, so that the mechanism is explained qualitatively. This is the first representative opinion that try to reveal mechanism qualitatively from the perspective of coefficient changes with the vibration.

The second opinion is from the perspective of normal force change induced by the tool [7] once incorporated the fluid hammer effect in the normal force calculation formula. The radial vibration and pressure change along the CT cause the normal force oscillation simultaneously.

The third viewpoint is that the vibration changes the direction of friction force periodically [9,20-22]. Due to the vibration of the tool, the CT movement direction is also changed periodically. As the direction of CT is reversed some fraction of the oscillation period, so the time-averaged friction forces are decreased (Figure 1).

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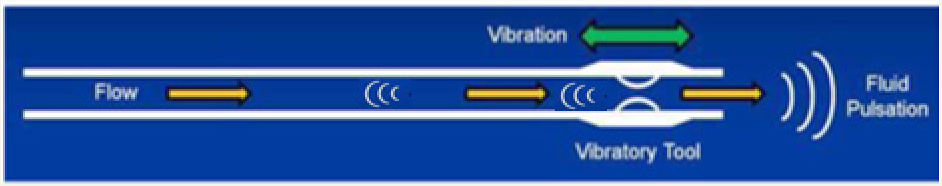

Figure 1: Working mechanism of hydraulic axial vibratory tool [22].

In summary, the four-method intended to reveal the action mechanism of the tool, but no unanimous conclusion has been drawn and the mechanism was still unrevealed completely because of its complexity.

The Future of Tool Development

The current challenges of vibratory are in the structure optimization and better understanding the mechanism of friction reduction. As the failure of the moving part limits the tool life seriously because of the high abrasion, so that develop and optimize the tool without moving part would further improve the life and stability. On the other hand, it is also of great importance to study the tool performance under downhole condition, reveal the effect of tool parameters, downhole pressure, CT parameters and wellbore parameters on tool performance, and develop relevant models to predict the tool performance accurately and reliably.

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