第 28卷 第 6期 石 油 钻 采 工 艺 Vol.28 No.6
2006年 12月 OIL DRILLING & PRODUCTION TECHNOLOGY Dec. 2006

文章编号：1000－7393(2006)06－0001－03

大位移井摩阻/扭矩预测计算新模型*

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摘要：井下摩阻/扭矩预测是大位移井钻井成功的关键技术之一。常用的预测模型大都忽略了井眼的间隙，因此无法判断钻杆接头和本体与井壁的接触情况。通过假设井壁对钻柱的支承点按一定的间隔分布，将钻柱在支承点处断开，相邻两断点间的钻柱作为一跨，根据加权余量法在每一跨内计算出钻柱的转角与弯矩的关系；根据相邻两跨在断开点处的转角相同，求出弯矩的迭代方程；再由已知的边界条件计算出各点的弯矩；进而计算出各支承点处支反力的大小和方向，根据这一方向逐渐调整钻柱在井眼中的位置；推导出一套新的没有忽略井眼间隙的摩阻与扭矩计算公式。新模型能够计算出钻柱与井壁的接触情况，为合理的确定减扭接头或钻杆保护器等工具在钻柱上的安放位置提供更准确的依据。

关键词：大位移井；摩阻；扭矩；加权余量法

中图分类号：TE22 文献标识码：A

大位移井具有长水平位移、大井斜角以及长裸眼稳斜段的特点。大位移井钻井过程中的摩阻/扭矩的预测和控制是成功实施大位移井的关键和难点所在。摩阻扭矩分析是大位移井轨道优化设计的基础，是选择合理的钻井和下套管工具的前提。在实钻速，通过预测值和实测值的对比，可以了解井下的情况。所以建立一个符合实际情况的，正确合理的摩阻扭矩计算模型是很有意义的。

国内外有多篇文献对摩阻/扭矩计算模型进行过研究[1－12]，但这些模型大都忽略了井眼的间隙，即假设钻柱与井壁处处接触，因此无法判断钻杆的接头和本体与井壁的真实接触情况。笔者根据加权余量法和三弯矩方程法的思想，推导出一套新的摩阻与扭矩计算公式，该套公式没有忽略井眼的间隙。在分析中采用如下基本假设：(1)井壁对管柱呈刚性支承；(2)管柱与井壁的摩擦为滑动摩擦；(3)忽略管柱的动力效应。

1 计算步骤

(1)根据井眼轨迹的设计数据或测斜数据，计算出井眼上任一点的坐标值。

(2)假设间隔一段长度井壁对钻柱有一支承点，这些支承点的位置先假定在井眼中心线上。

(3)将钻柱在支承点处断开，相邻两断点间的钻柱作为一跨，将两点间的连线与过上断点的铅垂线所组成的平面作为井斜平面，与井斜平面垂直并通过 2点连线的平面作为方位平面。

(4)根据加权余量法，在 2个平面内分别计算出钻柱的转角与弯矩的关系。

(5)根据相邻两跨在断开点处的转角相同，求出弯矩的迭代方程。

(6)由于大钩处和钻头处的边界条件已知，所以可根据迭代法计算出各点的弯矩情况。

(7)由所计算出的弯矩情况就可计算出各支承点处力的大小和方向。

(8)根据支反力的方向逐渐调整钻柱在井眼中的位置，直到确认钻柱与井壁的接触位置或是不接触。

(9)根据最终的支反力的大小就可计算出摩阻与扭矩的分布情况。

*基金项目：获国家自然科学基金重大研究计划项目(编号：90410006)和教育部“长江学者和创新团队发展计划”创新团队项目资助(批准号：IRT0411)。

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2 公式推导

2 1 单跨钻柱受力分析

图 1为单跨度钻柱的受力情况,已在文献[1]中给出了具体的受力计算公式和推导的全过程,在此只写出结果(公式中各项意义也与文献[1]相同),不再赘述细节。

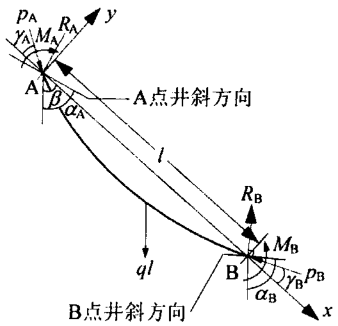

图 1 单跨度钻柱的受力情况

A点的切线斜率公式

$$\theta_A = \frac{\frac{q\sin(\beta)l^3}{12} + \frac{M_A + M_B}{24EI}P_a l^3}{\frac{P_a l^2}{5} - 2EI} - \frac{2M_A + M_B}{6EI}l \tag{1}$$

B点的切线斜率公式

$$\theta_B = -\frac{\frac{q\sin(\beta)}{12} + \frac{M_A + M_B}{24EI}P_a}{\frac{P_a l^2}{5} - 2EI}l^3 + \frac{M_A + 2M_B}{6EI}l \tag{2}$$

2 2 上下跨间几何关系

图 2为上下跨间的几何关系。

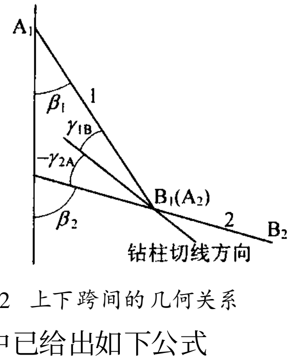

图 2 上下跨间的几何关系

在文献[1]中已给出如下公式

$$\theta_{2A} = \frac{\theta_{1B} + \tan(\beta_2 - \beta_1)}{1 - \theta_{1B}\tan(\beta_2 - \beta_1)} \tag{3}$$

由于上下跨间的转角很小,所以 $\theta_{1B}\tan(\beta_2 - \beta_1)$与 1相比是高阶小量,可以略去不计,最后得

$$\theta_{2A} = \theta_{1B} + \tan(\beta_2 - \beta_1) \tag{4}$$

2 3 弯矩迭代公式

将(1)式和(2)式代入(4)式,可求得弯矩的迭代公式

$$\frac{\frac{q_2\sin(\beta_2)l_2^3}{12} + \frac{M_{2A} + M_{2B}}{24EI_2}P_{2a}l_2^3}{\frac{P_{2a}l_2^2}{5} - 2EI_2} - \frac{2M_{2A} + M_{2B}}{6EI_2}l_2 = -\frac{\frac{q_1\sin(\beta_1)}{12} + \frac{M_{1A} + M_{1B}}{24EI_1}P_{1a}}{\frac{P_{1a}l_1^2}{5} - 2EI_1}l_1^3 + \frac{M_{1A} + 2M_{1B}}{6EI_1}l_1 - \tan(\beta_2 - \beta_1) \tag{5}$$

式中,$M_{2A} = M_{1B}$。

由于钻头处和大钩处的弯矩已知,通过迭代(5)式,就可求得钻柱在各跨端点处的弯矩情况。

以上公式为在井斜平面的计算方法,只要令 $q = 0$,将井斜角改为方位角,就可得到方位平面的计算公式。

将计算出的弯矩代入到文献[2]中支反力的计算公式,就可计算出各点的支反力和轴向力情况。支反力乘以摩擦因数即为摩擦阻力,支反力乘以摩擦因数再乘以管柱的半径,即为扭矩损失。

2 4 确定钻柱在井眼中位置的计算方法

先将钻柱放在井眼的中心线上,计算出各点支反力的方向后,将钻柱向这一方向移动一个很小的距离,在新的位置上重新计算各点的支反力的大小和方向,然后再移动,如此反复直到钻柱与井壁接触或是判断出钻柱不与井壁接触。当每一点都判断完成后,计算结束。这就找出了钻柱在井眼中的位置情况,而没有忽略井眼的间隙。

3 大位移井摩阻 扭矩计算程序框图

图 3为摩阻 扭矩计算程序框图。根据此框图和上面推导的公式编写了摩阻 扭矩计算软件。

4 算例

以目标点垂深 2650 m,水平位移 4000 m,造斜点深度为 400 m,稳斜角为 75°的井眼曲线为例。井身结构为:前 3000 m为 Ø244 5 mm套管段,摩擦因数为 0 2;其余为裸眼段,摩擦因数为 0 3。钻柱结构为 Ø216 mm钻头+127 mm加重钻杆×135 m+

127 mm 钻杆到井口。考虑与不考虑井眼间隙的差别情况见表 1。

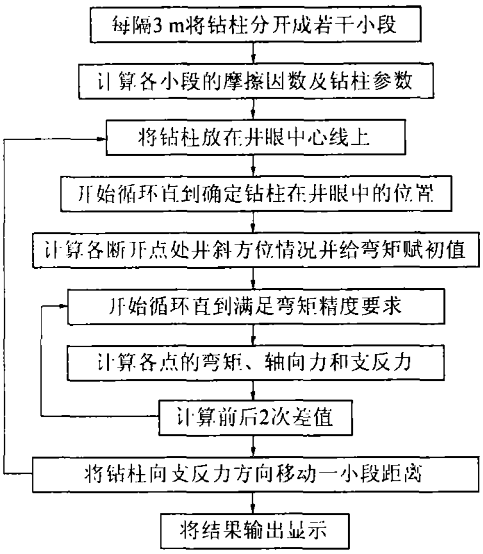

图 3 摩阻扭矩计算程序框图

表 1 计算结果对比

参数	考虑间隙	不考虑间隙
起钻摩阻 /kN	304 32	306 21
旋转时扭矩损失 /kN · m	18 61	18 72
下钻摩阻 /kN	257 26	260 14

5 结论

(1)根据加权余量法和三弯矩方程法的思想，推导出一套新的摩阻与扭矩计算公式。新公式没有忽略钻柱与井眼间的间隙，所以其计算结果更真实可信。

(2)从算例计算结果可见，井眼间隙对总的摩阻 扭矩的影响并不是很大。但用文中的方法能更准确地计算出支反力在钻柱上的分布情况，因此能够为合理确定减扭接头或钻杆保护器等工具在钻柱上的安放位置提供依据。

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(收稿日期 2006 – 07 – 23)

〔编辑 薛改珍〕

ABSTRACTS AND AUTHORS

New model for forecasting drag and torque in Extended Reach Well SONG ZHI-wu GAO De-li MA Jian ODPT, 2006 28(6): 1-3

Abstract Drag/torque prediction is a key technique of drilling an Extended Reach Well successfully. The contact situation between drill pipe and wall of well was not clear because the clearance was ignored in most models. It was assumed that there is an support point every 3 meter between wall of borehole and drillstring, disconnected the drillstring at the support point, according to the residual method, the relationship of corner and moment in one segment was found; based on the condition that the corners of drillstring are same when two segments are adjacent to each other, the moment iterative formulas were found, and base on the bounder condition, the moments could be calculated, which could be used to calculating the support force. The position of drillstring could be repositioned by the direction of support force. So we got a new set of friction and torque calculation formulas and the clearance was not ignored and the contact situation between drill pipe and wall of well is clear, which could be used for determining the proper position of torque reduction sub and drill pipe protection sub.

Key words: Extended Reach Well; drag; torque; the method of weighted residuals

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Kinetic simulation study on borehole inside movement of reaming tool while drilling MA Qing-ming WANG Rui-he ODPT, 2006 28(6): 4-7

Abstract For the movement of while drilling reaming tool in the borehole, the kinetic analytical method based on the Lagrange equation was presented. In terms of the penalty rules of normal direction contact restriction, the contact force between reamer wings and rock was calculated. Meanwhile, the movement process and dynamic response of reaming tool in the borehole were investigated by kinetic simulation. Results show that with the increase of eccentricity between reaming tool axes and well bore axes, or with the decrease of reamer wing number, the actual pervious radius of reamed borehole will reduce gradually while the maximal contact force between reamer wing and borehole wall will increase simultaneously. The simulation results present practical and applicable proposition. Research results agree well with relevant experimental law, which explains the availability of proposed analytical method. Research results offer extensive guidance for the design and application of multi-winged oil well drilling devices.

Key words: Reaming While Drilling (RWD); reamer wing; wellbore; contact; kinetics; simulation study

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Application of air drilling technology in Puguang gasfield ZHANG Jin-cheng WEI Hua YU Wen-hong ODPT, 2006 28(6): 8-10

Abstract Puguang gasfield is the largest gasfield in Sichuan basin that had been found. In order to increase drilling speed, shorten drilling cycle, and speed up expoitation progress of Puguang gasfield, well PD-1, well P2-2, well PA-2, well P4-2, well P6-3 were tested with air drilling technology. This paper analyzed feasivility of air drilling for the Puguang gasfield, introduces drilling operations in detail, and evaluated operational effects, analyzed problems that need to pay attention to and settle in the end provide the research direction for the future.

Key words: air drilling; Puguang gasfield; application; problem; research direction

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Key technologies for drilling and completion in sub-salt carbonate reservoir with high pressure and low permeability. BIAN De-zhi DONG Ben-jing SUN Zhen-chun ODPT, 2006 28(6): 11-14

Abstract The sub salt carbonate reservoir in Kenhkiak, Kazakhstan is an oil pool with abnormal pressure, low permeability and complicated geological conditions. At the initial stage of development, problems encountered in drilling practice were the complex of casing program, thick salt dome difficult to drill and low production rate due to perforation completion. The drilling cost was about 10 million USD. Based on careful study about the geological features of the reservoir, pore pressure and drilling technical requirements, the casing program was simplified from 4-string design to 3-string design, anti-salt drilling fluid system like witterion polymer system was screened out to use on field and open hole completion was tested. As a result, the drilling duration of vertical wells were reduced from initial over 500 days to 180 days or so. The daily production rate of a single well increased from the original 30 tons to over 200 tons in average. So far, many wells have been into production with initial daily output over 500 m^3/d. The shortening of drilling duration and the increase of initial production rate of a single well can be attributed to many factors. However, the simplification of casing program, break-though of salt dome drilling and open completion are undoubtedly the key factors.

Key words: open hole completion; sub-salt; kiloton well; low permeability; horizontal wells

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Completion technology of Lin4-ping2 well XIA Jian ZHU Jian-wei LU Shu-qin YANG Xiao-