定向井井眼轨迹最优化设计方法研究*

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摘　要　现有的井眼轨迹设计方法有很多种, 涉及到二维的方法和三维方法。但它们有一个共同的缺点, 就是设计出来的井眼轨迹不能从定量的角度确信为一条可行的最优轨迹。为此, 文章把非线性不等式约束下非线性目标函数的非线性数学规划理论引入到定向井井眼轨迹的最优化设计中, 提出了定向井井眼轨迹设计定量意义上的最优化方法。为讨论方便, 文中以常用的双增型剖面为例, 讨论其最优化的设计方法, 并进行了方位漂移设计。应用此文的研究思路, 稍加修改就可以得到 S 型等井眼剖面的最优化设计方法。这些理论和模型已经利用 Visual Basic 语言编制成为一个用户界面非常友好的软件 GJYHSJ, 操作简单, 使用方便。

主题词　定向井　井眼轨迹　优化设计　方法　研究

目前关于井眼轨迹设计的方法很多, 发表的文章和专著也不少, 涉及到二维的设计方法和三维方法, 已覆盖到各种井型(水平井、定向井、大位移井、侧钻水平井等) 和各种曲率半径(大曲率半径、中曲率半径、短曲率半径和超短曲率半径) 。但是它们都有一个共同的特点, 设计出来的轨迹能够满足现场施工的要求, 却不能肯定它是一条可行的最优轨迹。所谓最优轨迹有以下三个含义:

(1) 设计轨迹必须满足现场施工条件的限制;

(2) 设计轨迹应当是满足各种设计要求下的最短轨迹;

(3) 设计轨迹的钻柱扭矩和摩阻力应当相对最小。

现有轨迹设计方法一般是以反复试算为基础, 它们依赖于设计者的经验, 具有随意性和经验依赖性。下面以常规的双增型剖面轨迹为例加以说明。双增型剖面轨迹设计一般采用以下步骤:

(1) 假设第一、第二造斜点的位置, 第一、第二造斜率的大小, 计算能否设计出一条轨迹达到靶点;

(2) 如果不能设计出一条满足要求的轨迹, 则改变造斜点位置、造斜率大小的假设, 重复计算, 重复改变各种假设, 直到设计出一条能达到靶点的轨迹来。

从以上设计思路不难看出, 反复试算是它的最大特点, 当然设计出来的轨迹肯定是一条可行的轨迹方案, 但不能确信它是否为一条最优的轨迹, 因为它可能是一条最优轨迹, 也可能不是一条最优的轨迹。

本文把非线性不等式约束下非线性目标函数的非线性数学规划理论引入到定向井井眼轨迹的最优化设计中, 提出了定向井井眼轨迹设计定量意义上的最优化方法。这种新的设计方法摆脱了设计者人为的因素, 不需要反复的试算, 只要设计者提供一些必要的约束参数即可自动优化出一条真正意义上的最优轨迹。

最优化数学模型的建立

双增型剖面井眼轨道如图 1 所示, 从图 1 中不

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难得到双增型剖面具有以下特征: 六个关键点、六个关键参数和八个约束条件。

六个关键点为: ①井口位置; ②第一造斜点位置; ③第一造斜末点位置; ④第二造斜点位置; ⑤第二造斜末点位置; ⑥靶点。

六个关键参数为: ①第一造斜点垂深; ②第一造斜率大小; ③第一稳斜角大小; ④第二造斜点垂深; ⑤第二造斜率大小; ⑥第二稳斜角大小。

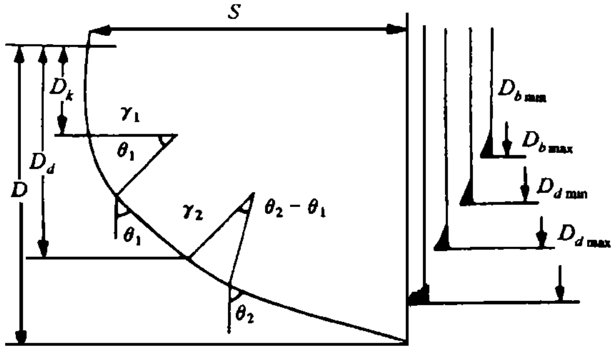

图 1　双增型剖面轨迹示意图

八个约束条件为: ①实际第一造斜率必须小于现场工具的最大造斜能力; ②第一造斜点位置必须在比较稳定的适合于造斜的地层层位; ③第一造斜末点位置必须在地质条件适合于下中间套管的层位; ④第一稳斜角必须小于地层允许的最大井斜角; ⑤实际第二造斜率必须小于现场工具的最大造斜能力; ⑥第二造斜点位置也必须在适合于造斜的地层层位; ⑦第二造斜末点位置必须位于地质条件适合于下第二中间套管的层位; ⑧第二稳斜角必须在地层允许和设计要求的井斜角大小范围以内。

假设第一造斜点垂深为 D_k, 造斜率为 K_1, 第二造斜点垂深为 D_d, 第二造斜率为 K_2, 水平位移为 S, 靶点垂深为 D , 则第一造斜半径为:

$$r_1 = \frac{5\ 400}{\pi K_1} \tag{1}$$

第二造斜半径为:

$$r_2 = \frac{5\ 400}{\pi K_2} \tag{2}$$

井深为:

$$\left.\begin{aligned}
L &= Z_5 + \theta_1 r_1 + (\theta_2 - \theta_1) r_2 + Z_1/\cos\theta_2 + Z_4/\sin\theta_1 \\
Z_1 &= D - D_d - r_2(\sin\theta_2 - \sin\theta_1) \\
Z_2 &= r_2(\cos\theta_1 - \cos\theta_2) \\
Z_3 &= r_1(1 - \cos\theta_1) \\
Z_4 &= S - Z_1\tan\theta_2 - Z_2 - Z_3 \\
Z_5 &= D_d - Z_4/\tan\theta_1 - r_1\sin\theta_1
\end{aligned}\right\} \tag{3}$$

根据以上各关键点、关键参数和各种约束条件的要求, 可以得到以下的数学方程:

$$\left.\begin{aligned}
&\min L \\
&s.t.\ \theta_{1\max} - \theta_1 \geqslant 0 \\
&\quad \theta_{2\max} - \theta_2 \geqslant 0 \\
&\quad \theta_2 - \theta_1 \geqslant 0 \\
&\quad K_{1\max} - 5\ 400/(\pi r_1) \geqslant 0 \\
&\quad K_{2\max} - 5\ 400/(\pi r_2) \geqslant 0 \\
&\quad D_{k\max} - D_k \geqslant 0 \\
&\quad D_k - D_{k\min} \geqslant 0 \\
&\quad D_{d\max} - D_d \geqslant 0 \\
&\quad D_d - D_{d\min} \geqslant 0 \\
&\quad D_{b\max} - D_k - r_1\sin\theta_1 \geqslant 0 \\
&\quad D_k + r_1\sin\theta_1 - D_{b\min} \geqslant 0 \\
&\quad D_{dd\max} - D_d - r_2(\sin\theta_2 - \sin\theta_1) \geqslant 0 \\
&\quad D_d + r_2(\sin\theta_2 - \sin\theta_1) - D_{dd\min} \geqslant 0 \\
&\quad r_2(\cos\theta_1 - \cos\theta_2)/\sin\theta_1 \geqslant 0 \\
&\quad \theta_2 - \theta_{2\min} \geqslant 0 \\
&\quad [D - D_d - r_2(\sin\theta_2 - \sin\theta_1)]/\cos\theta_2 \geqslant 0
\end{aligned}\right\} \tag{4}$$

式中: $D_{b\min}$ 为下入第一中间套管垂深上极限; $D_{b\max}$ 为下入第一中间套管垂深下极限; $D_{dd\min}$ 为下入第二中间套管垂深上极限; $D_{dd\max}$ 为下入第二中间套管垂深下极限; $D_{k\min}$ 为适合于第一造斜的地层垂深上极限; $D_{k\max}$ 为适合于第一造斜的地层垂深下极限; $D_{d\min}$ 为适合于第二造斜的地层垂深上极限; $D_{d\max}$ 为适合于第二造斜的地层垂深下极限; θ_1 为第一稳斜角; θ_2 为第二稳斜角。

式(4) 就是双增型剖面轨迹最优化设计的数学模型, 应用最优化理论求解上式, 即可得到在满足工程设计要求下各种参数达到最优状态的最优轨迹。

最优化理论

仔细分析最优化数学模型(4), 不难发现它可以归结为如下的数学规划问题:

对目标函数 $F(x)$ 极小化, 即:

$$\min_x F(x);\quad x \in D \subset R^n$$

使满足 p 个不等式约束条件, 即:

$$g_i(x) \geqslant 0;\quad i = 1, 2, \cdots, p$$

所以可以简写为:

$$\min_{x \in D \subset R^n} \{F(x) \mid g_i(x) \geqslant 0;\quad i = 1, 2, \cdots, p\} \tag{5}$$

分析式(4), 不难得到对应的 $F(x)$ 是一个 $n(n$

$= 5)$ 向量 X 的非线性函数, $g_i(x)$ 可能是非线性函数, 也可能是线性函数, 因此井眼轨迹优化设计属于一种非线性约束下的非线性规划问题, 应当寻找一种求解非线性约束下的非线性规划问题的解法进行求解。

序列无约束极小化方法(SUMT 法) 即是一种有效方法。它包括 SUMT 外点法和 SUMT 内点法。在内点法中, 依靠障碍项 $r\sum_{i=1}^{p}\frac{1}{g_i(x)}$ 或 $-r\sum_{i=1}^{p}\lg g_i(x)$ 限制所求解的点被围在可行域的附近; 而在外点法中, 尽量消耗不在可行域的现象就完全依赖于消耗项 $R(x)=\sum_{i=1}^{p}[\min(0, g_i(x))]^2$ 的作用。如果按照序列无约束极小化技巧, 即一般的 SUMT 的算法, 几乎每一步都会得到所求极值点对一部分约束条件成立, 而对另一部分并不成立。所以, 最好的办法是对那些不成立的约束部分采用消耗项; 而对成立的部分, 特别是那些适合于不等式约束严格为不等的部分, 采用障碍项。这就是所谓的 SUMT 混合法。本文采用 SUMT 混合法研究最优化模型(4) 式。由于篇幅所限, 在此不予详细介绍。

方位漂移设计

在进行二维井眼钻进中, 方位漂移几乎是很难避免的, 尤其在水平位移较大时, 水平位移越大, 偏离二维轨道的可能性加大, 脱靶的概率增高。在无性能优良的井下可调扶正器和斜接头或高性能稳定器的情况下, 方位漂移设计是十分必要的。

影响方位漂移的因素很多, 如钻井方式、钻具组合、井斜、地层层位及地层走向和倾向等。精确研究在不同区域、不同地层的方位漂移规律是非常困难的。国内外曾经有许多学者研究过这类问题, 包括理论分析、实验研究和统计分析等。但是取得的成果被世人公认的很少, 因为各家都有自己不可忽视的问题, 大多数离不开对地下某深度地层进行取心, 然后对取出的岩样进行分析, 以期得到在他们建立的模型中所需要的各种岩石参数, 而实际上, 对于同一地层取出的岩样分析得到的结果都不可能是完全一样的, 更何况要推广应用到其它地区或地层。在所有的方法中, 统计分析法具有很强的灵活性, 当然它依赖于作业者们的经验和这个地区的邻井资料。只要对邻井资料分析正确, 这种方法不失为一种很可行的方法之一。

纵观各种方法, 我们采用统计分析法来研究方位漂移问题。通过统计分析得到不同层位下, 不同井斜方位范围内所使用钻具的方位漂移量, 由此确定二维轨迹中, 从造斜点开始各个井段的方位漂移量, 然后进行三维方位漂移设计。

实 例 计 算

实例: 某井井口坐标为: 北坐标 0 m, 东坐标为 0 m, 垂深为 0 m。靶点坐标为: 北坐标 1 293 m, 东坐标 1 293 m, 垂深 3 567.6 m。根据地质条件、井身结构设计和现场工具的实际能力, 给出以下双增型剖面轨迹必须满足的条件:

(1) 造斜约束条件。第一造斜点垂深上限值为 400 m; 第一造斜点垂深下限值为 600 m; 第一造斜率极限值为 2°/30 m; 第一稳斜角上限值为 30°; 第二造斜点垂深上限值为 3 000 m; 第二造斜点垂深下限值为3 250 m; 第二造斜率上限值为 2°/30 m; 第二稳斜角上限值为 45°。

(2) 下套管约束。第一中间套管下至垂深的上限值为 920 m; 第一中间套管下至垂深的下限值为 1 000 m; 第二中间套管下至垂深上限值为 3 300 m; 第二中间套管下至垂深下限值为 3 580 m。

经过最优化计算后可得到: 第一造斜点垂深为 428.04 m, 造斜率为 1.816°/30 m, 第一稳斜角为 29.91°, 第二造斜率为 1.196°/30 m, 第二稳斜角为 41.826°, 最优井深为 4 170.829 m。

双增型剖面井眼轨迹分段数据见表 1。表 1 中同时给出了应用最优化设计方法和常规设计方法得到的双增型剖面轨迹分段数据。

表 1　双增型剖面轨迹的分段数据

最优化设计方法			常规设计方法		
井深(m)	井斜角(°)	方位角(°)	井深(m)	井斜角(°)	方位角(°)
0.00	0.00	45.00	0.00	0.00	45.00
428.08	0.00	45.00	524.18	0.00	45.00
922.13	29.91	45.00	1 022.20	29.83	45.00
3 534.14	29.91	45.00	3 490.22	29.83	45.00
3 833.09	41.83	45.00	3 718.19	44.99	45.00
4 170.83	41.83	45.00	4 193.40	44.99	45.00

为了验证应用最优化设计方法得到的井眼轨迹确为一条最优轨迹, 本文应用纵横弯曲连续梁理论分别计算了应用最优化方法和常规方法得到的井眼轨迹的摩阻力和扭矩, 计算结果见表2。计算时, 取

内腐蚀是陇东地区套管腐蚀穿孔的主要因素

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胡文瑞等. 内腐蚀是陇东地区套管腐蚀穿孔的主要因素. 天然气工业, 2000; 20(1) : 60~ 64

摘　要　长庆油田陇东油区套管腐蚀的严重程度在国内是知名的, 曾作过不少的研究工作, 其主要结论是洛河水引起的外腐蚀穿孔, 为此提出的措施是封固洛河水层, 采用阳极保护等。近两年来, 通过对 1990 年以来完井的套管腐蚀穿孔井的穿孔段、腐蚀段的层位、固井质量、穿孔段与动液面的关系, 以及现场井下挂片试验等八个方面的分析与研究表明, 在水泥已全封固以及油井进入中后开发期的情况下, 套管内腐蚀已成为陇东油区套管腐蚀穿孔的主要因素。这一结论是该区套管腐蚀研究工作的一次认识上的突破, 并为这一区域采取防腐新措施提供了理论依据。

主题词　甘肃　东　套管腐蚀　内腐蚀　固井质量　动液面　腐蚀试验

为了弄清长庆油田陇东油区套管腐蚀穿孔的原因, 近年来投入上百万的研究经费进行了现场工程测井、封隔器找漏、井下挂片、水质化验、井下作业对水泥环的破坏等研究工作, 以便从中找出宏观规律, 提出切实可行的延长套管寿命的措施。

90 年代后投产油井套管穿孔的基本状况

1990 年至今投产井中已经有 27 口井出现套管穿孔。它们分布在马岭、元城、樊家川、华池油田, 均

钻柱组合为: 钻头(Ø215. 9 mm) + 钻铤(Ø177. 8 mm × 120 m) + 加重钻杆(Ø127. 0 mm × 100 m) + 钻杆(Ø127. 0 mm) ; 钻井液密度为 1. 14 g/ cm^3, 钻压为 15 t, 转速为 60 r/ min。

表 2　两种设计轨迹的扭矩和摩阻力计算结果对比

项　目	钻　进		起　钻	
	摩阻(t)	扭矩(kN• m)	摩阻(t)	扭矩(kN• m)
最优化设计方法	86. 57	13. 57	91. 42	0. 00
常规设计方法	89. 98	16. 83	102. 20	0. 00

从以上计算结果中不难得到: ①应用最优化方法得到的井眼轨迹比常规方法得到的长度要短, 在本例中为 22. 57 m。②应用最优化方法得到的井眼轨迹的摩阻力和扭矩比常规方法得到的摩阻力和扭矩要小。这是因为应用最优化方法得到的井眼轨迹的造斜率更小, 光滑度更好, 将更有利于管柱的运动, 使得钻井、完井和采油管柱能够更加顺利地进入和取出井筒, 减少井下事故的发生。

结　　论

(1) 应用最优化方法计算得到的井眼轨迹比其它方法得到的井眼轨迹具有更好的光滑度, 其管柱的摩阻力和扭矩要小。这将大幅度地减少井下事故的发生, 节约钻井成本。

(2) 应用本文研究得到的井眼轨迹最优化设计方法设计得到的井眼轨迹比用常规方法得到轨迹要短, 这也将缩短钻井周期, 节约钻井成本。

(3) 本文研究得到的井眼轨迹最优化方法是有效的、可靠的, 应当在各油气田推广应用。

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can reach about 80 %.

SUBJECT HEADINGS: Drilling parameter, Lithology identification, Drilling speed, Prediction

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A SUMMARIZATION OF DEVIATION-CONTROLLING DRILLING TOOL ASSEMBLY TECHNIQUE FOR STRAIGHT WELL

Yin Chaoyang, Bo Jinghai and He Juncai (No. 2 Drilling Co. of Daqing Petroleum Administration). *NATUR. GAS IND.* v. 20, no. 1, pp. 50～53, 1/25/2000. (ISSN 1000 - 0976; **In Chinese)**

ABSTRACT: In the process of oil and gas well drilling, the factors causing hole deviation are various. The drill tool assembly and its operation pay a very important role in controlling hole deviation. With the development of drill tool assembly technique, the technical level and capability of hole deviation control have been continuously raised. In this paper, the foreign and domestic representative deviation-controlling drill tool assembly for straight wells by rotary drilling, especially the domestic last deviation-controlling drill tool assembly developed in recent years is briefly expounded and the advantages and shortcomings of these tools are analyzed and compared, and the foreign most advanced closed-loop system for hole deviation control and its application situation are briefly presented also, in order to offer the scientific-technological personnel in drilling circles the technical informations of this field for their selection and application in drilling practice.

SUBJECT HEADINGS: Straight well, Inclining prevention device, Bottom hole assembly, Technique, Review

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A RESEARCH ON THE DAMAGE OF DRILLING FLUID TO CORE OF T_3x^2 GAS RESERVOIR IN PINGLUOBA GAS FIELD

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ABSTRACT: The second member of Xujiahe formation is the main gas-producing interval of Pingluoba gas field. The pay is a tight fracture-pore-type reservoir composed of fine-grained, fine-to-medium-grained or medium-grained feldespathic quartz sandstone and feldspathic lithic sandstone, with a burial depth of 3 400～3 900 m. The content of clay minerals varies from 5 % to 15 %, of which, illite occupies 88 %～94 % and chlorite 5 %～10 %. In majority of the samples, the mixed-layer minerals of illite and montmorillonite varied in amount are found. The average porosity of the reservoir is 3.55 %, permeability $0.2 \times 10^{-3} \mu m^2$ and average water saturation 54 %. All wells yield slurry in the initial stage after the reservoir was put into production and the production was very unstable. It was necessary to eliminate blokage before wells were put into production in general, and after which, the output could be raised by more than three times. Through experiment, it is proved that the T_3x^2 gas reservoir of this gas field is damaged by drilling fluid, the mean rate of damage to permeability reaching 50 %. The damage mechanism is as follows: First, the filtrate of drilling fluid entered into formation makes the water membrane thickened, and second, the particulates in the drilling fluid invaded in core plug up the percolation flow passage. In order to alleviate the damage, it is proposed that the density of drilling fluid should be improved and the pay should be drilled at a balanced pressure or at a pressure slightly higher than that of the formation.

SUBJECT HEADINGS: Sichuan, West, Pingluoba gas field, Core, Drilling fluid, Research

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A STUDY OF OPTIMIZED METHOD FOR DESIGNING DIRECTIONAL WELL TRAJECTORY

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ABSTRACT: The existing methods for designing well trajectory are varied, in which the 2-D and 3-D methods are involved. However, they have a common shortcoming that the designed well trajectory can not be sure to be a feasible optimized one quantitatively. For this reason, in this paper, the monlinear mathematical programming theory of the nonlinear objective function restrained by nonlinear inequality is introduced in the optimized design of directional well trajectory, putting forward a quantitative optimized method for designing directional well trajectory. For the convenience of study, the optimized design method is discussed and the azimuthal displacement design is made by taking the double-build section most in use for example in this paper. An optimized design method for S-type borehole section can be obtained by applying the train of thought in this paper and slightly modifying it. These theories and models have been programmed into the software GJYHSJ in Visual Basic, which has a very good user interface and is easy to be used.

SUBJECT HEADINGS: Directional well, Hole trajectory, Optimizing design, Method, Research

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INTERNAL CORROSION—A MAIN FACTOR CAUSING CORROSION AND PERFORATION OF CASING IN EAST GANSU REGION

Hu Wenrui, Liu Hailang, Gong Wei'an and Zhang Fengkui (Changqing Petroleum Exploration Bureau). *NATUR. GAS IND.* v. 20, no. 1, pp. 60～64, 1/25/2000. (ISSN 1000－0976; **In Chinese)**

ABSTRACT: The severity of casing corrosion in Longdong (East Gansu) oil area of Changqing oil field is widely known at home. More research works have been done and the main conclusion is the perforation by external corrosion caused by the water of Luohe river. The measures proposed are to seal up the water layer of Luohe river and to adopt anodic protection. Through the analysis and study of the casing-perforated interval, horizons of casing-corroded interval, cementing quality, relation between casing-perforated interval and producing fluid level as well as downhole coupon test, etc., for the wells in which casings have been corroded and perforated and which have been completed in the past two years, it is shown that, on condition that the cement has fully set and the oil wells have entered the middle-late development period, the internal corrosion of casing is the main factor causing casing to be corroded and perforated in Longdong oil area. This conclusion is a breakthrough in the research on casing corrosion in this area and furnishes a theoretical basis for adopting new anti-corrosion measures in this area.

SUBJECT HEADINGS: Gansu, East, Casing corrosion, Internal corrosion, Cementing quality, Working fluid level, Corrosion test

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THEORETICAL CALCULATION OF THE FLUID CRITICAL POINT OF CONDENSATE GAS

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ABSTRACT: The purpose of this paper is to investigate the theoretical algorithm of the real fluid critical point of condensate gas. Firstly, the study history and determination methods of critical point are briefly reviewed. The critical point means such a state that all the differences between gas and liquid disappear completely, being a most important parameter of dividing the types of fluid and being widely verified in both theory and practice. Currently, four methods of determining critical point are summarized as follows: ¹ laboratory measurement through examining critical opalescence or recording the bubble point and dew point curves; ④empiric relation; ㈣calculation of the bubble point and dew point curves by PVT software; and ¼ direct calculation according to thermodynamic theories. Because the critical point measure in laboratory is time-consuming and highly expensive, how to accurately calculate the critical point is always a difficult problem. Currently, more near critical condensate gas reservoirs have been found in deep strata and the complex critical phase changes will be able to occur during the production of condensate gas reservoirs. Therefore it is an important basis of electing development scheme and correctly analyzing production per-