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A New Well Profile for Extended Reach Drilling (ERD)

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Abstract: Well profile design is one of the critical technologies in extended reach drilling (ERD), because an optimum well profile is an effective means for reducing the torque, drag and cost. This paper proposes a new well profile based on an inverse proportional function, and the new profile design method is analyzed in detail. The new well profile is also compared with other existing well profiles in many aspects such as the hook load, the maximum well curvature, the well length, the torque and so on. The results show that the well profile design based on an inverse proportional curve is superior to the existing well profiles used for drilling extended-reach wells, in several aspects such as the maximum well curvature, drag, torque and well length. It is expected that the use of this new well profile may play an important role in the design of extended-reach drilling wells in the future.

Keywords: Profile, Inverse proportional curve, Drag, Torque, Wellbore curvature, ERD

1 Introduction

ERD technologies have advanced rapidly since the late 1980s. ERD refers to directional drilling to geological targets which are located at a significant distance from the rig. Oil and gas reservoirs in beaches or lakes, and in offshore locations, can be effectively exploited by using the ERD technology. Extended reach wells, especially horizontal extended reach wells, with a high ratio of horizontal displacement to true vertical depth , represent a frontier technology, and challenge the limits of drilling [Gao, (2009)].

The design of a well-profile is one of the critical technologies for success in ERD [Payne, (1994)]. An optimum well profile will enable the reach of a well to a greater displacement, by reducing the drag, the torque and the severity of the dogleg [Mason, (1998); Rodman, (1997); Payne, (1995); Blikra, (1994)].

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Usually, the build section of an extended reach well is designed with a curve of a constant curvature (circular arc). With the development of the rotary-steering drilling technology, many experts have presented some new types of profiles for designing the build sections.

A review of the existing literatures indicates that six types of well profile designs have been developed. In order to reduce the drag and the torque in extended reach wells, the catenary profile was first introduced into the drilling industry [Aadnoy, (2006); Liu, (2009); Han, (1997); Liu, (2010)]. But this profile has some drawbacks, such as the big wellbore curvature at the end point of the build section. In order to overcome this shortcoming, some experts have presented the modified catenary profile. Han (2007) introduced the sideway catenary profile. Liu (1989) introduced the parabolic profile, based on the different load distribution on a drilling string. Zh (2000) introduced the sideway parabola design method, for eliminating the effect of the transition circular arc section. Lu (2003) has put forward a new well profile called the cycloid, based on the principle of the fastest slipping line.

In summary, these well profiles all have their advantages and drawbacks. While summarizing the above profile design methods, this paper presents a new well profile based on the inverse proportional function, and the proposed new well profile is analyzed in detail in the following sections.

2 Inverse proportional curve

This paper proposes the use of an inverse proportional function as the profile for the build section. The inverse proportional function is expressed as follows:

$$y = \frac{m}{x} \tag{1}$$

Where m is the characteristic coefficient, and y and x are the Cartesian coordinates.

2.1 The proposed Well profile design based on an inverse proportional curve

Since the curvature of the inverse proportional curve is infinite at the starting point, a small circular arc section is required from the kick off point to the starting point (x is not equal to zero) of the inverse proportional curve. A typical inverse proportional curve profile is shown in figure 1. It consists of four sections: a vertical section to the kick off point, a circular arc section, the inverse proportional curve section, and a hold section.

The inclination at any point of the inverse proportional curve section can be written as:

$$\tan\alpha = \frac{dx}{dy} \tag{2}$$

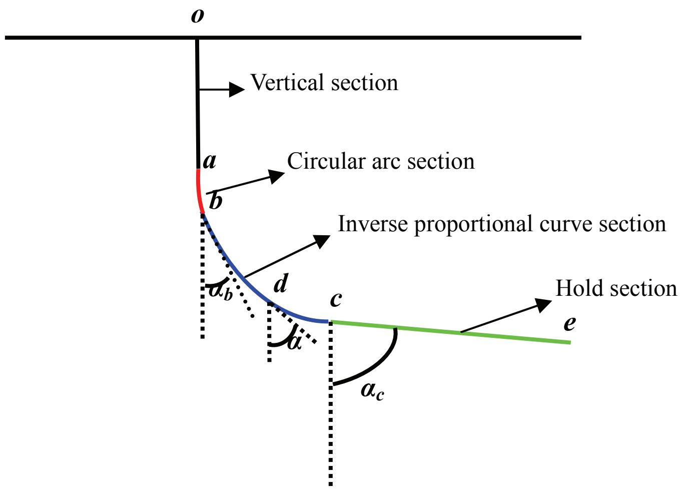

Figure 1: Inverse proportional curve profile of extended-reach well

Where α is the inclination.

Based on the Eq.(1), the following equations can be derived :

$$y' = \frac{dy}{dx} = -\frac{m}{x^2} \tag{3}$$

$$y'' = \frac{2m}{x^3} \tag{4}$$

The combination of Eqs.(2) and (3) gives

$$\tan\alpha = \frac{dx}{dy} = \frac{1}{y'} = \frac{x^2}{m} \tag{5}$$

The curvature of the inverse proportional function can be given by the following expression:

$$k = \frac{\left|y''\right|}{(1+y'^2)^{3/2}} = \frac{\frac{2m}{x^3}}{(1+\frac{m^2}{x^4})^{3/2}} \tag{6}$$

Where k is the curvature of the inverse proportional function. .

From Eqs.(5) and (6) the curvature k can be written as:

$$k = \frac{(\sin(2\alpha))^{3/2}}{\sqrt{2m}} \tag{7}$$

By using the formula for the arc length of a curve, the arc length can be written as:

$$dl = \frac{d\alpha}{k} \tag{8}$$

The combination of Eqs.(7) and (8) gives

$$dl = \frac{\sqrt{2m}}{(\sin(2\alpha))^{3/2}} d\alpha \tag{9}$$

Integrating Eq.(9) gives the equation for the arc length of the inverse proportional curve:

$$l = \int \frac{\sqrt{2m}}{(\sin(2\alpha))^{3/2}} d\alpha \tag{10}$$

Based on Eqs.(1) and (5), the coordinates x and y can be evaluated by the following expressions:

$$x = \sqrt{m \tan\alpha} \tag{11}$$

$$y = \sqrt{\frac{m}{\tan\alpha}} \tag{12}$$

2.2 The Description of Any point Along the inverse proportional curve

By using Eq.(10), the length along an inverse proportional curve in Fig 1 can be written as:

$$L = \int_{\alpha_B}^{\alpha_C} \frac{\sqrt{2m}}{(\sin(2\alpha))^{3/2}} d\alpha \tag{13}$$

By using Eqs.(11) and (12), the vertical and horizontal displacements of the any point d, from end point b of the circular arcin Fig.1, are:

$$H_d - H_b = \sqrt{m/\tan\alpha_b} - \sqrt{m/\tan\alpha_c} \tag{14}$$

$$S_d - S_b = \sqrt{m \tan\alpha_d} - \sqrt{m \tan\alpha_b} \tag{15}$$

Where H is the vertical distance; S is the horizontal displacement;

In Fig 1, the vertical and horizontal displacement of the point c along the inverse proportional curve can be expressed as follows:

$$H_c - H_b = \sqrt{m/\tan\alpha_b} - \sqrt{m/\tan\alpha_c} \tag{16}$$

$$S_c - S_b = \sqrt{m \tan\alpha_c} - \sqrt{m \tan\alpha_b} \tag{17}$$

The profile of the inverse proportional curve has six parameters, depth of the kick-off point-H_0, the radius of curvature of the circular arc-R, the inclination of the inverse proportional curve at its starting point -α_b, the characteristic coefficient of the inverse proportional curve-m, the inclination of the hold section-α_c, and the length of the hold section-L_w. Only four parameters are independent, so we should specify the four parameters in order to provide the unique design of the profile. Usually H_0, R, α_b, α_c are specified, hence the m and $L_w$can be calculated by the following equations:

$$H_0 + R\sin\alpha_b + \sqrt{m/\tan\alpha_b} - \sqrt{m/\tan\alpha_c} + L_w\cos\alpha_c = H \tag{18}$$

$$R(1-\cos\alpha_b) + \sqrt{m\tan\alpha_c} - \sqrt{m\tan\alpha_b} + L_w\sin\alpha_c = S \tag{19}$$

By combining Eq.(18) and (19) the values of m and L_w can be obtained. .

3 A Comparison of different types of well profiles

3.1 Case study

A well is taken as an example to compare the different well profile types. The parameters of the well profile design are: vertical depth of target 2985m; horizontal diaplacement 8062.7m; the depth of the kick off point 442m; the inclination of the hold section is 78°; the coefficient of friction is 0.15; the density of mud is 1.2g/cm^3; the weight on the bit is 100KN; ROP is 20 m/h; RPM is 60 r/min.

Based on the above derived equations for the inverse proportional curve, the design results for the 2D inverse proportional curve profile are shown in Table 1.

3.2 Comparison

There are many factors that should be considered, in order to obtain an optimum well path. Well profile design is not only a simple design of a geometric curve , but it is also an integrated project. There are three main principles that should be obeyed when planning a well profile. (1) minimum drag and torque; (2)minimum well length; (3)minimum well curvature.

This paper has compared the inverse proportional curve profile with six other types of profiles. Table2 shows the hook load about three typical drilling operations, torque, well length, length of build section and maximum wellbore curvature for seven types of profiles.

The findings are summarized below:

1. Among the seven curves, the maximum wellbore curvature of the nverse proportional curve is the smallest. Figure 2 shows that the wellbore curvature

Table 1: Design results for the 2D inverse proportional curve profile

Measured depth /m	Inclination /°	Measured depth /m	Inclination /°	Measured depth /m	Inclination /°
0	0	966.0654	38	1543.031	60
442	0	1017.418	40	1574.325	61
452.0007	1	1042.716	41	1606.66	62
482.0029	4	1067.829	42	1640.157	63
512.0052	7	1092.804	43	1674.955	64
542.0074	10	1117.688	44	1711.206	65
572.0096	13	1142.527	45	1749.087	66
602.0118	16	1167.365	46	1788.797	67
632.014	19	1192.249	47	1830.569	68
662.0162	22	1217.224	48	1874.669	69
692.0184	25	1242.337	49	1921.412	70
722.0206	28	1267.635	50	1971.168	71
742.0221	30	1293.169	51	2024.375	72
772.3834	31	1318.988	52	2081.564	73
801.9107	32	1345.146	53	2143.373	74
830.6931	33	1371.701	54	2210.592	75
858.8121	34	1398.711	55	2284.202	76
886.3422	35	1426.241	56	2365.443	77
913.3524	36	1454.36	57	2455.908	78
939.9068	37	1483.143	58	9156.908	78

varies with the measured depth. As can be seen from the Figure 2, the wellbore curvature of the proposed nverse proportional curve is more stable than others.

2. The wellbore length of the profile with the inverse proportional curve is shorter, and it is only a little longer than the sideway catenary.

3. The values of torque on the tubular string in these seven curves havevery little differences between them, and the torque in the case of the inverse proportional is only bigger than those for the modified catenary and the cycloid.

4. As we know, the smaller the hook load it is better when tripping out. As can be seen from Table 2 the hook load (trip out) of the inverse proportional curve is the smallest , except for case of the sideway catenary. However, the two results are very close.

Table 2: Comparison results

NO.	Curve type of build section	Well length (m)	Length of build section (m)	Hook load -sliding (KN)	Hook load-trip out (KN)	Hook load-rotary drilling (KN)	Rotating torque (KN/m)	Maximum wellbore curvature (°/30m)
1	circular arc	9249.637	1394.031	269.008	956.513	521	33.34	1.679
2	catenary	9200	1443.948	264.513	951.614	520.95	32.98	2.176
3	sideway catenary	9150.162	2703.481	267.692	921.311	521.03	33.34	2.991
4	modified catenary	9189.292	1554.184	265.037	943.206	520.86	32.47	1.480
5	parabola	9208.027	1353.943	264.012	958.346	520.97	33.49	3.302
6	cycloid	9168.449	1833.335	266.189	922.185	520.90	32.75	1.453
7	inverse proportion curve	9156.908	2013.908	266.031	921.436	520.82	32.80	1.208

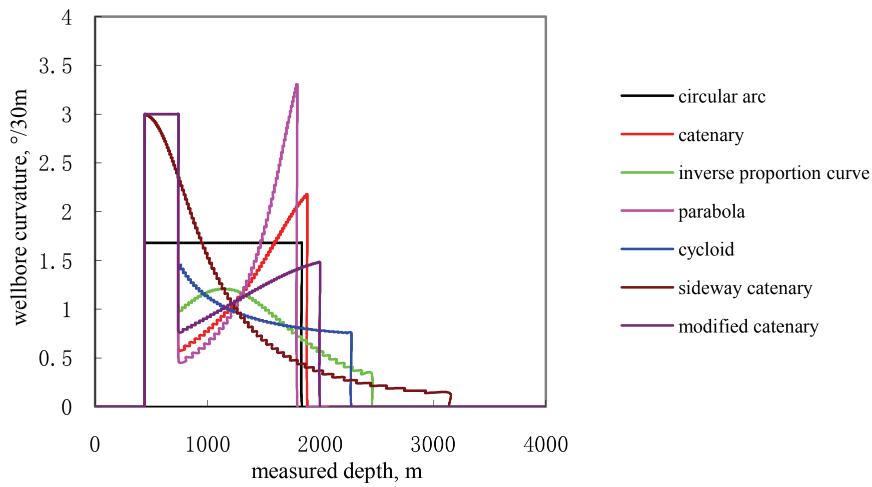

Figure 2: Wellbore curvature of different well profiles

5. As we know, the bigger the hook load it is better when sliding and rotary drilling are used. As can be seen from Table 2 the hook loads (rotary drilling) have very little differences among these seven types of curves. The hook load (sliding) of the inverse proportional curve is bigger than those for the catenary, modified catenary and parabola.
6. The length of the build section of the inverse proportional curve is larger than those of the others, except for the sideway catenary, hence this is a shortcoming of the inverse proportional curve.

Overall, the inverse portion profile has a great potential value in extended-reach drilling.

4 Conclusion

A new well profile is proposed, based on an inverse proportional function, and the well profle design method is evaluated in detail.This newly proposed well profile is compared with other existing well profiles in many aspects, such as the hook load, the maximum well curvature, the well length, the torque load and so on, in this paper. The presented results show that the proposed profile is better than others in many aspects, such as the well curvature, the well length and so on. When extended reach wells are drilled with rotary steering drilling systems, the well profile based on the proposecd inverse proportional curve can be recommended, in practice.

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