Reason of Intermediate Casing Wear in Ultra-deep Wells in China’s Tarim Oil Field

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Abstract. The intermediate casing wear is often found in ultra-deep wells in Tarim area. This phenomenon usually leads to many troubles in following well construction. By investigating 9 wells in this area that have severe intermediate casing wear, it is found that all casings are badly cemented, and the reason of casing wear is supposed to be helical buckling of casing string. In order to verify this judgment, geometry relationship among enlarged wellbore, buckled casing string and drill pipe joint are studied. When helical buckling occurs in casing string, apparent inner diameter of casing is usually smaller than the outer diameter of drill pipe joint. Therefore, rotating drill pipe joints wear casing inner surface continuously and forms a spiral scratch. Key factors that affect casing wear, such as wellbore enlargement rate, casing dimensions, casing centralizer and diameter of drill pipe joint, are discussed.

1. Introduction
With the improvement of exploration capability for deep oil and gas resources, more ultra-deep wells have been drilled in China’s Tarim oil field. Due to lost circulation during casing running or cementation, a large number of uncemented intermediate casing sections are found in this area. And in the subsequent well construction, the inner wall of the uncemented casing section is often worn and even worn out. According to the preliminary analysis, helical buckling of casing is directly related to the casing wear.

Since the 1950s, with the efforts of many scholars, the theory of tubular mechanics has been improved gradually. In 1950, the first rigorous treatment of drill string stability was presented by Lubinski [1]. In this work an analysis of two-dimensional buckling of drill pipe in vertical wells were discussed. In 1957, Lubinski et al. [2] published another fundamental paper where for the first time the concept of helical buckling of drill string was proposed. In 1962, Lubinski et al. [3] studied the helical buckling of tubing string with packer, and gave a pitch model. Later, Mitchell [4,5], Chen [6], Wu [7,8], He [9], Gao Deli [10], Gao Baokui [11], Gao Guohua [12-13] and many other scholars continued to study on tubular buckling, and great progress have been made.

But casing string buckling is seldom mentioned and there is no mature result published. The purpose of this paper is to analyze the reasons for the wear of uncemented casing, describe the wear process of casing during drilling, compare and analyze the factors that affect casing wear, and propose measures that can reduce casing wear.

2. Engineering Background

2.1. Formation and Structure of Ultra-Deep Wells in Tarim Area
All the ultra-deep wells in Tarim area are over 7000m in depth, and the main formations from top to
bottom are Quaternary, Neogene, Paleogene, Cretaceous, Jurassic, Triassic, Permian, Carboniferous, Devonian, Silurian, Ordovician. The main target layer is the Ordovician.

These ultra-deep wells are generally designed as three or four times drilling. The lower end of surface casing is normally down to the Neogene Kuqa, with a depth of 1000-1500m. The intermediate casing is usually down to below the bottom of Carboniferous, with a depth of more than 4000m.

2.2. Cementing Method and Problem for the Intermediate Casing
The reverse cementing method for the intermediate casing is used in Tarim area. And the well cementation is mainly divided into three steps. First, the cement slurry is injected to the Triassic in positive cementing method. Second, the casing is hung after the upper cement slurry is initially gelled (about 2-3 hours). Third, the reverse cementing is performed.

However, the casing section from surface casing shoe to the Permian cannot be cemented properly due to formations have lower bearing capacity. Table 1 shows the intermediate casing cementing information from 9 ultra-deep wells in Tarim area.

| No. | Hole Depth of the surface section (m) | Intermediate casing dimension (mm) | Intermediate casing section (m) | Uncemented casing section (m) |
|-----|--------------------------------------|----------------------------------|-------------------------------|-------------------------------|
| 1   | 1506                                 | φ273.05×11.43                    | 0-5401                        | 1500-5000                     |
| 2   | 1500                                 | φ273.05×11.43                    | 0-5308                        | 1510-5160                     |
| 3   | 1000                                 | φ244.48×11.99                    | 0-5214                        | 1000-3800                     |
| 4   | 1504                                 | φ200.03×10.92                    | 0-7294                        | 1510-4880                     |
| 5   | 1500                                 | φ200.03×10.92                    | 0-6923                        | 1500-5075                     |
| 6   | 1489                                 | φ200.03×10.92                    | 0-7193                        | 1490-5300                     |
| 7   | 1505                                 | φ200.03×10.92                    | 0-6589                        | 1505-5892                     |
| 8   | 1501                                 | φ200.03×10.92                    | 0-7045                        | 1500-4610                     |
| 9   | 1500                                 | φ200.03×10.92                    | 0-7217                        | 4726-7137                     |

In these wells, a large cement empty section from surface casing shoe to Permian is produced after well cementation. The longest free section is 4387m, and the shortest one is 935m.

In the subsequent construction, these uncemented casing sections are often worn or even worn out. This phenomenon will greatly reduce the strength and safety of the casing, which will bring great difficulties to the later well construction.

3. Analysis of Uncemented Casing Wear

3.1. Characteristic of Uncemented Casing Wear
Figure 1 shows an internal image of a casing section from an ultra-deep well in Tarim area. Where $H$ is the hole depth; $\theta$ is the circumferential deployment angle of the casing.

![Figure 1. Internal image of casing wear in an ultra-deep well.](image_url)

A clear helical wear scar with a pitch of about 26m can be found from this picture. According to the
field well construction, it can be inferred that the casing wear are likely to be caused by the following wear of drill pipe joint after the uncemented casing has been helically buckled.

### 3.2. Geometry Character of Buckled Casing

In a vertical well, the casing string is assumed to be centered within the wellbore. Apparent inner diameter of the casing is equal to its inner diameter when look down the casing from the top, as shown in Figure 2-a, where $D_{av}$ is apparent inner diameter of casing without buckling.

After the casing has been helically buckled, the casing is in a spiral state, and its outer wall will lean against the wellbore. In this case, the apparent inner diameter of casing is greatly reduced, as shown in Figure 2-b, where $D_{ah}$ is the apparent inner diameter of casing after casing helical buckling.

The apparent inner diameter of casing after helical buckling ($D_{ah}$) can be expressed as

$$D_{ah} = D_b (1 + K) - 4r - 2t$$

and

$$r = \frac{1}{2} [D_b (1 + K) - D_{co}]$$

(1)

where $D_b$ is the diameter of bit; $D_{co}$ is the outer diameter of casing; $K$ is the hole diameter enlargement rate; $t$ is the casing wall thickness.

It can be seen from equation (1) that apparent inner diameter of casing ($D_{ah}$) is closely related to hole diameter enlargement rate ($K$), outer diameter of casing ($D_{co}$) and casing wall thickness ($t$).

After the casing is helically buckled, its apparent inner diameter may be smaller than the outer diameter of drill pipe joint, and may even be smaller than the outer diameter of the drill pipe body.

### 3.3. Process of Casing Wear

When drill pipe joint is larger than the $D_{ah}$ of the casing, every tool joint inside the helical buckled casing will contact with the inner wall of the casing. The contact point between the drill pipe joint and the casing is directly opposite the contact point between the casing and the wall. As shown in Figure 3.
During the rotation of the drill string, the drill pipe joint inside the helical buckling casing will constantly wear the inner wall of the casing. This results in wear scar at the contact point. And this mark is crescent-shaped in the cross section of the casing.

With the advance of the drilling, the casing will be rubbed to similar crescent wear scar in each cross section. And then a spiral scar will be formed in casing inner surface. Figure 4 shows the schematic diagram of a spiral wear scar on the casing. The left part shows a three-dimensional illustration of a spiral wear scar on the casing, and the right part shows a two-dimensional sectional development view of a spiral wear scar corresponding to Figure 1.

In addition, casing wear will be more severe with the increase of the rotary drilling time and the number of drill string trips.

4. Example Analysis

In this section, three dimensional combinations commonly used in Tarim area are taken as examples, as shown in Table 2. These combinations include the outer diameter of the drill bit, the intermediate casing dimension and the drill pipe size.

Table 2. Three common combinations in Tarim area.

| No. | $D_b$ mm | $D_{ci}$ mm | $t$ mm | $D_{co}$ mm | $D_d$ mm | $D_{dj}$ mm |
|-----|----------|-------------|--------|-------------|----------|-------------|
| 1   | 241.3    | 200.03      | 10.92  | 178.19      | 101.6    | 139.7       |
| 2   | 311.15   | 244.48      | 11.99  | 220.5       | 127      | 165         |
| 3   | 333.4    | 273.1       | 11.43  | 250.24      | 139.7    | 185         |

Where $D_{ci}$ is the inner diameter of casing; $D_d$ is the outer diameter of drill pipe body; $D_{dj}$ is the outer diameter of drill pipe joint.

![Figure 3. Schematic diagram of drill pipe joint inside the helical buckling casing.](image)

![Figure 4. Schematic diagram of a spiral wear scar on the casing.](image)

![Figure 5. Relationships between $D_{ah}$ and $K$ of three combinations.](image)

a. Casing string without centralizers.  
b. Casing string with centralizers.

**Table 2.** Three common combinations in Tarim area.
4.1. Analysis of Casing Wear Conditions

According to the previous analysis, the most important factor affecting $D_{ah}$ of casing is the $K$. Therefore, $D_{ah}$ of these combinations are calculated at different $K$ values. Figure 5 shows the relationships between the $D_{ah}$ and the $K$ of these combinations.

1) Relationship between $D_{ah}$ and $K$

It can be seen from figure 5 that with the increase of $K$, the $D_{ah}$ of every combination decreases linearly.

2) Conditions that drill pipe joint contact casing

The mark “○” in the figure 5-a gives the corresponding $K$ when the drill pipe joint contacts the casing. And it can be seen that for combination No.1 and No.2, as long as the casing undergoes helical buckling, the $D_{ah}$ will be smaller than the $D_{dj}$. For combination No. 3, when $K$ exceeds 1.5%, the $D_{ah}$ will also be smaller than the $D_{dj}$. Therefore, once the casing instability occurs, it is easy for the drill pipe to wear the casing.

3) Conditions that drill pipe body contact casing

The mark “□” in the figure 5-a gives the corresponding $K$ when the drill pipe body contacts the casing. And it can be seen that for these three combinations, when the $K$ exceeds 14.6%, 8.6%, and 15.1%, respectively, the $D_{ah}$ will be smaller than the $D_{dj}$. The survey shows that the $K$ of this well section in Tarim area is usually about 10%. Therefore, for combination No. 1 and No. 3, the phenomenon of abrasion between the drill pipe body and the casing basically cannot occur.

4.2. Analysis of Measures to Reduce Wear

To reduce casing wear, centralizers can be installed on the casing string. This measure can reduce $D_{ah}$ of casing, thereby alleviate the contact force between drill pipe joint and casing.

When centralizers are not used, the $D_{ah}$ is usually smaller. In this case, the casing is more severely worn. After centralizers are used, the $D_{ah}$ will be significantly increased. In this case, the wear on the casing can be reduced accordingly.

After installing 238mm, 308mm and 330mm centralizers on the casing string of these combinations, respectively, the relationships between $D_{ah}$ and $K$ of these combinations are plotted, as shown in Figure 5-b. For these three combinations, when $K$ exceeds 14.6%, 16.8%, and 18.5%, respectively, $D_{ah}$ will be less than $D_{dj}$. Therefore, the wear can be effectively reduced after the centralizer is installed.

However, a centralizer is usually installed every 3-5 casings during field construction. This is likely to lead to the distance between the two centralizers to be longer than the pitch. Therefore, installing centralizers on the casing string cannot completely avoid the casing wear.

In addition, the $D_{dj}$ and the hanging weight are also important factors affecting the casing wear.

With the increase of the $D_{dj}$, the corresponding $K$ when the drill pipe joint contacts the casing decreases. Moreover, when the drill pipe joint contacts the casing, the larger the $D_{dj}$, the greater the contact force between the tool joint and the casing, and the more severe the casing wear.

The hanging weight can directly affect the degree of casing buckling during drilling. And the helical buckling of the casing will be more severe with the decrease of the hanging weight.

5. Conclusion

(1) The main reason for intermediate casing wear of ultra-deep wells in Tarim area is that the apparent inner diameter of casing is greatly reduced after helical buckling.

(2) The hole diameter enlargement rate is the main factor that determine the apparent inner diameter of the casing after helical buckling.

(3) Installing centralizers on the casing string can reduce the casing wear, but cannot completely avoid.

(4) Drill pipes with smaller outer diameter joint and the smaller hanging weight should be used during well construction if possible.

(5) Avoiding casing helical buckling is the most fundamental measure to avoid casing wear.

6. Acknowledgement

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7. References

[1] Lubinski A. 1950 A study of the buckling of rotary drilling string API Drilling and Production Practice 178-214.

[2] Lubinski A., Blenkarn K.A. 1957 Buckling of tubing in pumping wells, its effects and means for controlling it Trans., AIME 210 73-88.

[3] Lubinski A., Althouse W.S. 2013 Helical buckling of tubing sealed in packers Journal of Petroleum Technology 14(06) 655-670.

[4] Mitchell R.F. 1982 Buckling behaviour of well tubing: the packer effect Society of Petroleum Engineers Journal 22(05) 616-624.

[5] Mitchell R.F. 1988 New concepts for helical buckling SPE Drilling Engineering 3(03) 303-310

[6] Chen Y.C., Lin Y.H. and Cheatham J. B. 1990 Tubing and casing buckling in horizontal wells SPE Journal of Petroleum Technology 42(02) 140-141.

[7] Wu J., Juvkam-wold H.C. and Lu R. 1993 Helical buckling of pipes in extended reach and horizontal wells-part 1: preventing helical buckling Journal of Energy Resources Technology 115(03) 190-195.

[8] Wu J., Juvkam-wold H.C. and Lu R. 1993 Helical buckling of pipes in extended reach and horizontal wells-part 2: frictional drag analysis Journal of Energy Resources Technology 115(03) 195-201.

[9] He X., Kyllingstad A. 1995 Helical buckling and lock-up conditions for coiled tubing in curved wells SPE Drilling & Completion 10(01) 10-15.

[10] Gao D.L., Liu F.W. and Xu B.Y. 2000 Research on buckling behaviour of tubular string in curved wellbore Oil Drilling & Production Technology 04 1-4+83.

[11] Gao B.K., Gao D.L. 1995 Possibility of drill string buckling in slant hole Oil Drilling & Production Technology 05 6-11+105.

[12] Gao G.H., Li Q. and Li S.F. 1996 Buckling analysis of pipe string in horizontal wellbore Acta Petrolei Sinica 03 123-130.

[13] Gao G.H., Li Q. and Li S.F. 1996 Buckling analysis of compressed pipe string in curved wellbore Chinese Journal of Applied Mechanics 01 115-120+152.