Development of a Drilling Fluid Drive Downhole Tractor in Oil Field

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Abstract. This paper proposes a drilling fluid drive downhole tractor, which has the advantages of compact structure, large traction, fast speed and high reliability. The overall mechanical structure of the tractor is introduced, the concrete structures including supporting structure and cushion mechanism are designed. And its all-hydraulic drive continuous propulsion principle is analyzed. Finally the simulation analysis of the tractor operation is carried out to prove that the traction motion scheme is feasible.

1. Introduction

In the development of oil field, the technology of continuous tubing is widely used, and the operations underground of continuous tubing must be assisted by downhole tractor. Downhole tractor is the underground tool that can provide traction at the bottom of the well, which operates in the complex and narrow environment with high temperature and high pressure. Therefore, downhole tractor must have a compact structure to adapt to the complex environment and provide enough traction to meet larger load requirements [1-2].

There are two kinds of downhole tractors according to its structure and working principle. One is the wheel tractor, which can realize the motion by driving wheel which contacts with oil pipe wall. The main research companies are Welltec and Sondex[3-4]. The other type is the telescopic tractor, which can realize the motion by the two centralizers alternately supporting to the wall. One holding arms can be held on the pipe wall, while the other moves in opposite direction to realize motion of the tractor. Products of this type in SmarTract and Omega are famous[5].

However, the existing tractors have the following disadvantages. In the aspect of structure, the wheel tractor is relatively mature. But the driving force is small and the tractor is easier to skid in the inner wall of the oil pipe. And when it comes to the irregular inner wall, the tractor stability is poor. In the drive mode, the current tractors are most electric drive mode, which driven by the motor drive screw or the gear. Although the design is simplified, the structure of the tractor is complicated and the mechanical efficiency is low. Most hydraulic drive tractors are controlled by electric. All electrical
components and hydraulic components are difficult to work in high temperature and high pressure for a long time, greatly reducing the tractor reliability in the underground [6-7]. Therefore, in order to solve the shortage of existing tractor, this paper proposes a drilling fluid drive downhole tractor, which is driven from drilling fluid, not electrically driven. Firstly the paper introduces the overall mechanical structure, supporting structure and cushion mechanism. Then its all-hydraulic drive continuous propulsion mechanism is analyzed. Finally the simulation analysis of the tractor operation is carried out to prove that the traction motion scheme is feasible.

2. Structure Design of Downhole Tractor

2.1. Overall Mechanical Structure

The overall structure of downhole tractor is shown in figure 1, which consists of three parts: the front supporting arm, hydraulic control unit and the rear supporting arm.

![Figure 1](image)

**Figure 1.** Overall structure model of downhole tractor

The specific structure of the supporting arm is shown in figure 2. The main composition contains flexible supporting unit, supporting cylinder, walking cylinder and cushion cylinder.

![Figure 2](image)

**Figure 2.** Structure model of supporting arm

2.2. Design of Supporting Mechanism

The supporting arm is the key module to ensure that the tractor can advance normally. The supporting arm enables the supporting claw to hold the well wall, ensuring that the part of the mechanism is fixed, and the other sections of tractor move relatively.

Figure 3 shows the three-dimensional model diagram of supporting arm. Where, the major components include, supporting cylinder 12, walking cylinder 13, cushion cylinder 14, center pipe 4, supporting piston 121, walking piston 131, cage 111, sliding block 112, flexible supporting bar 1131, fixed block 1132, scroll wheel 1133, supporting bar A 1135, supporting bar B 1135.
The cushion mechanism is the key module to ensure that the tractor can realize changing direction. As shown at point A, the left side of the cushion mechanism is a walking piston with a slow punch. In the middle, the cylinder head is cushioned, and the thrust piston and compression spring are arranged, as well as the relevant sealing elements.

2.3. Mechanical Analysis

The force diagram of supporting mechanism is shown in figure 4.

\[
F \cdot \delta x_A = N \cdot \delta y_B \tag{1}
\]

Based on the coordinate relation,

\[
\begin{cases}
x_A = l_1 \cdot \cos \alpha + l_2 \cdot \cos \beta \\
y_B = l_2 \cdot \sin \beta = l_1 \cdot \sin \alpha
\end{cases} \tag{2}
\]

The relationship 2 is differentiable,

\[
\begin{cases}
\delta x_A = -l_1 \cdot \sin \alpha \cdot \delta \alpha - l_2 \cdot \sin \beta \cdot \delta \beta \\
\delta y_B = l_2 \cdot \cos \beta \cdot \delta \beta = l_1 \cdot \cos \alpha \cdot \delta \alpha
\end{cases} \tag{3}
\]
Also,
\[
\delta \alpha \cdot \sqrt{l_1^2 - l_2^2 \cdot \sin^2 \beta} = \delta \beta \cdot l_2 \cdot \cos \beta \quad (4)
\]

The formula (4) is substituted into equation (5),
\[
\delta x_A = -\frac{l_2 \cdot \cos \beta \sin \delta \beta}{\sqrt{l_1^2 - l_2^2 \cdot \sin^2 \beta}} - l_2 \cdot \sin \beta \cdot \delta \beta
\]

Finally, the relationship between $F$ and $N$ is
\[
F = -\frac{-N \cdot \cos \beta}{1 + \frac{l_2 \cdot \cos \beta}{\sqrt{l_1^2 - l_2^2 \cdot \sin^2 \beta}}} \cdot \sin \beta \quad (6)
\]

The relationship between traction and positive pressure can be studied by relational expression (6), which can lay a foundation for the establishment of downhole traction performance index.

3. Motion Principle of Hydraulic Drive Tractor

3.1. Motion Principle

The schematic diagram of drilling fluid drive telescopic tractor is shown in figure 5. The basic structure of the supporting arm and the two working conditions (supporting arm extension and supporting arm contraction).

In this paper, the driver of the tractor is aided by drilling fluid. When the high pressure filtered fluid flows into the supporting circuit, the piston drives the supporting grip to lock the well wall. The high pressure fluid flows into left cavity of walking cylinder, pushing the drilling centre pipe forward. Low pressure fluid returns from right cavity of walking cylinder, and the fluid crossing the hydraulic control unit returns to the outer layer.

![Schematic diagram of telescopic tractor](image)

**Figure 5.** Schematic diagram of telescopic tractor

When the supporting cylinder fills with low pressure fluid, the supporting grip retreats. The fluid of walking cylinder left cavity is low pressure fluid, and flowing across hydraulic control unit returns to the outer layer. The right cavity of the walking cylinder is filled the oil, pushing the support arm move forward relative to the drilling centre pipe.

3.2. Operation Process

The tractor can move forward continuously through the contraction and expansion of the front and the rear supporting arms, as shown in figure 6 (the tractor moves to the right).
Figure 6. Schematic diagram of continuous propulsion

Figure 6 (a) is the initial state of tractor. Each hydraulic cylinder chamber has no pressure fluid and each supporting arm is in a contraction state.

When the high pressure filtered fluid flows into the supporting circuit. Operation 1 is shown in Figure 6 (b), after the tractor is started, the front supporting cylinder is pressed into high pressure fluid (red liquid path), and the front supporting clam holds the inner wall. The left cavity of the front walking cylinder is pressured high pressure fluid (red liquid path), and the drilling centre tube is moving forward. The rear supports cylinder relieves, and the rear supporting cylinder press the low pressure fluid (blue liquid path). The right cavity of the rear walking cylinder is pressured high pressure fluid (red liquid path), the rear support arm is moving forward relative to the drill pipe. The current moving cylinder piston moves to the right side, touching the cushion tank (yellow liquid path), which leads to movement of reversing valve, making fluid circuit change.

Operation 2 is shown in Figure 6 (c). The action of the reversing valve causes the fluid circuit to change. The rear supporting cylinder is pressed into high pressure fluid (red liquid path), and the rear supporting clam holds the inner wall. The left cavity of the rear walking cylinder is pressured high pressure fluid (red liquid path), and the drilling centre tube is moving forward. The front supports cylinder relieves, and the front supporting cylinder press the low pressure fluid (blue liquid path). The right cavity of the front walking cylinder is pressured high pressure fluid (red liquid path), the front support arm is moving forward relative to the drill pipe. The current rear moving cylinder piston moves to the right side, touching the cushion tank (yellow liquid path), which leads to movement of reversing valve, making fluid circuit change. Such periodic cycle operation can realize the continuous advance of downhole tractor

4. Simulation of Operation Process

Based on the motion principle, the tractor operation process is simulated by software. The simulation parameters are set as follows: the work pressure is 14 MPa, and the input flow is 45 L/min. because of the modular design of the walking cylinder and the supporting cylinder, they have the same size and structure, and the cylinder stroke is 150 mm. The time of simulation is set 20s, and some curves are shown in below figures.
Because the front and the rear cylinders are the same, the rear walking cylinder is chosen as the analysis object. As shown in figure 7, the dynamic characteristic in the rear cylinder is got.

**Figure 7.** Displacements of walking cylinders

In the figure 7, the red curve represents the piston displacement of the cylinder. The green line represents the pressure change of the left cavity in walking cylinder. It can be seen that the changes of displacement and pressure are both periodic. In the initial stage, the pressure fluctuates, and after one cycle the pressure tends to be stable. It can be seen from the slope of displacement curve, the walking speed is not stable in the whole process, which may be influenced by the buffering action.

As shown in figure 8, the horizontal coordinate is the time, and the vertical coordinate represents the displacement curves of the walking cylinders piston. In the figure, you can see that both the movements of the cylinder pistons are periodic, and the motion cycle is about 4.67 s. because of the hydraulic cylinder stroke is 0.15 m, so the walking speed is calculated indirectly of 0.03 m/s. The two piston displacements characteristics are the same quantity and opposite direction, which is due to motion principle of the downhole tractor.

**Figure 8.** Displacements of walking cylinders

**Figure 9.** Pressures of walking cylinders

Figure 9 shows the left cavity pressure curves of two walking hydraulic cylinders. As shown in the figure, the left cavity pressures of the two cylinder changes alternately. In the initial state, pressure in the rear cylinder fluctuates, and then operates smoothly later. We can see that the pressure in the rear walking cylinder is a little larger than the pressure in the front walking cylinder, which may be caused by the different resistance in thrust and drag.
5. Conclusion
In order to solve the shortage of the existing tractor, this paper proposes a drilling fluid drive downhole tractor. The main advantage of the tractor is that the whole process is driven by drilling fluid, which increases the reliability of the complex environment. The overall mechanical structure was introduced firstly in the paper, and the concrete structure was designed, including supporting structure and cushion mechanism. Subsequently its all-hydraulic drive continuous propulsion operation was analyzed. Finally the simulation analysis of the tractor operation was carried out, which can prove that the traction motion scheme is feasible.

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7. References
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