Design and analysis of deep well hydraulic piston pump

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Abstract

In deep wells and ultra-deep wells, due to the high depth of the lower pump, large formation pressure and high temperature, the traditional mechanical pumping equipment does not function well in the above oil wells due to the reduced reliability and reduced efficiency. In view of the complex structure and low reliability of the traditional hydraulic piston pump, this paper innovatively designed a new single-acting deep well hydraulic piston pump with simple structure, high reliability and high pump efficiency, which can operate efficiently under deep well heavy oil conditions. structure. It provides important guiding significance for the further study of hydraulic piston pumps.

Keywords

Hydraulic piston pump,Slide valve,finite element.

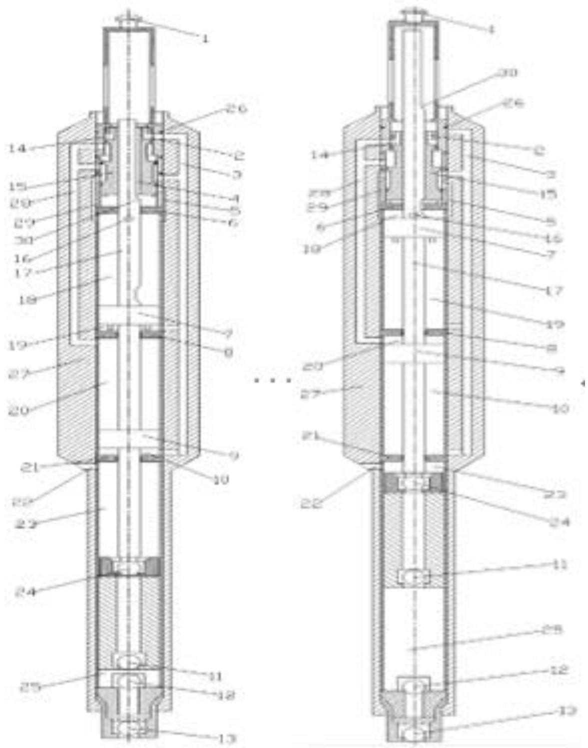
1. Introduction

With the continuous development of oil and gas resources, the mining progress has gradually shifted to the marginal areas such as wasteland, offshore and desert, and the depth of reservoir burial is increasing. With the deepening of development, the pressure under the oil well has been continuously reduced, and the mining method has changed from self-spraying oil production to artificial lifting[1]. In the current conventional rod pump production, with the deepening of the oil production depth, the suspension point load is further increased, so that the weight of the pumping unit itself is increasing, resulting in an increase in oil well accidents, and also cannot meet the oil recovery requirements of deep wells[2].

Foreign E. Lisowski and W. Czyggzycki and others used the CFD method to solve the force of the sliding valve with high reliability [3]. Abdalla M.O. obtained the relationship between flow and pressure drop through simulation [4]. Himadri Chatto padhyay used Fluent to analyze the effect of inlet and outlet pressure difference on the flow field in the valve under different working conditions [5]. Hailing An found that the structure of the spool caused different degrees of shunting and vortex [6]. Marko Simic reduces system energy losses by optimizing the structure [7]. These basic ideas are to optimize the design and simulation of the local structure of the hydraulic piston pump, and the overall structure and working principle have not changed greatly. Domestic research on deep well super deep wells and hydraulic piston pumps under complex conditions is not sufficient. The research of deep well hydraulic piston pumps developed in this paper is of great significance..

2. Deep well hydraulic piston pump structure and working principle

The working principle of the deep well hydraulic piston pump is shown in Figure 1:



a-upstroke b-downstroke

1-salvage assembly; 2-slider right communication hole; 3-first flow path; 4-second flow path; 5-fifth flow path; 6-upper baffle; 7-upper piston; 8-mid baffle 9-lower piston; 10-lower cylinder lower chamber; 11-lower discharge valve; 12-suction valve; 13-fixed valve; 14-slide valve left communication hole; 15-spool valve; 16-pump bore; 17- Piston rod; 18-upper cylinder upper chamber; 19-upper cylinder lower chamber; 20-lower cylinder upper chamber; 21-lower baffle; 22-liquid discharge port; 23-pump drain chamber; 24-up discharge valve 25-pump suction chamber; 26-seal; 27-pump; 28-third flow; 29-fourth flow; 30-piston groove boss.

Figure 1. Schematic diagram of the structure and working principle of the hydraulic piston pump.

The upper stroke, as shown in Figure 1-a, the hydraulic fluid enters the lower end of the slide valve through the second flow passage, and enters the lower chamber of the upper cylinder and the lower chamber of the lower cylinder through the first flow passage, and the piston rod starts to move upward. The spent power fluid enters the upper chamber of the upper cylinder through the third and fourth flow passages and is discharged through the pump cylinder hole. When the valve stem is ascending, the discharge valve at the lower end of the piston pump is closed, and the fixed valve and the suction valve at the lower end of the piston pump are opened under the action of the negative pressure. The formation fluid enters the pump suction chamber through the open fixed valve and suction valve. When the piston rod is up to a certain position, the piston rod will gradually block the second flow passage, the sliding valve begins to descend, the power liquid passing through the first flow passage is gradually reduced, and the upward speed of the piston rod is slowed down when the spool valve is lowered to the limit position. , the end of the trip.

Down stroke, as shown in Figure 1-b, the power fluid enters the upper chamber of the lower cylinder through the third flow passage, the piston rod moves downward, the fixed valve and the suction valve close, the discharge valve opens, and the pump sucks into the chamber to enter the pump drain Chamber. When the piston rod descends to a certain extent, the second flow passage gradually communicates, the slide valve starts to ascend, and the downward speed of the piston rod slows down until it reaches zero, and the lower stroke ends.

The basic parameters of the deep well hydraulic piston pump are as follows:

Table 1. Basic parameters of deep well hydraulic piston pump.

Head	Radial size	Stroke length	Number of strokes	Piston rod diameter	Pump piston diameter
5500m	72mm	480mm	100times/min	19mm	50mm

3. Calculation of operating parameters of deep well hydraulic piston pump

3.1 Determination of power hydraulic pressure

The deep well hydraulic piston pump has greater resistance to overcome the upper stroke than the down stroke, and the output pressure of the ground power pump is higher. Therefore, the calculation of the power hydraulic pressure is mainly based on the force of the piston pump on the upper stroke..

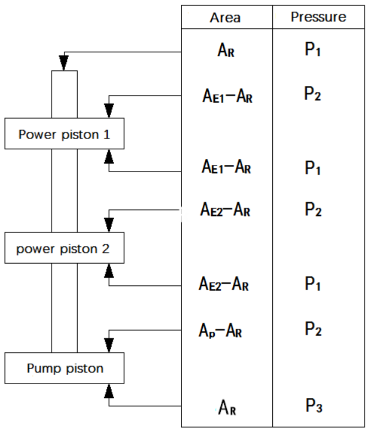


Figure 2. Schematic diagram of the force of the piston group of the upper stroke downhole unit.

$$P_1 = h_1 G_1 - F_1 + P_s$$

$$P_2 = h_1 G_2 + F_3 + P_{FL}$$

$$P_3 = h_4 G_3 \tag{1}$$

3.2 Theoretical displacement calculation of the pump

In a single-acting deep well hydraulic piston pump, the pump piston discharges the volume of fluid produced in a chamber during one stroke. The theoretical displacement of the pump can be determined by:

$$Q = 24 \times 60 \times n \times L \times A_p \tag{2}$$

Q-the theoretical displacement of liquid production, m3/d; n-rushing times, times/min; Ap -the cross-sectional area of the pump piston, m2; L-stroke length, m.

3.3 Power flow theoretical flow calculation

When the stroke is n times per minute, the required power flow of the piston pump downhole unit is determined by the following formula:

$$q = 24 \times 60 \times n \times \left[L\left(A_{E1} + A_{E2} - 2A_R\right) + Y\left(A_n - A_R\right)\right] \tag{3}$$

q-power fluid theoretical flow, m3/d;AE1-liquid motor 1 piston cross-sectional area, m2; AE2-liquid motor 2 piston cross-sectional area, m2;AR-piston rod cross-sectional area, m2; An -slide valve head End face area, m2; Y-spool stroke length, m.

3.4 Calculation of pump leakage

For the convenience of analysis, the concentric annular gap flow between the piston and the pump cylinder is simplified as the flow between the parallel plates. Since the viscosity of the crude oil changes little when the temperature is constant, and the gap size is small, the ideality of the gap flow can be regarded as laminar flow.

According to the differential equation of fluid mechanics for the incompressible actual fluid motion, considering that the fluid is a steady, continuous, incompressible fluid,Simplify the gap Navier-Stoker equation[8] to:

$$\begin{cases} g-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\nabla^2 u_x=u_x\frac{\partial u_x}{\partial x} \\ -\frac{1}{\rho}\frac{\partial p}{\partial y}=0 \\ -\frac{1}{\rho}\frac{\partial p}{\partial z}=0 \end{cases} \tag{4}$$

Determine the optimal gap formula for the pump[9]:

$$\delta_0=\delta=\sqrt{\frac{2\mu lU}{p_2-p_1}} \tag{5}$$

u-power fluid viscosity, Pa•s; l-plunger length, m; U-plunger maximum speed, m/s; P_2-P_1-pressure difference across the plunger, Pa.

3.5 Pump power and efficiency calculation

Pump power calculation[10].

$$N_h=\frac{Qp}{86400}=\frac{Q_T\rho gL_E}{86400\times10^3} \tag{6}$$

N_h-pump power, kw;p-pump pressure, KPa;L_E-effective lifting height, m;ρ-liquid density, kg/m^3; Q-actual displacement, m^3/d; Q_T-theoretical displacement, m^3/d.

Pump efficiency calculation.

$$\eta_v=\eta_c\eta_B\eta_q \tag{7}$$

η_c-pump cylinder fullness factor;η_B -liquid volume effect coefficient; η_Q-leakage coefficient.

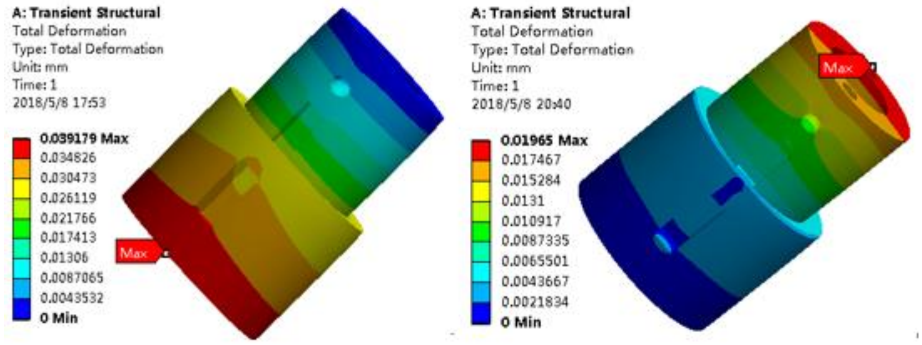
3.6 Hydraulic piston pump operating parameters

Table 2. Operation parameters of hydraulic piston pump.

Ground power pump working pressure	Theoretical displacement of the pump	Power flow theoretical flow	Pump leakage	Pump power	Volumetric efficiency
23MPa	135.72m^3/d	242m^3/d	9.907×10-3m^3/d	51.4KW	0.76

4. Finite element simulation analysis of reversing slide valve

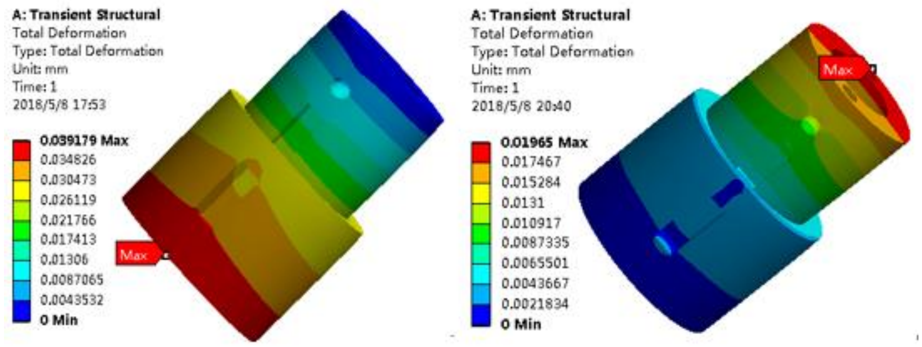
There are upper limit positions (a) and lower limit positions (b) of the slide valve during the movement, and there are two kinds of limit conditions for the force of the slide valve.



(a) (b)

Figure 3. Sliding valve deformation cloud diagram under different working conditions.

It can be seen from Fig. 3 that the maximum deformation under the two extreme conditions is 0.039179 mm and 0.01965 mm, respectively. The maximum deformation occurs on both end faces of the spool, which is consistent with the actual working conditions.


A: Transient Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
2018/5/8 17:53
0.039179 Max
0.034826
0.030473
0.026119
0.021766
0.017413
0.01306
0.0087065
0.0043532
0 Min
Max
A: Transient Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
2018/5/8 20:40
0.01965 Max
0.017467
0.015284
0.0131
0.010917
0.0087335
0.0065501
0.0043667
0.0021834
0 Min
Max

(a) (b)

Figure 4. Spool valve stress cloud diagram under different working conditions.

It can be seen from Fig. 5 that the maximum stress value under different working conditions occurs at the opening of the upper end of the spool valve. The maximum stress corresponding to the working condition 1 is 261.71 MPa, and the maximum stress corresponding to the working condition 2 is 160.47 MPa. The opening of the upper end of the slide valve is subjected to an axial force, and the end points of the circular hole in the radial direction are concentrated in stress, and the cloud image is consistent with the force.

5. Conclusion

Aiming at the difficulties faced by China's deep well ultra-deep oil production, combined with the advantages of the hydraulic piston pump, a high-efficiency hydraulic piston pump that can be used in deep wells was designed and developed. The following conclusions were obtained through research:

(1) Aiming at the problem of insufficient pump depth in domestic hydraulic piston pump, a deep well hydraulic piston pump structure scheme was designed, and the relevant operating parameters of the pump were determined through analysis and calculation.

(2) Static mechanical analysis of the reversing valve of the deep well hydraulic piston pump was carried out by ANSYS. The analysis showed that the reversing valve can meet the requirements under the actual working conditions.

(3) The designed deep well hydraulic piston pump has the characteristics of high pump efficiency, simple structure and single-pump driven by two-liquid motor, which is suitable for deep well heavy oil exploitation.

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