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THE ART OF ENGINEERING: OPTIMIZING THE STRUCTURE OF LPS ROPE SUSPENSION UNLOADERS

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Abstract:
In recent years, the oil industry has grappled with persistently low oil prices, a surge in low-producing wells, and the continued erosion of oilfield extraction efficiency. The global count of operational pumping wells in oilfields has surpassed 2 million. Currently, both domestic and international oil production predominantly relies on mechanical pumping systems [1], wherein pumping machines supply the mechanical power required for oil extraction. This method prevails across most oilfields [2-4]. Among the various mechanisms employed, the swimming beam pumping machine stands out for its simplicity, ease of maintenance, and reputation for stability and reliability. However, it lags in terms of extraction efficiency, with an average range of only 12% to 23% [5,6]. This deficiency poses a significant hurdle to the economic development of oilfields and energy conservation initiatives. To address these challenges and significantly enhance energy efficiency while reducing emissions, we propose the design of a single-drive multi-well pumping machine [7]. The innovative single-drive multi-well pumping machine employs a load distribution mechanism that effectively eliminates the inefficient load (pumping rod weight) from the system while ensuring that alternating loads are uniformly distributed. This approach rectifies the issues of irregular force sinusoidal fluctuations, high energy consumption, and inefficiencies inherent in traditional swimming beam-type pumping machines. Consequently, it results in substantial energy savings of 65% to 80% and cost reductions of 65% to 75% when compared to similar models.

Keywords: Oilfield Extraction, Pumping Machine, Energy Efficiency, Load Distribution, Emission Reduction

1. Introduction

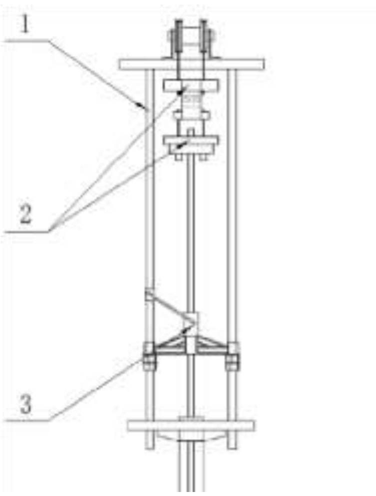
In recent years, oil prices have been low, the number of low-producing wells has been increasing, and the efficiency of oilfield extraction has been deteriorating year by year. The total number of existing pumping wells in oilfields at home and abroad can reach more than 2 million. The current domestic and foreign mechanical oil production method is mainly realized by pumping machines [1], and the operation principle is that pumping machines provide mechanical power for oilfield extraction, and this production method is adopted by most of the oilfields [2-4]. Among them, the swimming beam pumping machine is widely used because of its simple structure, easy maintenance, stability and reliability, but its average efficiency of extraction is only 12%-23% [5,6], which has seriously affected the economic and efficient development of oil fields and energy saving and consumption reduction, so to achieve significant energy saving and emission reduction, a single drive multi-well pumping machine is designed[7]. By distributing the load evenly for the phase, the ineffective load (pumping rod weight) between the system cancels each other and the alternating load is uniformly distributed, which effectively solves the problems of unreasonable force sinusoidal fluctuation, high energy consumption and inefficiency of conventional swim beam type pumping machine, and saves energy up to 65%~80% and reduces the cost by 65%~75% compared with similar models.

There is a key problem with single drive multi-well pumping units, namely, when a single well fails to stop pumping for repair or wellhead maintenance, the main engine of the multi-well unit needs to be shut down for repair, which can greatly delay the timeliness of oil recovery work. To address this problem, a wellhead unloading protection system is proposed. The system not only has a single well overload protection function, which can automatically disconnect the faulty well from the multi-well machine system to ensure the normal operation of other well groups, but also has a manual unloading function, which can be used for daily wellhead maintenance or component replacement. This paper focuses on a detailed design study of the manual unloading auxiliary module (i.e. LPS rope suspension auxiliary unloading device) in the wellhead unloading protection device.

2. Structural design

2.1. Brief description of wellhead unloading protection system

The wellhead unloading protection system is applied at the wellhead support of the even-phase multi-
well pumping unit and consists of two parts: the overload protection module and the auxiliary unloading module, as shown in Figure 1.



1 - Wellhead support 2 - Overload protection module 3 - Auxiliary unloading module Figure 1: General assembly sketch of wellhead unloading protection device

(1) Overload protection module

The overload protection module consists of a vertical overload clutch and an unloadable rope suspension with two functions: automatic unloading and manual unloading. The vertical overload clutch is divided into two parts and connected by multiple pins, the lower part of which is connected to the unloadable rope suspension by a specific structure. The multiple pins connected to the overload protector reach the automatic unloading protection after the overload is disconnected due to the wellhead fault. Manual unloading is relying on the specific structure of the unloadable rope suspension, after the rope suspension is lifted a certain distance, the rope suspension is disconnected from the lower part of the overload clutch to complete manual unloading.

(2) Auxiliary uninstallation module

Auxiliary unloading module that is LPS suspension rope device auxiliary unloading device, the main role is to assist in lifting the unloadable suspension rope device, trigger the manual unloading function. This part has the following functions.

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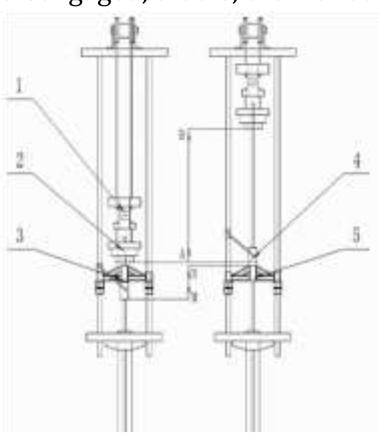
1) Auxiliary unloading limit. The auxiliary unloading limit is positioned at the time of working time such as wellhead maintenance or replacing packing, casing, adjusting punching times, etc. to disconnect from the multi-well machine to ensure that other wells can still operate normally.

2） Shift and positioning. The LPS rope suspension aid can be adjusted according to the different strokes or heights of the wellhead and fixed at the right position, with high universality.

3） Wellhead protection: LPS rope suspension auxiliary device is installed on the upper part of the oil recovery tree at the wellhead, which can ensure that the rope suspension will not hit the oil recovery tree after the flexible rope connected to the rope suspension is disconnected, resulting in problems such as oil coming out of the wellhead and component damage.

2.2. LPS rope suspension auxiliary unloading device working principle

In Figure 2 A-B path is the reciprocal motion trajectory of the unloadable rope suspension, point A is the lowest point that the rope suspension can reach, point B is the highest point. Single well normal operation, LPS suspension rope device auxiliary unloading device in a static state (Figure 2 left M point), through the limit device and positioning shift platform side of the beveled edge of the round tube with each other to achieve self-locking, to ensure that the device vibration and other factors will not be disconnected. When a single well needs to stop or replace components, the limit device in the LPS rope suspension auxiliary unloading device will be moved manually to the N point as in Figure 1, and when the rope suspension runs to the lowest point near the lower stroke, it will contact with the limit block on the limit device and be lifted up a certain distance, the rope suspension and the overload clutch will be disengaged, that is, the manual unloading is completed.



1-Vertical overload clutch 2-Dischargeable overload clutch 3-LPS auxiliary discharging device
4-Limiting device 5-Positioning and shifting platform
Figure 2: Schematic diagram of the working principle of LPS suspension rope assisted unloading device

3. Key structure design

The key structure of LPS rope suspension auxiliary unloading device includes two pieces of limit device and positioning shift platform, where the limit device serves to hold the unloadable rope suspension at the lowest point of the down stroke and trigger the unloading function, the structure is shown in Figure 3 and consists of beveled edge round tube (below), connecting rod and limit block.

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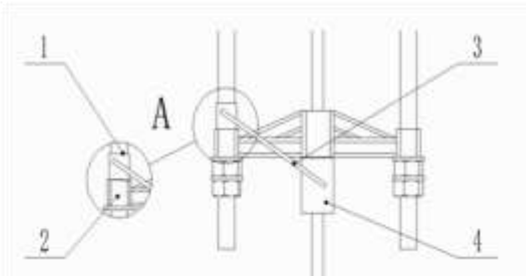

1-Bevelled round tube (bottom) 2-Bevelled round tube (top) 3-Connecting rod 4-Limiting block

Figure 3: Schematic diagram of limit device

Considering the working environment, easy disassembly and safety, it is installed in the wellhead part and designed to be rotatable and shiftable. In order to meet the working condition of rotatable shift, the limit block needs to be made into open type, so the channel steel is chosen as the limit block; the connecting rod only plays the role of connecting the two parts, so the thin steel bar or thin round steel can be used. When the limiting device is stationary, it is located in the position in Figure 3, that is, the beveled edge round pipe (below) is on the upper side of the positioning shift platform, and the limiting block is on its lower side. Considering that the limit device may be disconnected due to vibration and other external factors when it is stationary, the limit device and the round tube in the positioning shift platform are made into complementary bevels, as shown in Figure 3 at A. The two cooperate with each other to achieve self-locking.

The lower side of the positioning shift platform structure can be adjusted on the wellhead through the double nut structure to adapt to different strokes of the wellhead, and also can play a certain role in the protection of the oil recovery tree, the structure is shown in Figure 4, mainly made of round tubes and different types of square steel welded together. The positioning and shifting platform is a triangular structure with better force; a round tube is set in each of the square tubes at the end, so that the platform can move better on the screw; a large square tube is used in the middle to ensure the normal passage of the pumping rod and the coupling.

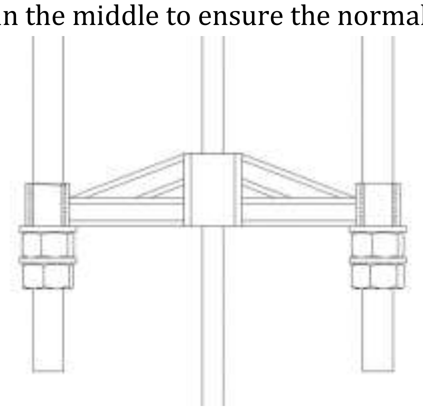

Figure 4: Positioning shift platform

4. LPS rope suspension assisted unloading device model design calculation

4.1. Structural model design of limit device

As shown in Figure 5, the limit device is only subject to the static force P from the wellhead when the limit block is in operation, and the beveled edge round tube (below) and the connecting rod only play the role of rotation and connection, so only the limit block in the limit device needs to be optimally designed.

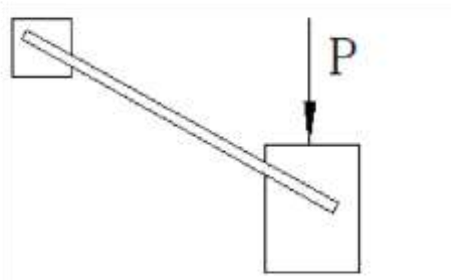

Figure 5: Limit device structure force sketch

The optimal calculation of the limit block can be designed according to the pressure bar stability. It is assumed that the limit block is a fixed end and a lateral and axial section of the lever.

By stability conditions.

P
P (1)

—
A

where: P - static force. A - cross-sectional area. φ - discounting factor.

A, φ are unknown quantities, using the trial method to determine the cross section of the compression rod, first assume φ = 0.5.

P
A (2) $_P$

After calculating the cross-sectional area A, according to the cross-sectional type and cross-sectional area A, the profile is selected for calculation. Calculate I_{min}, i_{min} and λ values according to the selected profile cross-section (I_{min} can be obtained from the mechanical design manual).

$$i_{min} = \sqrt{\frac{I_{min}}{A}} \quad (3)$$

l
—— (4)
i_{min}

where: I_{min} - minimum moment of inertia.

i_{min} - minimum radius of inertia. λ - compression flexibility or length to slenderness ratio E.

μ - length coefficient.

According to the material and the calculated λ value, find φ1 by interpolation in the table of discount coefficients of the central compression bar, and calculate the permissible pressure of the compression bar.

[P]A $_1$$_P$ (5)

If the permissible pressure [P] is much larger (smaller) than the actual pressure P, reselect the section and φ value again according to the above process, until the resulting permissible pressure [P] is close to the actual pressure P.

Take the parameters of type 2 swimming beam machine as an example, set the static pressure of the wellhead P=20690N, the permissible stress is taken as [σ_P]=160×102N/cm, and it is calculated that 5# channel steel can meet

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the design requirements, but due to the structural limitations of the positioning and shifting platform, 8# channel steel needs to be used.

4.2. Structural model design of positioning and shifting platform

The calculation of the optimal design of the displacement platform can be reduced to the selection of the rod type for the structure. The process is to simplify the positioning platform, calculate the forces of each rod according to the cross-section method, and then select the optimal rod type according to the stability calculation of the compression rod.

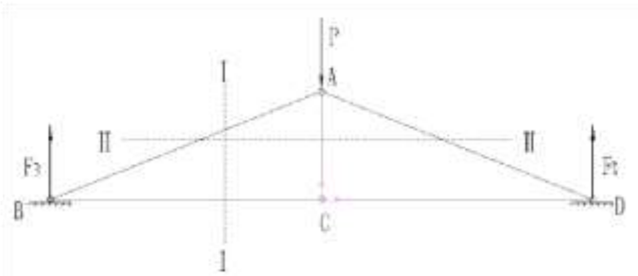

Figure 6: Sketch of the structure of the positioning and shifting platform

As shown in Figure 6, the positioning displacement platform is simplified and divided by Ⅰ-Ⅰ and Ⅱ Ⅱ, and the support reaction forces at points B and D are first calculated as follows.

y0 :

F_B F_D P0 (6)

F_B F_D (7)

P

According to (6) and (7) it can be derived: F_B F_D

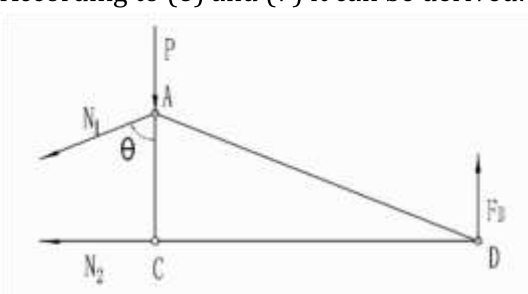

Figure 7: Ⅰ-Ⅰ section right structure

y0 :

P

PNCOS 1 (8) 2

—

M_A 0:

P

$N_2 L_{AC}$ —L_{CD} 0 (9) 2

According to (8) and (9), we can find N1 and N2.

In Figure 8, take the upper side part of section II-II.

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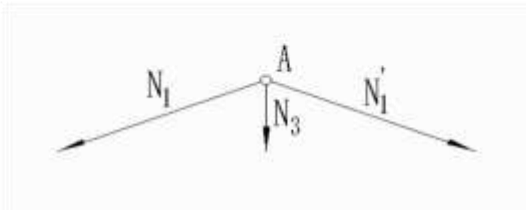

Figure 8: Structure of the upper side of section II-II

□y□0 :

N_3 □P□NCOS$_1$ □□NCOS$_1$' □□□ (10)

Ask for N3.

So far, the force of each rod is obtained, and then the optimal model of the rod is selected by the above-mentioned pressure rod stability calculation method.

Set the static pressure P = 20690N, θ = 68 °, L_{AB} = L_{AD} = 214mm, L_{AC} = 80mm, L_{BC} = L_{CD} = 198mm, calculated AB, AD, BC, CD rod using 40 × 40 × 2.5 square tube that meet the design requirements, AC rod is not stressed, according to demand can be selected.

5. Finite element analysis based on Solidworks Simulation module

To further verify the reliability of the device, a finite element model of the key components of the device was established and statically analyzed, and the finite element results were analyzed according to the strength check theory, and the strength requirements were satisfied when the maximum stress obtained from the analyzed components was lower than the allowable material stress.

5.1. Limit device finite element analysis

A Voronoi-Delaunay meshing scheme is used to generate a positive tetrahedral mesh in order to improve the adaptability of the mesh and ensure the computational accuracy. The meshing results are shown in Figure 9.

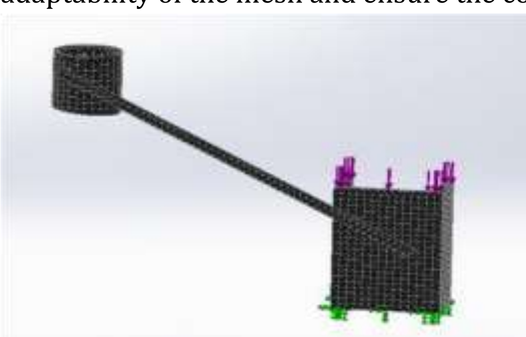

Figure 9: Schematic diagram of grid division of limit device

By fixing the bottom section of the channel steel and applying a load of 20690N at the top, the results of finite element analysis of the limiting device were obtained, with stress and strain clouds, as shown in Figure 10.

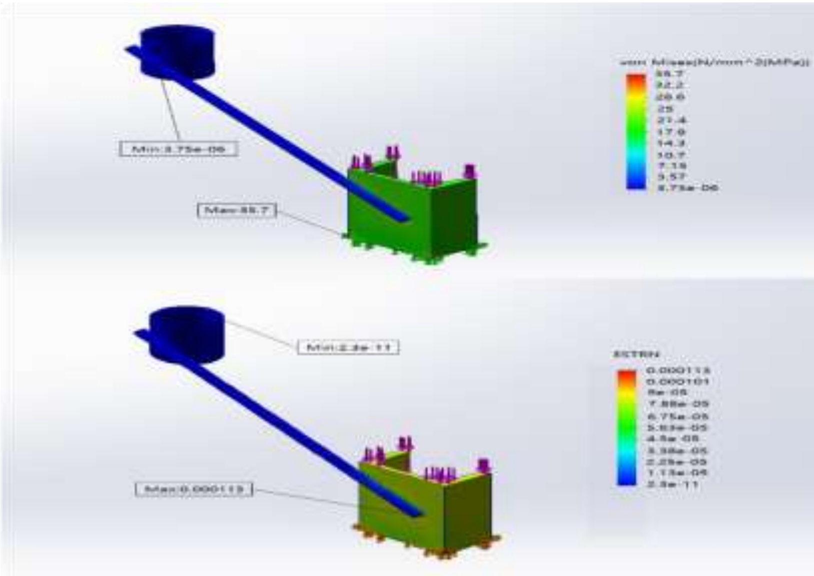

Figure 10: Stress-strain cloud diagram of limit device

The maximum stress is 35.7 MPa, which is much smaller than the yield limit of the limit block material Q235. However, since the limit device needs to cooperate with the positioning and shifting platform, the limit block structure model has been the most preferred one.

5.2. Finite element analysis of positioning displacement platform

It is an important part of the auxiliary unloading device, and its strength is a key factor affecting the success of the auxiliary unloading device test. The curvature-based meshing method built into solidworks enables it to generate more dense mesh cells at the stress concentration and stress location to ensure the accuracy of the simulation analysis, and the meshing of the platform is shown in Figure 11.

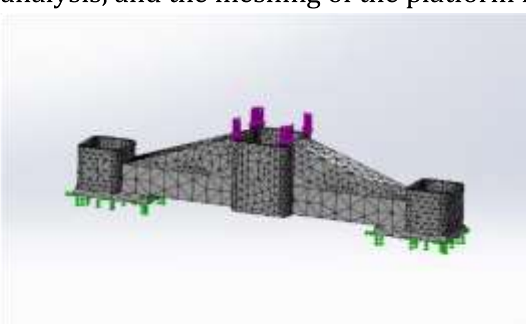

Figure 11: Schematic diagram of grid division of positioning displacement platform

The positioning shift platform was fixed at both ends and a load of 20690N was applied to the upper part of the central square tube to obtain the stress and strain clouds as shown in Figure 12.

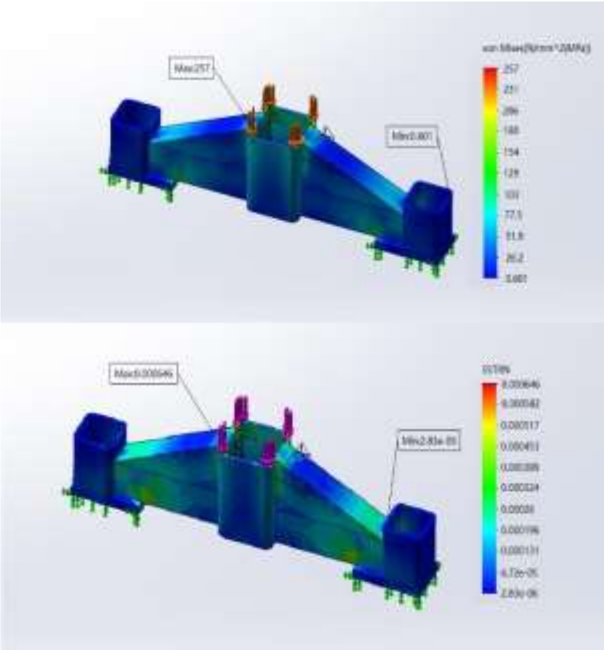

Figure 12: Strain distribution cloud of positioning displacement platform

As can be seen from Figure 12, the maximum stress value is 257MPa, and the material used for positioning and shifting platform is 45 steel with a yield limit of 355MPa and a safety factor of 1.4. The strength of the positioning and shifting platform meets the design requirements.

6. Conclusions

The auxiliary unloading function of LPS suspension rope auxiliary unloading device realizes the function of stopping the well without stopping the well when the multi-well machine system is working on the maintenance of the well set or replacing the coiled tubing and casing elements, which effectively improves the timeliness of the homogeneous phase multi-well machine operation. And the correctness of the results of the theoretical calculation is verified by comparing the calculated stress and strain clouds according to the strength calibration of the finite element software. And it shows that the strength of LPS rope suspension auxiliary unloading device meets the mechanical design requirements.

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