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Development of All-electric Discharge Device for Working String

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Abstract: Most of the existing pipe string discharge devices in China are suitable for drilling operations, but some auxiliary devices for surface pipe string discharge in workover operations are not mature enough, and there are some problems such as inconvenient transportation, complex structure and large area. Based on the actual situation of small workover operation site, this paper puts forward the scheme of all-electric discharge device for well site operation pipe string, determines the structure function and work flow of the discharge device, carries out structural design for three parts of the lift, conveying device and pipe rack, and analyzes and calculates the structural parameters of the device. Through the static analysis of the main force components, the rationality of the device design is verified, and its structural strength is in line with the safe range.

Keywords: Column discharge, All-electric, Mechanical analysis.

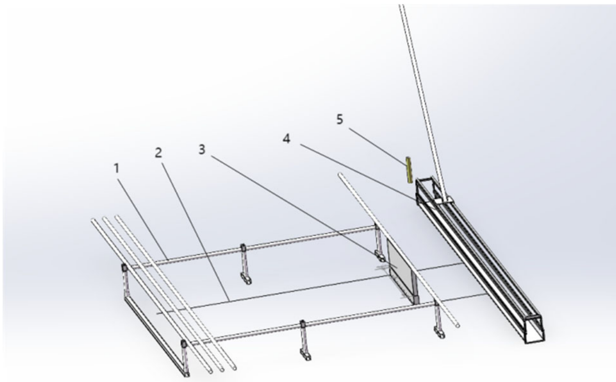
1. Introduction

For any independent country, oil and natural gas have long been particularly important strategic materials, so the smooth and stable exploitation of oil and natural gas has become a very important task, and oil and gas has special significance for the development of a country[1]. Workover is a crucial step at the operating well site. In the production process of the operating well site, a variety of problems can occur at any time and the probability of occurrence is high, and these problems can only be eliminated by workover operations. Specific faults such as tubing fracture, tubing connection trip, etc[2].

2. Structure Design and Work Flow of All-electric Discharge Device for Working Pipe String

2.1. The construction of the all-electric discharge device developed for the working string

The all-electric discharge device for wellsite operating pipe string is mainly composed of three parts: lift, conveying device and pipe rack, as shown in Figure 1, which shows the complete model of all-electric discharge device for wellsite operating pipe string. The whole device is placed on the same side of the operating wellhead, the lifting device is vertically aligned with the wellhead, the pipe rack is vertically aligned with the lifting machine, and the track of the conveying device is connected at the end of the lifting machine and the pipe rack, and is placed in the middle of the pipe rack to provide guidance for the transport device[3]. The lower two parts of the lifting machine are separated, and the electric push rod is connected. The lower body of the lifting machine provides stable support for the ground, and the electric tow rod drives the upper body movement to realize the rising and moving of the lifting machine. The conveying device is composed of a four-wheel chassis and an upper telescopic bracket, which is driven by a motor to achieve reciprocating migration on the track. The telescopic bracket is connected with the upper section of the electric push rod, and the lower end face of the electric push rod is fixed on the four-wheel chassis to realize the drag and drop function of the pipe column. The pipe rack is mainly composed of the field oil pipe splicing, supported by the bracket.

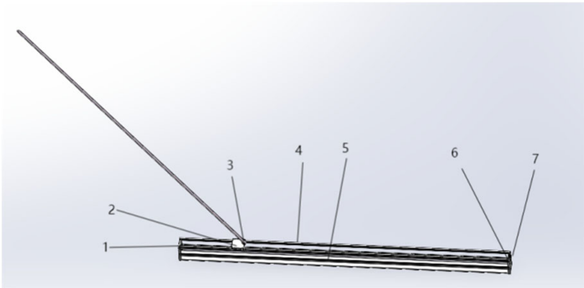


1-Pipe rack 2-Conveyor track 3-conveyer 4-lifter 5-wellhead

Figure 1. Operating string all-electric discharge device

2.1.1. lifter

When the pipe string is lifted out of the wellhead by the crane of the workover rig, the site operator pushes the end of the pipe string on the slider of the lift machine, and the lift machine starts to work. On the one hand, its core function is to realize the pipe string from the vertical state of the wellhead to the stable and safe fall to the ground. On the other hand, a single pipe string can be lifted and lowered to complete the stable, safe and low noise movement of the pipe string between the height of the conveying device and the height of the wellhead. The structure of the lifting machine is shown in Figure 2, which is mainly composed of SBR guide rail, guide slide, guide support, lifting machine body, lifting machine lower body, limiting baffle and electric push rod.

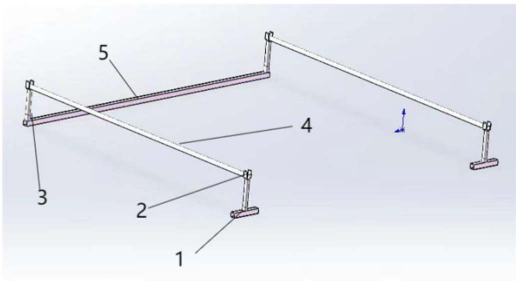


1-SBR guide rail 2- guide slide 3- guide support 4- lifting machine body 5- lifting machine lower body 6- limit baffle 7- electric push rod

Figure 2. Elevator structure

2.1.2. Pipe rack

The pipe rack is a device to store the pipe string in the all-electric discharge device of the pipe string operating in the well site, and bears the weight of the pipe string[4]. During the operation of the well site, the placement of the pipe rows on both sides should ensure that they are parallel and corresponding to the position of the elevator. The total length of the pipe rows is 9.7m and the height is 1m. The front and rear support frames of the pipe rack can be flexibly disassembled and assembled, and can be added or reduced according to the actual operation situation of the well site. The specific structure of the pipe rack is shown in Figure 3.

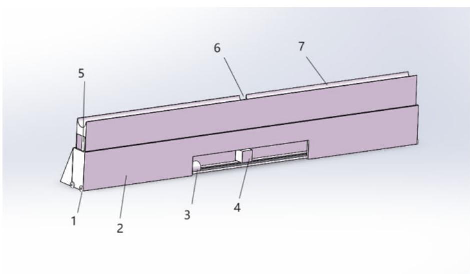


1- Front support frame 2- fixing bolts 3- Rear support frame 4- tubing 5- Positioning connecting rod

Figure 3. Row pipe frame structure

2.1.3. Conveyer

The main function of the conveying device in this paper is to transport the pipe string safely and stably, to realize the stable transport of the pipe string from the lifting machine to the pipe rack, or the pipe string from the pipe rack to the lifting machine[5]. The overall structural weight of the conveying equipment is 100kg, based on the oil pipe. The weight of the column is 183kg, the overall weight is 283kg, and the distance of the transport is about 11m. The general structure of the conveying device is shown in Figure 4, which is mainly composed of conveying wheel, conveying chassis, motor, remote control module, electric push rod, sensor and bracket.



1- Conveyor wheel 2- Conveyor chassis 3- Motor 4- Remote control module 5- electric push rod 6- Sensor 7- bracket

Figure 4. Conveyor structure

2.2. Work flow of all-electric discharge device for working string

The all-electric discharge unit is divided into two workflows, that is, into the pipe and out the pipe. The working flow charts of the inlet and discharge columns are shown in Figure 5 and Figure 6 respectively. The expansion and contraction of the motor in Figure 5 and Figure 6 are controlled by the remote control.

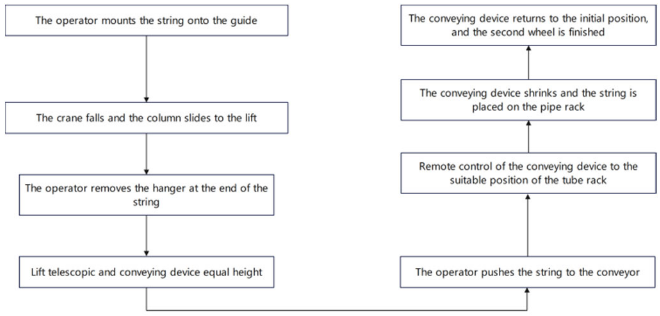


Figure 5. Discharge column workflow

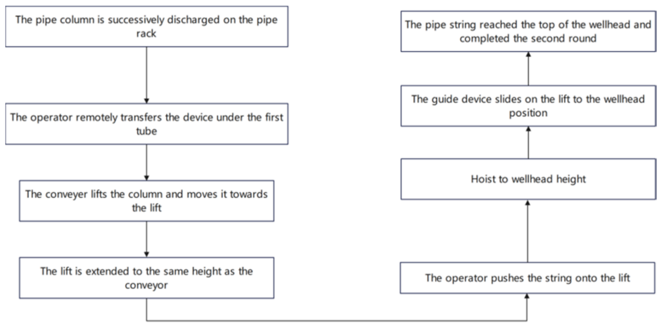


Figure 6. Work flow of the pipe column

3. Mechanical Analysis

3.1. Mechanical analysis of lift

Lifting and dropping the string is one of the key steps in the execution of the string discharge task. According to the previous weight analysis of different types of pipe strings, the load borne by the lift is the largest when transporting the pipe with an outer diameter of 114mm, and the load weight of a single pipe can reach 253.17kg. If the main components of the lift are not strong enough during lifting, the equipment may be damaged and the string may slip, resulting in a failure to ensure its safety[6]. Therefore, we have carried out a detailed force analysis on the key components of the lift, and carried out the corresponding verification.

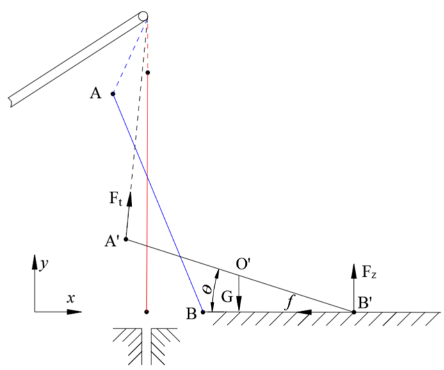


Figure 7. Force analysis of the lift when the tube column and guide rail form θ Angle

The pipe column and the lift frame are regarded as one unit respectively, and their mechanical analysis is carried out, as shown in Figure 7. When the pipe string is not completely flat on the support of the lifting machine, one end of the pipe string is always connected with the crane crane, and the pipe string is always subjected to the traction of the crane. Therefore, the force exerted by the pipe string on the lifting machine changes with the Angle θ between the falling and the ground. The plane force system is decomposed and the equilibrium equation is listed, where θ=84.14 degrees. G=2489.38N, the following equation can be obtained by calculation:

$$\sum F_x = F_{sx} - f = 0 \tag{1}$$

$$\sum F_y = F_{sy} + F_z - G = 0 \tag{2}$$

$$\sum M_{A'} = F_z \cos\theta - fl\sin\theta - G\frac{1}{2}l\cos\theta = 0 \tag{3}$$

$$F_z \bullet \cos\theta - f\sin\theta - \frac{1}{2}\bullet G\cos\theta = 0 \tag{4}$$

$$f = \mu F_z \tag{5}$$

$$\mu = 0.02 \tag{6}$$

$$F_z = \frac{\cos\theta}{2\cos\theta - 2\mu\sin\theta} \tag{7}$$

After calculation and derivation, it can be seen from the above formula that θ and Fz are functional relations, and the function image is shown in Figure 8 below. With the increasing θ Angle, Fz shows an upward trend. When the pipe string just contacts the lift, Fz reaches its maximum value, Fzmax=768.9N.

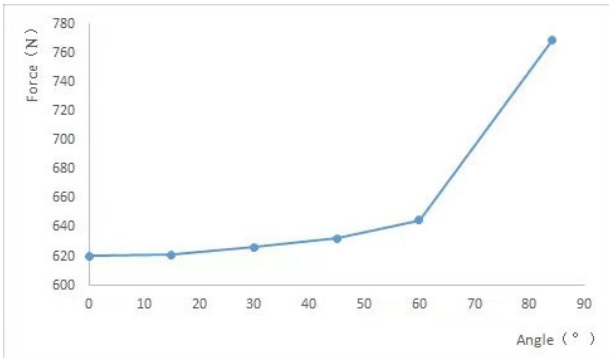


Figure 8. Relationship between θ Angle and Fz function

$$\tau = \frac{Fz}{A}\bullet S \le 178\text{Mpa} \tag{8}$$

Through calculation, the maximum shear stress of SBR guide rail is 4.89Mpa, which is smaller than the allowable shear strength of alloy guide rail 178Mpa. The stress subjected to SBR guide rail is within a reasonable range and meets the requirements of the lift for structural strength. The specific stress distribution can be obtained through the subsequent static simulation.

3.2. Mechanical analysis of pipe rack

The pipe rack on both sides jointly bears 50 tubing with an outer diameter of 114mm, and its total weight M=9166kg. In order to ensure the safety of the job site and the smooth operation, a group of support frame is added in the middle of the beam. Therefore, the weight of the pipe column borne by the single pipe rack is 0.25M=2291.5kg, and the acceleration of gravity g=9.8m/s^2. Ideally, the load bearing capacity of a section of beam is:

$$G = \frac{1}{4}Mg \tag{9}$$

The stress diagram of a single beam on the pipe rack is shown in Figure 9.

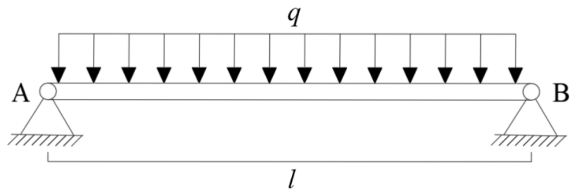


Figure 9. Stress analysis of beam

Point A is the support point of the front support frame of the beam, point B is the fulcrum of the back support frame of the beam, and the distance of section AB is 9700mm. At this time, the force is a static problem, and the column load is the ideal distribution force, so it is set as the uniform distribution load.

The bending moment diagram can be obtained by combining the equation calculation, as shown in Figure 10:

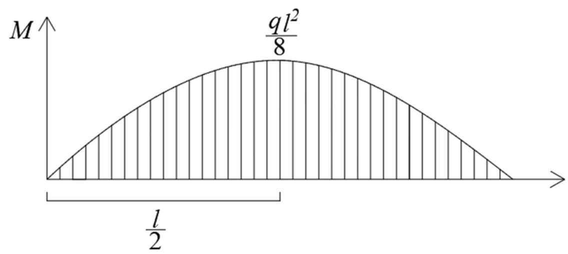


Figure 10. Bending moment diagram of beam

According to the bending moment diagram of the cross beam of the pipe rack above, it can be seen that the maximum bending moment Mmax=13613646N▪m, so it can be seen that the dangerous cross section of the cross beam is in the middle of the beam. The pipe rack has a beam in the middle of the beam. In order to facilitate the field operation, the cross beam of the pipe rack adopts the oil pipe of the operation well site, and the maximum normal stress of the dangerous section is:

$$M_{\max} = \frac{ql^2}{8} \tag{10}$$

$$W = \frac{\pi \bullet D^3(1\text{-}\alpha^4)}{32} \tag{11}$$

$$\alpha = \frac{d}{D} \tag{12}$$

$$\sigma_{\max} = \frac{M_{\max}}{W} \tag{13}$$

In the formula, W-is the bending section coefficient, and the calculation shows that W=129708mm^{3}.

The values are substituted into equation 10, and the final result is $\sigma_{\max} = 105$Mpa.

The yield strength of Q345 is 345MPa, then the allowable stress of the material is:

$$[\sigma] = \frac{\sigma}{S} \tag{14}$$

Where: S -- the safety factor of the material, S=2.

By substituting the value into equation 14, it can be seen that $\sigma_{\max} = 117.5$MPa is obtained from the bending stress strength condition of the cross beam of the pipe rack. Therefore, the strength of the selected tubing meets the requirements and can bear the maximum load of the pipe column.

4. Simulation Analysis of Lifting Device

The main force part of the lift is the rod, so the finite element analysis of the rod. In order to simplify the whole analysis and calculation process and improve the calculation speed, we first use the software to divide the grid, and carry on the preliminary analysis and simulation of the whole model of the lift[7]. We observed the maximum strain and maximum stress positions in the results, and then meticulously meshed the individual components in the region and performed an in-depth analysis.

Set the material of this model as Q345 in the material library, and its specific parameters are shown in Table 1:

Table 1. Performance parameters of the Q345

Materials	Density (kg/m^3)	Modulus of elasticity	Poisson's ratio	Yield strength
Q345	7850	200~210	0.25~0.33	345MPa

After selecting the appropriate material, we proceed to the DesignModeler module and apply the appropriate load to the raised string support position, which is vertically downward and the applied force F=2482N. During the analysis, we set a friction coefficient of 0.1 between the base and the upper bracket, guide rail and guide device, and added a fixed constraint condition when the base was off duty.

(1) Deformation cloud map analysis of the lift

After the overall calculation of the system, the deformation and displacement cloud map of the lift is obtained. As shown in Figure 11, it can be observed that the main deformation of the lift is concentrated in the middle region of the slide rail, and its maximum shape variable reaches 10.205mm, and the deformation value is within a safe range.

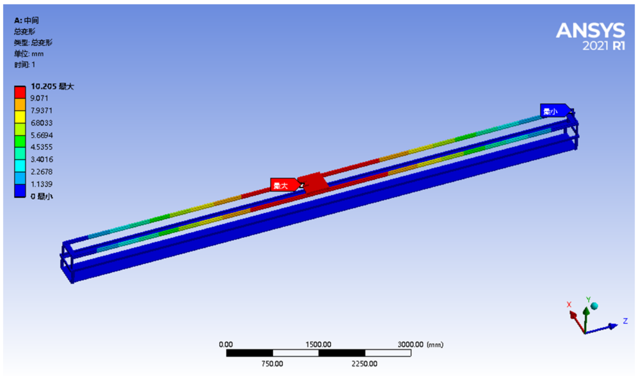


Figure 11. Cloud image of lift deformation and displacement

(2) Stress nephogram analysis of the lift

By running ANSYS analysis examples, the stress cloud diagram of the bar is calculated, as shown in Figure 12. As can be seen from Figure 12, the maximum stress of the model occurs at the connection between the bracket and the guide rail. The maximum stress value is 138.13MPa, which is close to the calculated value of $[\sigma] = 117.5$MPa above and less than the yield strength of the material of 345 MPa.

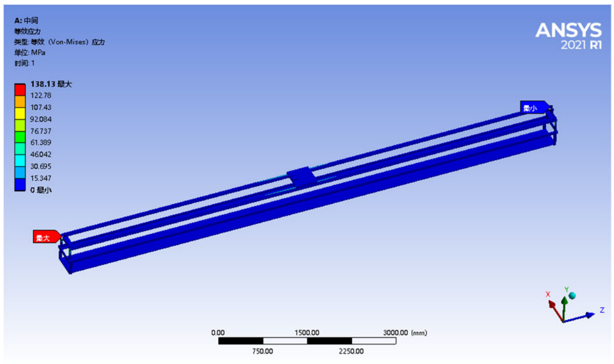


Figure 12. Stress cloud diagram of the lift

5. Conclusion

(1) Design and complete the structural design of the lift, conveying device and pipe rack according to the working requirements and actual conditions of the all-electric discharge device of the pipe column. Through the position treatment, lifting, conveying and lowering of the pipe column, the purpose of all-electric pipe row is achieved, the labor force is reduced, and the operation safety is improved.

(2) The force analysis of the lifting machine and the pipe rack is made respectively. The maximum stress point is the contact point between the support and the guide rail, and the maximum value is 138.13MPa, which is less than the yield strength of the material.

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