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Study on C-type Frame based on Drilling Derrick Pin Disassembly Mechanism

Changbiao Yang[1], Feifan Xu[2], Haihong Li[1], Xuemei Jin[1]✎, Yinghui Zhang[1]

[1]PetroChina Chuanqing Drilling Engineering Co., Ltd. Institute of Safety and Environmental Protection Quality Supervision and Inspection, Guanghan 618300
[2]PetroChina Chuanqing Drilling Engineering Co., Ltd., Chengdu 610000

Abstract: In oil and gas exploitation, the derrick is used to place the crane, hanging carriages, as well as carrying a variety of heavy equipment.The derrick mainly contains the body of the derrick, the crossbeam, and the tension bar, which are connected together by the pin shaft.After drilling operations, the derrick pin needs to be removed manually.However, due to the high operational risk and high cost of pin removal.Therefore, there is an urgent need to find a safer method for pin removal.In this paper, a new method of safe pin disassembly is proposed.After lifting the robotic arm and the pin ejector mechanism to a specified position by using a lifting device, the robotic arm is connected to the pin ejector mechanism by quick-change and arrives at the specified operating position, and the pin ejector mechanism is activated to eject the pin.Since the robotic arm and lifting device are standardized products, their reliability meets the requirements.However, the C-frame in the ejector mechanism is mainly used to counteract the reaction force of the pin on the ejector mechanism, and the reliability of this structure has a direct impact on the entire workflow.Therefore, In this paper, the reliability of C type is verified from two aspects of stress and deformation by static analysis.Then, the C-frame structure is topologically optimized, and the optimized structure not only meets the reliability requirements but also achieves the weight reduction of the mechanism.This research further promotes the construction of smart oilfields and can also provide reference value for other engineering fields.

Keywords: Derrick Pin Shaft,Automatic Disassembly,Ejection Mechanism,Topology Optimization

1. Introduction

As one of the major sources of energy in the world, the efficient and reliable development of oil and gas is crucial to maintaining the economic development and energy security of all countries. In the process of oil and gas development, the oil rig derrick, as a device for placing the overhead crane, hanging rover, big hook and carrying all kinds of heavy loads in the drilling operation. It undertakes the task of ensuring the drill bit to smoothly dig the hole underground to obtain oil and gas.The derrick mainly contains the derrick body, crossbeam, and tension bar, which are reliably connected by pins. Before and after the drilling operation, it is necessary to install and remove the derrick pins manually, so as to realize the installation and removal of the derrick.In the past few decades, the disassembly and assembly of oil rig derricks has been dependent on a large amount of manual input, and involves the operation of heavy machinery and high-altitude operations, which not only increases operating costs, but also limits operating efficiency and safety.Moreover, human operation is susceptible to the influence of the external environment, such as bad weather and complex terrain, which further increases the risk and difficulty of the operation.Therefore, there is an urgent need to find a safer pin removal method in order to improve the efficiency, safety and reliability of oil rig derrick removal.

With the development of material, computer and electronic technologies, electromagnetic actuators have been widely used in new energy vehicles, aerospace and intelligent robots.However, due to its insufficient dynamic stiffness, its application in high-precision servo control systems is limited[1-4].Therefore, it cannot be used in the complex environment of the oil field.The linear actuator is also known as the electric push rod. The linear actuator converts the rotational motion of the motor into a linear reciprocating motion of the screw through the screw mechanism, and has a certain thrust.Using the thrust generated by the linear actuator to eject the derrick pin has the advantages of simple operation, low noise and stable ejecting process compared with using the traditional impact force to eject the pin.At present, linear actuators are mainly used in the medical field and office field. It is a great innovation to use linear actuators in the disassembly of derrick pins.However, the use of linear actuators in engineering fields with complex environments requires higher demands on the control performance of linear actuators.For example, during the ejection of the derrick pin shaft, the thrust of the linear actuator needs to be adjusted adaptively according to the actual state of the pin shaft.The linear actuator is initially only open and closed in two states, unable to speed and control the thrust.Recently, more and more linear actuators use PWM technology for speed regulation, but this method has low control accuracy and can only

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✎ Xuemei Jin (Correspondence)
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meet the requirements of low field, which is not conducive to the field application of petroleum engineering[5].Song et al[6].studied the logic control of multiple linear actuators by using PLC as the controller, and realized the independent control of each linear actuator.Zhou et al[7].designed a linear actuator control system by using PID control technology. Under the action of the control system, the linear actuator can achieve the effect of precise control and simple control.Han et al[8].designed and fabricated a linear actuator control system by using DSP control technology, which further promoted the development of linear actuators.

Structural topology optimization is an advanced engineering design method, which is mainly used in the field of structural design to achieve the purpose of reducing structural quality and improving structural performance.By optimizing the distribution of materials in a given design space, this method minimizes the structural weight and material cost while achieving the predetermined performance objectives.In the process of structural topology optimization, the working environment and load conditions of the structure should be set first, as well as the performance indicators that need to be met, such as strength, stiffness, frequency response, etc.Then, by setting the optimization objectives and constraints, such as the amount of material, and then using the optimization algorithm to find the best distribution of materials.In addition, structural topology optimization is also closely related to modern manufacturing technology, especially additive manufacturing (3D printing). Additive manufacturing can produce complex geometric shapes that are difficult to achieve by traditional methods, which makes the structure after topology optimization easier to manufacture[9].In general, structural topology optimization is a cutting-edge and efficient design method, which achieves performance optimization and cost minimization by precisely controlling the use and distribution of materials[10].In this paper, the topology optimization of the existing C-frame is carried out to obtain a C-frame with better performance and lighter weight, so as to reduce the load of the manipulator and improve the reliability of the operation.

In this paper, a new method of automatic pin disassembly based on linear actuator is proposed: after lifting the robotic arm and the pin ejector mechanism to the specified position by using the lifting device, the robotic arm is connected to the ejector mechanism and reaches the specified operation position by means of quick-change to activate the linear actuator in the ejector mechanism to eject the pin. Then, the C-frame structural member in the method was numerically analyzed statically to guarantee the reliability of the structure. Finally, the C-frame structure is topologically optimized, and the optimized structure not only meets the reliability of use but also achieves the purpose of weight reduction of the mechanism.The method can not only significantly improve the derrick removal efficiency, thus shortening the drilling cycle, but also reduce the operational risk and protect the life safety and health of the operating personnel. This research further promotes the construction of smart oilfield while improving the derrick disassembly efficiency, reducing the operation cost, and safeguarding the safety of personnel, and can also provide reference value for other engineering fields.

2. Automatic disassembly process of derrick pin shaft

The overall process of automated derrick pin dismantling operation is as follows: 1) Lifting device is used to lift the robotic arm and pin ejector to the specified position; 2) The robotic arm is connected to the ejector by quick-change and arrives at the specified operation position; 3) The ejector is activated so as to eject the pin.

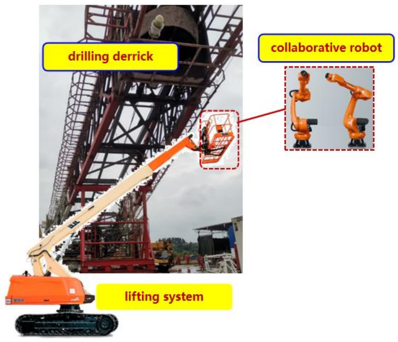

Fig 1. Automatic disassembly of pin shaft

Fig.2 is a schematic diagram of the pin ejection mechanism, including C-frame, linear actuator and linear actuator protection shell. Among them, the linear actuator is used to generate sufficient jacking force to achieve the purpose of ejecting the pin shaft ; the C type frame is used to counteract the reaction force of the pin shaft on the ejection mechanism when the linear actuator is working. The linear actuator protection shell separates the linear actuator from the external environment to prevent the linear actuator from being damaged.

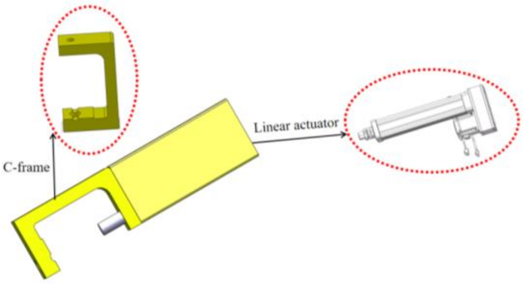

Fig 2. Pin shaft ejection mechanism

As shown in **Fig.3**,when the pin shaft is ejected, the C-type frame in the pin shaft ejecting mechanism is first stuck at the upper and lower ends of the pin shaft, and the pin shaft axis is collinear with the push rod axis of the ejecting mechanism, and then the lower end of the C-type frame is attached to the lower end of the binaural plate. Start the linear actuator, and the linear actuator ejector rod is slowly pushed out and the pin shaft is pushed out from the ear plate. During the actuation, the reaction force generated by the pin shaft to the ejecting mechanism is transmitted to the ear plate through the C-type frame, which avoids the ejecting mechanism from bearing a large reaction force.

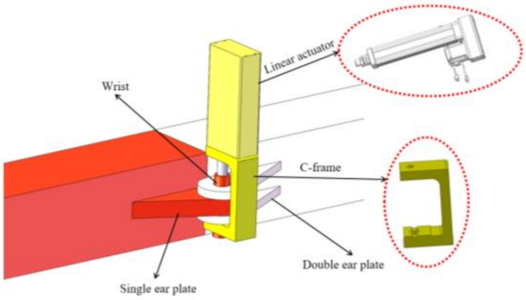

Fig3. Pin disassembly schematic diagram

3. Numerical analysis of mechanical properties of C-frame

It can be seen from Section 2 that in the pin ejection operation, the C-type frame is the key structure of the reaction force transmission, and its mechanical properties are directly related to the reliability of the entire ejection operation. Therefore, this section will conduct a numerical analysis of the mechanical properties of an existing C-frame, and the analysis results will provide a basis for the performance evaluation, structural optimization and experimental verification of the existing C-frame.

3.1 The establishment of numerical analysis model of C-frame

The actual geometric structure of the C-type frame is shown in Fig.4.After the geometric model is imported into the finite element analysis software, the material parameters are set. There are two types of C-type frame, one is 45 steel material C-type frame and the other is 7075 aluminum alloy material C-type frame. The specific material parameters of these two materials are shown in **Table 1** and **Table 2**.

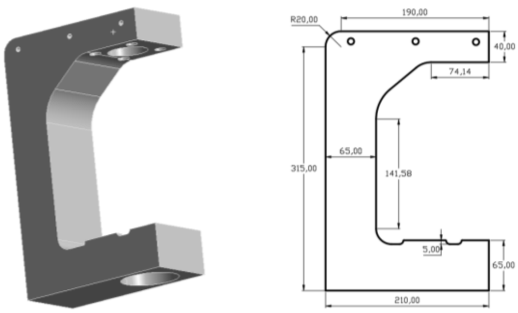

Fig 4. C-frame geometric model

Tab 1. material parameters of 45 steel

Density (kg/m^3)	Young's Modulus(Pa)	Poisson's Ratio	Bulk Modulus(Pa)
7890	2.12e+11	0.269	1.5296e+11

Tab 2. material parameters of 7075 aluminum alloy

Density (kg/m^3)	Young's Modulus(Pa)	Poisson's Ratio	Bulk Modulus(Pa)
2800	7.1e+10	0.33	6.9608e+10

To mesh the C-frame, a tetrahedral mesh is used in this paper, and the mesh parameters of the non-critical region are set larger and the mesh of the critical region is set denser to reduce the total number of meshes without affecting the calculation results. As shown in **Fig.5**, this meshing is divided into 281048 cells and 398849 nodes.

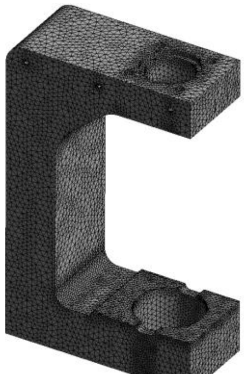

Fig 5. Model meshing results

After the meshing is completed, the boundary conditions of the model are set, and the boundary conditions of the fixed support (full constraint) are applied to the four bolt holes on the upper surface and the upper surface of the C-type frame. Since the linear actuator of this type can produce a maximum jacking force of 10000 N, a 10000 N force boundary condition is applied to the lower surface of the C-frame, as shown in **Fig 6**.

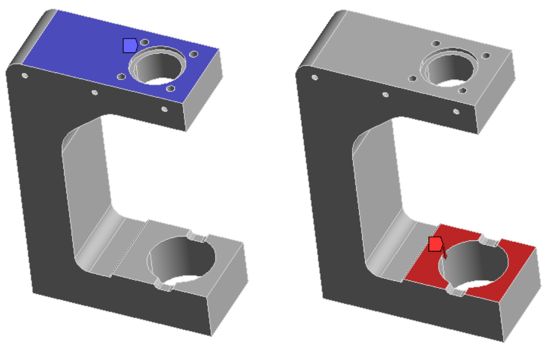

Fig 6. boundary condition setting

3.2 Results and discussion

Solve the appeal model, in which the deformation and stress solution results of 45 steel C-frame are shown in **Fig. 7**.

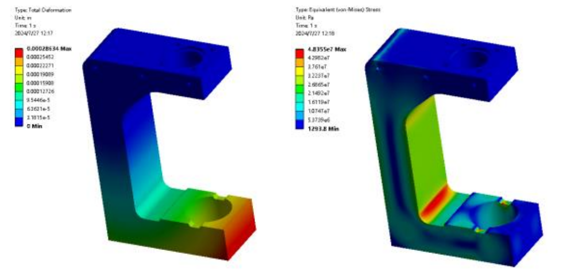

Fig 7. 45 steel C-frame solution results

According to the solution results, the maximum deformation of the 45 steel C-frame is 0.287 mm, which occurs at the lower end of the C-frame. The maximum equivalent stress appears at the bending part of the lower end of the C-frame. The maximum equivalent stress is about 48 MPa, which is less than the yield limit of 45 steel material 355 MPa. The results show that the maximum deformation of the structure meets the requirements, the maximum stress is less than the limit allowable stress, and the structure is safe and reliable.

The results of deformation and stress of 7075 aluminum alloy C frame are shown in 8 :

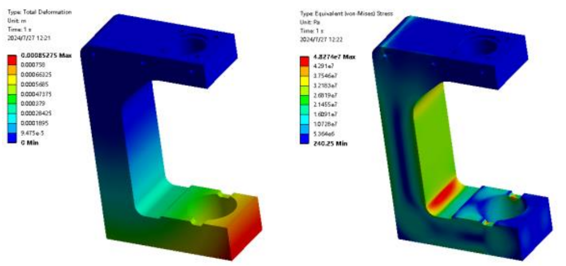

Fig 8. 7075 Aluminum Alloy C-Frame Solution Results

According to the solution results, the maximum deformation of the 7075 series aluminum alloy C-frame is 0.853 mm, which occurs at the lower end of the C-frame. The maximum equivalent stress occurs at the bending part of the lower end of the C-frame, which is about 48 MPa, which is less than the yield limit of the 7 series aluminum alloy material 455 MPa. The results show that the maximum deformation of the structure meets the requirements, the maximum stress is less than the limit allowable stress, and the structure is safe and reliable.

In summary, the maximum stress of 45 steel C-shaped frame and 7075 series aluminum alloy C-shaped frame is about 48 MPa under the action of maximum top force, which is less than the yield limit of its corresponding material. The maximum deformation of 45 steel C-shaped frame is 0.287 mm, the maximum deformation of 7075 series aluminum alloy C-shaped frame is 0.853 mm, and the maximum deformation of 7075 series aluminum alloy C-shaped frame is about 3 times that of 45 steel C-shaped frame. Although the maximum deformation of 7075 series aluminum alloy C-frame is about 3 times that of 45 steel C-frame. However, since the maximum deformation of 0.853 mm does not affect the reliability of the C-type frame, and considering that the quality of the 7075 series aluminum alloy C-type frame is 64.5 % lighter than that of the 45 steel C-type frame. Therefore, it is suggested that 7075 series aluminum alloy should be selected as the processing material of C-frame.

4. Research on structural optimization of C-type frame

The topology optimization of the C-type frame structure in the 3 summary is studied, and the quality is used as the corresponding constraint of the optimization, and 50 % of the quality is retained. As shown in **Fig 9**, after 14 iterations, the convergence condition is reached and the iteration is completed.

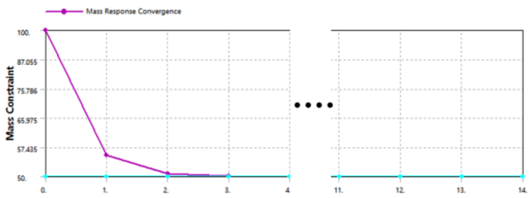

Fig 9. Iterative information

Considering the processing, practicability and installation of the structure, the optimized structure is further processed, and the final optimization model is obtained as shown in Figure 10. Since the structure volume before optimization is 0.003127 m3, and the final model volume is only 0.00246 m3, the optimized structure mass is reduced by 22.4 %.

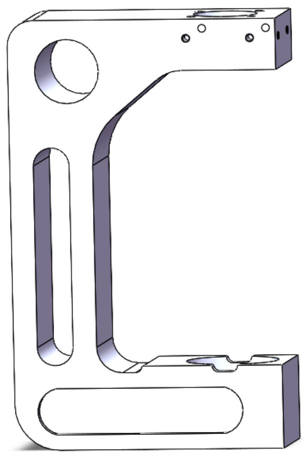

Fig 10. Optimized C-frame structure

Numerical analysis of the optimized structure is carried out to ensure the reliability of the structure, and the material parameters, boundary conditions and other settings are the same as in Section 3.1. The optimized model is meshed with tetrahedral mesh. The mesh is divided into 296211 cells and 425568 nodes, as shown in Fig. 11.

Fig 11. Optimized C-frame meshing.

The deformation and stress solution results of the optimized 45 steel C-frame are shown in Figure 12 :

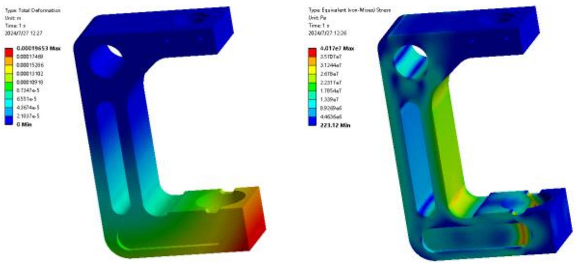

Fig 12. Optimized 45 steel C-frame solution results

According to the solution results, the maximum deformation of the optimized 45 steel C-frame is 0.197 mm, which occurs at the lower end of the C-frame. The maximum equivalent stress appears at the bending part of the lower end of the C-frame. The maximum equivalent stress is about 40.2 MPa, which is less than the yield limit of 45 steel material 355 MPa. The results show that the maximum deformation of the optimized C-type frame meets the requirements, the maximum stress is less than the limit allowable stress, and the structure is safe and reliable.

The deformation and stress solution results of the optimized 7075 series aluminum alloy C-frame are shown in **Fig 13** .

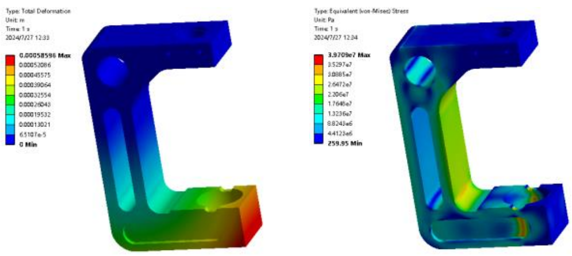

Fig 13. The results of the optimized 7075 series aluminum alloy C-frame are solved

According to the solution results, the maximum deformation of the optimized 7075 series aluminum alloy C-frame is 0.586 mm, which occurs at the lower end of the C-frame. The maximum equivalent stress occurs at the rounded corner of the lower end of the C-frame, which is about 39.7 MPa, which is less than the yield limit of the 7 series aluminum alloy material 455 MPa. The results show that the maximum deformation of the structure meets the requirements, the maximum stress is less than the limit allowable stress, and the structure is safe and reliable.

In summary, under the action of 10000 N force, the maximum stress of the optimized 45 steel C-frame and 7075 series aluminum alloy C-frame is about 40 MPa, which is less than the yield limit of the corresponding material. The maximum deformation of 45 steel C-shaped frame is 0.197 mm, the maximum deformation of 7075 series aluminum alloy C-shaped frame is 0.586 mm, and the maximum deformation of 7075 series aluminum alloy C-shaped frame is about 3 times that of 45 steel C-shaped frame. Under the condition of full load, the maximum stress and deformation of the optimized C-type frame meet the requirements, and the mass is reduced by 22.4%, which achieves the purpose of structural weight reduction.

5. Conclusion

In this paper, for the derrick pin disassembly problem, firstly, an automated derrick pin disassembly program is proposed instead of manual operation. Then a static numerical analysis is carried out for the C-frame in the automatic pin dismantling mechanism, and the stress and deformation of the C-frame are analyzed under full load. Finally, the structural topology of the C-frame was optimized to reduce the mass of the structure. The main conclusions drawn in this paper are as follows:

(1) The stress and deformation of 45 steel C-shaped frame and 7075 series aluminum alloy C-shaped frame under ultimate load are analyzed by establishing the static analysis model of C-shaped frame. The results show that the maximum stress of both is less than the allowable stress of the material, and the maximum deformation of both is within the allowable range.

(2) The maximum deformation of 7075 series aluminum alloy C-frame is three times that of 45 steel C-frame. Considering various factors, it is recommended to use 7075 series aluminum alloy as the processing material of C-frame.

(3) The topology optimization of the existing C-frame model is carried out, and the static numerical analysis of the optimized structure is carried out. The results show that the maximum stress and deformation of the optimized C-type frame meet the requirements under the condition of full load, and the mass is reduced by 22.4 %, which achieves the purpose of structural

weight reduction.

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