Energy Saving Research of New Load Reducer and Fatigue Life Analysis of Key Components

Yongjun Hou [1], Fangyuan Zhong [1,a], Zhengbin Xu [2]

[1]School of Mechanical Engineering, Southwest Petroleum University, Sichuan Chengdu 610500, China;

[2]The Fifth Oil Production Plant, Dagang Oilfield, Tianjin, 300280,China.

[a] 573481867@qq.com

Abstract

with the further exploitation of oil fields, the pumping depth of the well is limited.It has a certain restriction on the depth of the pump,the weight of sucker road and the rated load of pumping unit ,which will cause the low efficiency of the pumping unit, large energy consumption and high cost. The pumping load reducer can effectively descrease the polished load of pumping unit. It transfers the polished load to the tubing so that the minimum load of the polished load is reduced to zero, and the maximum load is reduced to the original minimum load. The load reducer has the advantages of saving energy, reducing load and deepening the pump, with high value of application. The main component of the axial load of pumping unit is the middle joint, which has alternating stress in the course of work, so it can cause fatigue damage and bring about hidden dangers. The static analysis of the middle joint is carried out by using ANSYS Workbench, and the fatigue life analysis is carried out with the fatigue analysis module (Fatigue, Tool). The results show that the allowable safety factor of the intermediate joint is smaller than the fatigue safety factor, and meets the requirement of use.

Keywords

Load Reducer; Energy Saving; Middle Joint; Fatigue Life Analysis.

1. Introduction

Sucker rod pumping equipment which is the earliest lifting equipment mainly consists of three parts:pumping unit, sucker rod and subsurface pump. Therefore, sucker rod pumping system is widely used in oilfields and plays an important role. However, it has some defects, such as low efficiency, poor balance ,energy dissipation ,large consumption and high cost in rod pumping system. with the further exploitation of oil fields, many poor reservoir burial depth, poor permeability and poor water injection effect are gradually developed, which are mainly exploited by small pump deep pumping. At present, the small pump is limited by a certain deep pumping technology. At present, small pump deep pumping technology has been limited, mainly under the pump depth , the development of the oil field is not met, which will result in large energy consumption, low efficiency and high cost. In order to solve the problem of sucker rod pumping system, we need to design a load reducing device for pumping unit downhole tools. The load reduction device has the functions of load reduction, energy saving and deep pumping. Have installed load reducer,the rod pumping system can take advantage of the existing oil rod pumping equipment to reduce the pumping unit horsehead suspension point load, reduce energy consumption, deepen pump for deep pumping, so as to improve oil production.

In the field, the load reducing device has been well applied and achieved better results. Load reducer reduces the flexibility of the sucker rod, weakening the influence of the oil pump, improving the pump efficiency and economic benefits. For example: in June 2000, Zhongyuan Oil Field Production Institute of petroleum engineering technology applied a down-hole load reduction energy-saving technology [1]; In June 2003, Shengli Oil Field and Dongpu Oil machinery co., LTD cooperation promote the application of pumping unit load shedding device[1]; In November 2006, the NO.3 factory in Zhongyuan Oil Field installed the load reducer pumping unit in the WC2-38 wells[2];In 2010, Huabei Oil Field applied seven wells at the construction site and the success rate was 100% by using the reduce device[2]. Pumping unit load shedding device significantly reduced the pumping unit horsehead suspension point load, to solve the existing pumping equipment load rating and polished rod string overweight problems[2].

At present, the energy saving technology of pumping unit is relatively mature, in which the pumping unit load reduction device is a good way to save energy. However, there is a big difference in the energy saving effect of the existing loader. But the loader is limited by the pressure difference, and further restrict the energy saving effect of the load reducer. In order to solve the above problems, a new load reduction device is designed. Pumping unit load reduction device is a new type of downhole tool, is also an energy-saving equipment.It is used in conjunction with downhole equipment to better match the use of underground tools, ground equipment, so that the energy efficiency of the loader to achieve the best. schematic diagram of existing load reducer structure is shown in figure[2], as shown in figure 1-1.

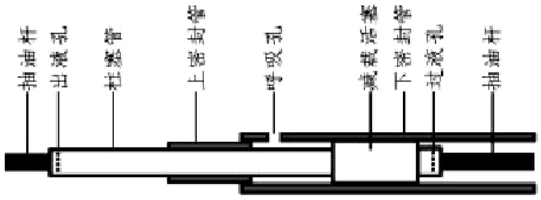

Figure 1-1. schematic diagram of existing load reducer structure

2. Scheme Design and Working Principle

The structure of the pumping loader is composed of five parts, which are the outer tube, the fixed pulley, the wire rope, the sucker rod and the pumping pump. The structure diagram is shown in Figure 2-1. With the exploitation time of oil field prolonged, the liquid surface depth of reservoir will cause severe shortage of liquid supply, which requires deep pumping of small pump. However, the rated load of pumping unit and the weight of sucker rod will influence the deep pumping of small pump, which will cause the depth of pump to be limited, and the energy consumption of pumping unit will increase, even when the pumping unit can not be continuous

production. The pumping loader is a very effective downhole load shedding device that allows the abovedeficiencies to be improved.

The load reducing device is a downwhole tool, which has the characteristic of simple structure, convenient installation, etc., and has the advantages of reducing suspension load, deepening pump hanging and reducing energy consumption, etc. It is the use of the principle of balance, the sucker rod and tubing is divided into two parts, so that the load of the sucker rod close to the balance, and then use the pulley to the pumping unit load load to the tubing, reduce the hanging load, The drop stroke is reduced by one-half of the pump stroke. When the pumping stroke is down, the plunger is running upward, and the weight of the lower part of the liquid is equal to the weight of the upper rod, and the minimum load of the donkey is reduced and close to zero. When the pumping stroke is up, The plunger is operated downward, and the weight of the upper rod is subtracted from the weight of the lower rod so that the maximum load is lower than the original minimum load.

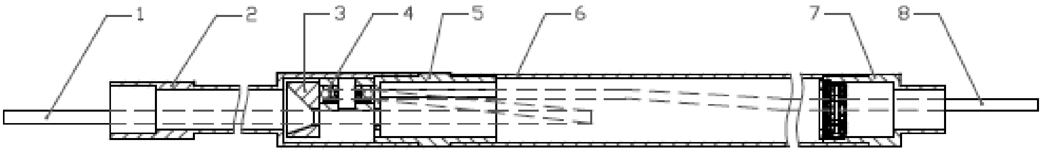

Figure 2-1. load reducer structure diagram

1- Sucker rod k1 2-top connection 3-center tap 4-fixed pulley 5-cener coupling

6-outer tube 7-lower contact 8-sucker rod

The original large-scale beam pumping unit can be converted into a small beam pumping unit by means of this scheme. At the top of the pump, the pump is equipped with a balance loader, Donkey head hanging point connected, and ultimately achieve energy saving and load shedding effect.

3. The Main Parameter Calculation

Reduction of residual calculation:

The size of the load shedding force and the pump diameter, pump depth, sucker rod diameter and other parameters.The pump diameter is 38mm,the pump depth is 2400m.

K1 rod: $\emptyset 25\text{mm} \times 2200\text{m}$,

K2 rod: $\emptyset 22\text{mm} \times 200\text{m}$.

Calculation is as follows:

The liquild gravity :$Y = 2449.694\text{kg}$

Improve the gravity of the column in the liquid:

$K1 = 6103.138\text{kg}$，$K2 = 415.7692\text{kg}$

Maximum load: $F1 = K1 - K2 = 5687.369\text{kg}$

Minimum load: $F2 = K1 - (K2 + Y) = 3237.675\text{kg}$

Table 1. Comparison of the original loader and the Improved loader

	The wight of rod/Kg	max load/Kg	min load/Kg
former	K=6667.7	9117.394	6667.7
At present	K1=6103.138 K2=415.7692	5687.369	3237.675
Reduction of scope		38%	51%

The gravity of the column in the liquid: $K = 6667.7\text{kg}$

Max load: $F1' = K + Y = 9117.394\text{kg}$

Min load: $F2' = K = 6667.7\text{kg}$

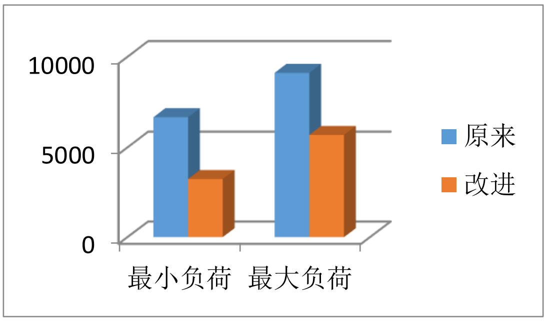

Figure 3-1. Comparison of the original loader and the improved loader chart

Comparison of the maximum load reduction 3430.0248kg, the reduction rate of 38%; minimum load reduction 3430.0248kg, a reduction rate of 51%.

As shown in Table 1 and 3-1, the load on the carrier is smaller than the original load. Through the calculation of the load reducing force of the load reduction device, adding a load reduction device can reduce the cantilever load of the pumping unit at least half. Load reducer can increase the pump stroke, also can make the stroke and stroke unit for the original 1/2. The speed, friction, and inertia load also decrease as the stroke and stroke are reduced by half. The service life of the pumping unit can be increased, and the output can be increased.

4. Static Strength Analysis Of Intermediate Joint

In pumping operation, the main component of the pumping unit is the middle joint, which is the main component of the bearing capacity. Therefore, the finite element analysis is carried out by using ANSYS WORKBENCH software.

4.1 Establish A 3D Model

According to the load condition of the carrier, the key components and intermediate joints of the load reduction truck are modeled in the Creo. In order to ensure the accuracy of finite element analysis, the discrete number is reduced as much as possible during mesh generation. The model is shown in figure 4-1.

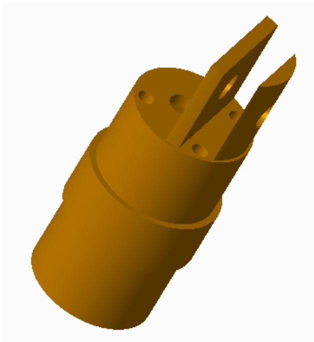

Figure 4-1. the intermediate connector model

4.2 Middle Connector Material Properties

The middle joint material is made of 40Cr steel, according to reference[3], [4] look-up table available, the material properties see Table 2.

Table 2. Middle connector material properties

property	unit	value
Tensile ultimate strength	MPa	980
Yield strength	MPa	785
Young`s modules	GPa	211
Poisson`s ratio		0.3

4.3 Model Meshing

The model is imported into ANSYS Workbench and meshed, and the element type is hexahedral element. The grid is manually divided by hexahedron and the grid size is set to 5mm. The contact places grid encryption, and encrypted grid size is set to 1mm.The grid node of a total of 349120, a total of 110084 units. The statics mesh results are shown in figure 4-2.

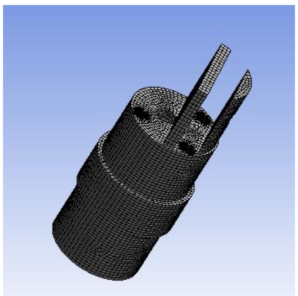

Figure 4-2. grid model

4.4 Constraints and Loads Applied

According to the actual operation of the loader, apply a load F = 55756N to the intermediate joint, the bottom and the upper end of the applied fixed constraint, and the simplified joint constraint applied cylindrical thread,installation of wire rope and a fixed pulley axis force. For specific constraints and loads, see Figure 4-3 below.

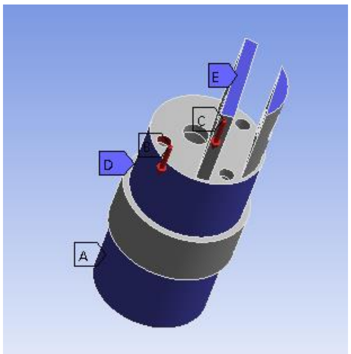

Figure 4-3. the intermediate connector of the constraint and load

4.5 Statics Analysis Results

The results of the static analysis are as follows: Displacement and stress results are shown in Figure 4-4, Figure 4-5.

As shown in Figure 4-4, the maximum deformation of the middle joint occurs at the installation of the steel wire rope and the fixed pulley shaft, and the maximum displacement is 0.007249mm. Due to the installation of wire rope intermediate joints directly bear the axial load is transferred from the head to the sucker rod, so that the emergence of deformation. The deformation range of the intermediate joint is small, and the normal operation of the load reduction device is not affected.

As shown in Figure4-5, the maximum stress of the middle joint appears at the installation of the steel wire rope and the fixed pulley shaft, and the maximum stress is 99.329MPa. In the whole load reducer structure is the key point of force, stroke, axial load bearing will pass down the middle connector, so that there will be stress concentration.

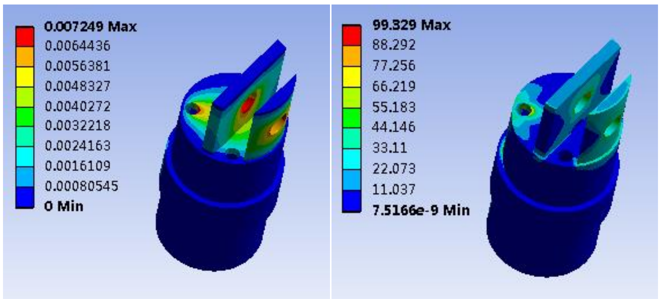

Figure 4-4. Displace image Figure4-5 Stress images

According to the rated condition of the load reducer, the allowable stress of the intermediate joint is less than the yield limit. According to table 2, the yield limit is 785MPa, and the allowable stress of the intermediate joint is 523MPa, greater than its maximum stress. Therefore, under the static load, the intermediate joint meets the requirements of the load reduction device. But in the actual work, the intermediate joint will have alternating load, so it is necessary to calculate the fatigue life of the intermediate joint.

5. Fatigue Strength Check of Intermediate Joint

According to the results of static analysis, the allowable stress of the middle joint is much greater than the maximum equivalent stress, so it belongs to high cycle fatigue, and its fatigue analysis.

According to the theory of fatigue cumulative damage, the stress is considered as the most dangerous symmetrical cyclic stress. The fatigue strength check formula [5] is:

$$n_\sigma = \frac{\sigma_{-1}}{K_{\sigma D}\sigma_a} \geq [n]$$

$$K_{\sigma D} = \frac{K_\sigma}{\varepsilon} + \frac{1}{\beta_1} - 1$$

Type: n-fatigue safety factor σ_{-1}-fatigue limit MPa;$K_{\sigma D}$-fatigue reduction coefficient σ_a-stress amplitude MPa;[n]-allowable safety coefficient;K_σ-fatigue notch factor;ε- size coefficient;β_1-surface factor.

According to the reference[5],we can see that fatigue ultimate strength of 40Cr steel is $\sigma_{-1} = 421.69$MPa,the allowable safety factor of the middle joint is 2.5， $\frac{K_\sigma}{\varepsilon} = 2.14, \beta_1 = 0.9011$, which can be regarded as $K_{\sigma D} = 2.25$.Since the stress concentration is the first place to be damaged by fatigue, the maximum value of stress range should be checked. For the middle joint stress concentration, σa = 31.6Mpa, calculated nσ = 5.93, greater than the corresponding safety factor of 1.5. In summary, the fatigue strength of the intermediate joint to meet the requirements.

6. Calculation of Fatigue Life of Intermediate Joint

6.1 Intermediate Joint Material S-N Curve

The material of the intermediate joint is 40Cr, and the S-N curve of the material can be determined by least square method. The fitting equation is[5]:

$$\lg N' = a + b\lg\sigma$$

In the formula, N′-the corresponding stress under the fracture of the material; a, b- undetermined coefficients σ-stress.

For structural steels, the Engineering Data in ANSYS Workbench has its fatigue characteristic S-N curve, as shown in figure 6-1.

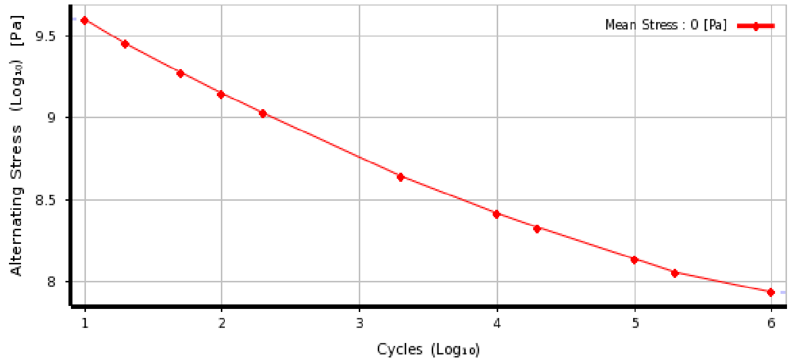

Figure 6-1. 40Cr S-N curves

6.2 Fatigue Life Analysis of Intermediate Joints

The load reduction device is a cyclic process in which the stress due to the indirect head is approximately equal to the symmetrical cyclic stress state, so the stress ratio R=-1 is taken. For 40Cr steel, the Goodman curve is taken as the average stress correction curve. Because the Goodman formula is suitable for high strength structural steel, and the actual situation is in good agreement with the correction results, the calculation results are more secure.The fatigue life of the intermediate joint is analyzed by using the Fatigue Tool module in workbench, and the analysis results are shown in figures 6-2.From Figure6-2 results showed that the minimum fatigue safety coefficient of intermediate joint appears in the installation of wire rope and a fixed pulley shaft, and the position of the maximum equivalent stress superposition, the size of 2.6377, and the joints between the allowable safety coefficient is 1.5, visible joints between the allowable safety coefficient in fatigue safety coefficient, meet use requirements.

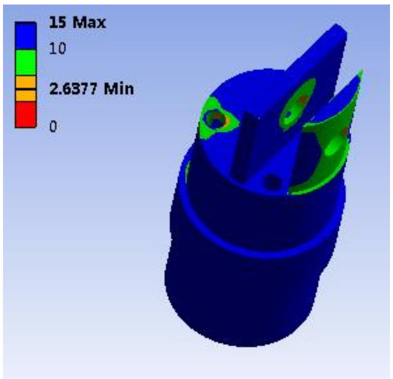

Figure 6-2. safety images

7. Conclusion

According to the principle of load reduction device, the load shedding force is calculated and the following conclusions are drawn:

(1) The load reduction device can realize the functions of energy saving, load reduction and pump suspension for pumping units. The design of the load reduction device is novel, and it can overcome the shortcomings of the conventional pumping unit's small pump deep pumping. The load reduction device can achieve the purpose of reducing the load and reducing the energy consumption, and the energy saving effect of the loader is better than that of the

conventional loader.

(2) The maximum equivalent stress of the middle joint is 99.329MPa, less than its allowable stress; the maximum displacement deformation is 0.007249mm, which belongs to small deformation range. The safety factor of the allowable safety of the intermediate joint is less than the fatigue safety factor and can be operated normally under the alternating load. The static stress and fatigue life analysis results of intermediate joints meet the application requirements.

References

[1] Wang Hongtao. Study on load shedding mechanism of pumping unit load reducer [D]. Xi'an Petroleum University, 2014.

[2] Meng ya. Study on dynamic characteristics of sucker rod pumping system with load reducer [D]. Northeast Petroleum University, 2012.

[3] Cheng Daxian. Mechanical design manual [M].Beijing:chemical industry press, 2008.

[4] Li Shunming. Mechanical reliability design of fatigue [M]. Beijing: Science Press,2007.

[5] Yao Weixing. Analysis on structural fatigue life [M]. Beijing: national defense industry press, 2003.

[6] Li Gang, Liaohe oil field pumping deep research and application of load reduction technology [J], special oil and gas reservoirs,2007 (12):144- 146

[7] Meng Tao,Yang Jianbin, Qing Hua, carrier in Zhongyuan Oilfield [J]. petroleum machinery, such as reduction of.Sc 2002, 30 (8):49-51.

[8] Zhang Wei, Sun Qingyu, Wang Zhu, et al. Application of anti [J]. pumping oil drilling technology in Shengli Oilfield, which contained 2004, 26 (2):79-80.

[9] YANG Jianping, JIANG Hui.Study and application of pumping loader [J].Machinery, 2004, 33 (4): 72-74.

[10] ZHAO Jing, REN Jiajun, LI Aifeng, et al. Fatigue Life Analysis of the Components of Bucket and Bucket Rod of WK-75 Mining Excavator [J].

[11] Mechanical Design and Manufacture, 2016 (12): 111-113.

[12] ZHAO Xi, LAI Xide, GOU Qiuqin. Fractal life analysis of upper frame of Francis turbine generator set [J]. Hydropower Engineering, 2015 (8):140-143.

[13] ZHANG Jiu-xiang, XU Zheng-bin, ZHAO Guang-qi, etal.Development of energy saving tool for high efficiency balancing load reduction unit of pumping well [J]. Henan Science and Technology, 2013 (23): 149-150.