Finite Element Analysis of Walking Beam of a New Compound Adjustment Balance Pumping Unit

Jufei Wu, Qian Wang, Yunfei Han
Qingdao University of Science and Technology, Professor, Qingdao, China

Abstract. In this paper, taking the designer of the new compound balance pumping unit beam as our research target, the three-dimensional model is established by SolidWorks, the load and the constraint are determined. ANSYS Workbench is used to analyze the tail and the whole of the beam, the stress and deformation are obtained to meet the strength requirements. The finite element simulation and theoretical calculation of the moment of the center axis beam are carried out. The finite element simulation results are compared with the calculated results of the theoretical mechanics model to verify the correctness of the theoretical calculation. Finally, the finite element analysis is consistent with the theoretical calculation results. The theoretical calculation results are preferable, and the bending moment value provides the theoretical reference for the follow-up optimization and research design.

Keywords. New Pumping Unit, Walking Beam, ANSYS Workbench, Mechanical Analysis, Bending Moment Calculation.

1. Introduction
At present, the number of mechanical wells in China accounted for at least 4/5 of the total number of wells, while the beam pumping unit accounted for more than 2/3 of the total number of pumping units [1]. Walking Beam beam is an important bearing of the pumping unit. If the strength is not enough, it will cause damage. If the rigidity is insufficient, it will produce a large deformation and affect the normal operation of the pumping unit [2]. As the pumping unit in the upper and lower stroke bearing the different load, so the pumping unit need the adjustment balance device to ensure the smooth operation of pumping equipment [3]. The traditional way of adjusting the balance was cumbersome, the labor of workers was very intensive, and cannot achieve real-time adjustment [4]. In order to solve the above problems, a crank automatic adjustment mechanism is designed. The device constructed the active crank block, to reduce energy consumption, improve motor efficiency, and increase the life of the pumping unit. Based on the finite element method, the paper discusses the walking beam in the pumping unit with the new compound balance. ANSYS Workbench is used to mechanically analyze and calculate the structure to verify the reliability of the whole structure design and provide technical support for the follow-up optimization and research design [5].

The new compound automatic balancing mechanism is based on the CYJY10-4.2-53HF type pumping unit, which is designed based on the original pumping unit size to construct the new active crank block and the balance block of the beam tail [6] [7], to meet the needs of the crank automatic
adjustment balance, before and after the transformation of the beam balance weight of the tail as shown in Table 1, after the transformation of the walking beam structure shown in Figure 1.

![Walking beam assembly drawing](image)

**Fig.1** Walking beam assembly drawing

| CYJY10-4.2-53HF | Balance weight required of fully balanced/kN | Balance weight required of 85% balanced/kN |
|-----------------|---------------------------------------------|-------------------------------------------|
| Original models | 27                                          | 18                                        |
| New models      | 25                                          | 16                                        |

2. **Analysis Of Shear Force And Overall Force In Beam**

The balance weight of the beam tail is changed, and the load of the well is constant, the force of the front and rear ends of the beam changes, the tensile, compressive and shear stresses of the tail and the force of the whole will change. Therefore, it is necessary to analyze the tail and the whole force to find the dangerous point of the beam. ANSYS Workbench is now used to analyze and simulate its forces and deformations.

First, use SolidWorks to build a simplified three-dimensional model, and then import it into ANSYS Workbench, set the material properties [8], as shown in Table 2.

**Table 2.** Q235 steel material properties

| Property                  | Mass Density / kg·m⁻³ | Elastic Modulus / GPa | Bow to Extremes / GPa | Poisson's Ratio |
|---------------------------|-----------------------|-----------------------|-----------------------|-----------------|
| Value                     | 7850                  | 210                   | 235                   | 0.3             |

According to the actual size of the model, the Element Size value in the grid is set to 20mm (4 times larger than the actual size thickness). The result is shown in Figure 2; the imposed constraints and loads are shown in Figure 3; the final results are shown in Figure 4, Figure 5, Figure 6 and Figure 7.
Fig. 2 Meshing results

Fig. 3 Constraint and load

(a). Tail shear stress map
Fig. 4 Simulation of the beam tail

(b). Tail pull stress map

(c). Tail compressive stress

(a). The pull stress of the upper surface
(b). The compressive stress of the lower surface

(c). Beam side stress map

Fig.5 Local simulation stress map of the beam

(a). Upper face deformation diagram
Fig. 6 Local simulation deformation map of the beam
Fig. 7 The overall simulation of the beam
It can be seen from the figure that the maximum stress of the beam is 56MPa, because the beam material used Q235, the material yield strength is 235MPa, so the safety factor of the beam is:

\[ n_{beam} = \frac{\sigma_y}{\sigma_{max}} = \frac{235}{56} = 4.2 \]

3. Simulation Of Moment Of Center Axis In Traveling Beam

3.1. Simplification of Moment Mechanics Model of center axis

When the angle between the beam and the horizontal line is 0 °, the bending moment of the beam is the largest. So choose this condition to simplify the calculation of the bending moment at the center of the beam. Based on the CYJY10-4.2-53HF type pumping unit, the oil well load is 10 tons, the designed balance of the tail beam is 2.5 tons, and the force model is simplified as shown in Fig8.

![Fig. 8 Simplified diagram of the mechanical model of the beam bending moment](image)

Where, the L1 length is 3390 mm, the L2 length is 3100 mm, the L3 length is 2550 mm, know by the balance conditions:

\[ G_1L_1 = G_2L_2 + F_yL_3 \]  \( (1) \)

3.2. Finite element calculation of bending moment in beam center axis

After the balance weight of the walking beam is changed, the bending moment at the axis of the beam will change, and the bending moment in the center axis of the pumping beam will directly affect the deformation of the beam, so it is necessary to simulate the bending moment. Establishment of local coordinate system, the coordinate system is built at the center of the beam, using the Coordinate Systems option, insert the local coordinate system as shown in Figure 9.

![Fig. 9 The establishment of local coordinate system](image)
Using the Solution option, select Insert → Probe → Moment Reaction to insert the bending moment, and then select the center of the beam, the final calculation results shown in Figure 10.

![Image of the bending moment of center axis](image)

**Fig. 10** The bending moment of center axis

It can be seen from the figure that the poor bending moment of the center axis around the axis of the beam is $2.925 \times 10^6 \text{N} \cdot \text{mm}$, the total poor bending moment is $2.925 \times 10^6 \text{N} \cdot \text{mm}$, the bending moments on the Y and Z axes are negligible; compared with the calculation results of the material science, the relative error $e$ is:

$$
e = \frac{2.925 \times 10^6}{3.39 \times 10^8} = 0.86\%$$

The accuracy rate is 99.14%, so the simulation is correct. The existence of the error may be due to simplify the model or the situation caused by instability and other factors.

4. **Summary**

1) Based on the design of the new compound balance pumping unit, ANSYS Workbench is used to analyze the tail and the whole of the walking beam. The stress and deformation meets the strength requirements and find the force dangerous place.

2) The theoretical model of the bending moment of the beam is simplified and the finite element simulation analysis and calculation are carried out. The calculated bending moment value is basically as same as the theoretical value, and the theoretical calculation value is preferable.

**Acknowledgements**

Corresponding Author: QIAN WANG, E-mail:wangqianhlz@163.com Tel: 15621008975

China Petrochemical Corporation (provincial and ministerial level) key research projects: intelligent beam pumping unit development, project number: 316088

**References**

[1] Fang Renjie, Zhu Weibing. Study on historical situation and development trend of pumping unit [J]. Drilling & Production Technology, 2011, 34 (2): 60-63.

[2] Feng Zhipeng. Study on carrying capacity of double-donkey head pumping machine [D]. Daqing Petroleum Institute, Northeast Petroleum University, 2003, 33-38.

[3] Zhang Jianjun, Li Xiangqi, Shi Huining. Design and calculation of beam pumping unit [M].
Beijing: Petroleum Industry Press, 2005, 45-55.

[4] Zhang Yajie, Huang Hua, Wang Weigang, etal. Design of automatic adjustment mechanism for pumping beam balance [J]. Petroleum Mine Machinery, 2013 (11): 38-41.

[5] Pan Wenhong, Cao Jujiang, Zou Feng, etal. Mechanical analysis of the outer ring roll ripple of the torque converter blade based on ANSYS Workbench [J]. Modern Manufacturing Engineering, 2017 (2): 149-152.

[6] Feng Z, Zhang J, Gu H, et al. Research on Energy-saving Technology of Crank Balanced Pumping Unit [J]. Research Journal of Applied Sciences Engineering & Technology, 2013, 6(22):4152-4157.

[7] Dong Ping, Yang Yonghong, Wang Qingxin. Design and analysis of automatic balance mechanism of beam pumping unit [J]. Science Technology and Engineering, 2016, 16 (33): 189-192.

[8] Metallurgical Industry Ministry of Iron and Steel Research Institute. Alloy steel manual [M]. Beijing: China Industry Press, 1964.