Advances in Machinery, Materials Science and Engineering Application IX
M. Chen et al. (Eds.)

doi:10.3233/ATDE230479

Finite Element Analysis on the Rack of the JC-17B Mobile Lifting Jack

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Abstract. Mobile lifting jack is one of the important equipment to CRH train overhaul, mostly in the manual mobile lifting jack. The JC-17B mobile lifting jack is often used as a lifting jack of CRH, which can implement lifting operations of 8 and 16 trains simultaneously. The mobile lifting jack mainly consists of the rack, transmission device, head supporting portion, walking device and other components. For efficiency, some structural modifications have been carried out, with electric pushing rods used for the expansion and contraction of the head supporting portion, and motor drive used for the walking device. At the same time, the original motor has been modified from the traditional top installation to the bottom installation to facilitate the maintenance of the lifting jack. Rack as an important component bears all loads, and its mechanical properties, especially the strength, play an important role in the normal operation of the entire equipment. This is the use of modern design method, using Pro/E, ANSYS and other modern engineering software platform, to do mechanical and modal analysis for rack on JC-17B mobile lifting jack, complete the rack design optimization, The analysis results show that the maximum stress is, which does not exceed the yield limit. Additionally, the thickness of the rack is reduced by 2mm, and the mass is reduced by 21.9%, thereby having saved materials and reduced production costs. Practice has proved that the mobile lifting jack developed based on the optimization method in this paper works well in actual operation, and for the future of all types of mobile lifting jack development, technological transformation and equipment renewal provides a reliable basis for the design.

Keywords. Mobile lifting jack, rack, mode, Finite element analysis

1. Introduction

The maintenance of the CRH train according to regulations is crucial to ensure its safe operation. Centralize maintenance at the overhaul base is the main mode adopted for the maintenance of CRH train in China [1], and the lifting jack is the main equipment for the maintenance of the CRH train [2]. At present, there are four types of domestic CRH: CRH1, CRH2, CRH3, and CRH5, each with different technical parameters. To meet the requirement of maintenance of multiple types of motor cars, the lifting jack must have good reliability and compatibility. The JC-17B mobile lifting jack is often used as a lifting jack of CRH, which can implement lifting operations of 8 and 16 trains simultaneously. For efficiency, some structural modifications have been carried out, with electric pushing rods used for the expansion and contraction of the head

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supporting portion, and motor drive used for the walking device. At the same time, the original motor has been modified from the traditional top installation to the bottom installation to facilitate the maintenance of the lifting jack. Among them, the rack is an important component, especially the mechanical characteristics of the rack play an important role in the working performance of the entire equipment. At present, the structural design and optimization of mechanical equipment have moved from previous experience, analogy, and static design to modeling, optimization, and dynamic design [3-7]. Therefore, the Pro/E, ANSYS and other modern engineering software platforms have been applied in this article to conduct mechanical analysis of rack on the JC-17B mobile lifting jack, and the optimization design of rack on the JC-17B mobile lifting jack has been completed, for the future of all types of mobile lifting jack development, technological transformation and equipment renewal provides a reliable basis for the design.

2. Basic Structure of Lifting Jack

Mobile lifting jack mainly consists of the rack, transmission device, head supporting portion, walking device and other components. The transmission adopts screw-nut strip transmission, mainly including trapezoid screws, driving nuts, security nuts, bearings and other components, to achieve the up and down movement of the lifting device. And the device is equipped with safety nuts to minimize risk of accidents happening of the transmission nut. The safety nut is not loaded during operation. In addition, when the setting distance decreases, the control system should alarm and automatically shut down. And there is no need to disassemble the entire system when repairing the screw and nut. The thrust bearing and deep groove ball bearing group are arranged between the upper of the screw and the frame to make the screw endure indentation load. The working nut drives the up and down of the head supporting portion, and each mobile lifting jack adopts a single point automatic lubricator (Taiwan PERMA), which has low operating noise and high transmission efficiency.

The lifting device consists of the circular support head, cylindrical bracket, swinging mechanism, electric push rod, needle bearing for the lateral movement of the support head, pressure switch, safety nut and its upper clearance monitoring switch, locking monitoring sensor, alignment sensor, pressure sensor, etc. The pressure sensor sends a signal to stop the bracket from rising after the bearing plate contacts the vehicle body lifting point and the pressure reaches the set value, to ensure synchronous lifting of the vehicle in the future. The safety nut and its clearance monitoring switch ensure that when the bearing nut is worn or tripped, a signal is sent to stop the equipment for protection, and can be carried by the safety nut. The bracket moving mechanism and locking monitoring switch are designed to be suitable for subway and trains with different widths and ensure stable and reliable lifting. This structure ensures the safety of the lifting operation and the reliable use of the lifting machine. The travel mechanism is the walking mechanism of the lifting jack, and the walking track is composed of a guiding mechanism and a walking driving mechanism. The travel mechanism is located at the bottom of the frame, guided by the wheel flange, and the track walking is electrically driven. The material of the traveling wheel (contact with the track) is quenched and tempered steel, with high strength and good wearing quality. The rack is the mechanical body of the lifting jack, which is composed of welded shaped steel and steel plates. Moreover, transmission, travel mechanism and many other assemblies also take it as their carrier. The frame bears compressive and bending loads during design phase of this lifting jack. Therefore, a double-column box structure welded with channel steel and thick plates is designed for the frame, and the lower part of the column, bottom plate, and vertical rib plate are welded into a box structure, forming a stable foundation for lifting jack. Flame hardening for the surface of the column guide rail mounting plate, which has high wear resistance. The model of JC-17B mobile lifting jack is shown in figure 1.

Figure 1. Basic Structure of Lifting Jack.

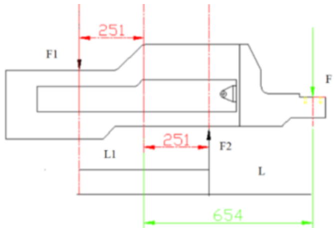


Figure 2. Force analysis of the lifting device.

3. Mechanical Analysis of the Rack

The strength of the rack determines whether the lifting jack can be used safely, and if the strength of the rack is insufficient, it will cause serious safety issues. On the premise of saving materials and optimizing structure, it is necessary to ensure that the strength of the rack is sufficient to complete the driving task. Analysis on strength of the rack is as follows. The designed bearing capacity of the mobile lifting jack is 17T. The force analysis of the lifting device is shown in figure 2, and the force on the rack is its reacting force.

The equilibrium equations are:

$$\sum M2 = 0 : F \times L - F_2 \times L_1 = 0 \tag{1}$$

$$F_1 + F = F_2 \tag{2}$$

F_1 is the support force on the left, F is the load of head supporting portion, F_2 is the support force on the right, L is the horizontal distance from the force point of the support head to the force point of the left support, taken as 905mm, L_1 is the horizontal distance from the force point of the left to the force point of the right, taken as 502mm, and $F = 17\text{T}$.

The obtained solutions are:

$$F_2 = \frac{F \times L}{L_1} = \frac{166600 \times 0.905}{0.502} = 315600\text{N} \tag{3}$$

$$F_1 = F_2 - F = 315600 - 166600 = 149000\text{N} \tag{4}$$

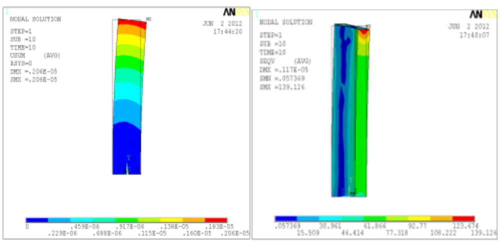
Due to the symmetry of the four forces on the head supporting portion with respect to the centerline, the solution is divided by 2, resulting in:

$$\begin{aligned} F_2 &= 157800 \approx 160000\text{N} \\ F_1 &= 75400 \approx 75000\text{N} \end{aligned} \tag{5}$$

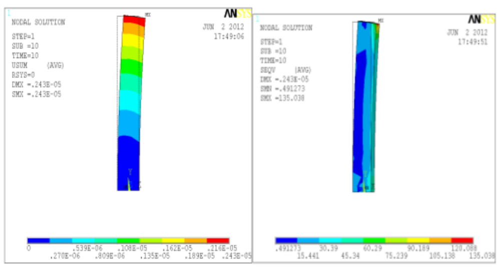
Material properties are as follows: the material of the rack on the lifting jack is cast iron, elastic modulus $E = 1.6 \times 10^{11}\text{Pa}$, the Poisson's ratio is 0.27, the density is $7860\text{kg}/\text{m}^3$, yield limit $\sigma_S = 320\text{MPa}$. The load conditions are as follows: apply the load on the red arrow in the figure 3, and the load distribution of the rack is shown in figure 3.

Figure 3. Load distribution of the rack.

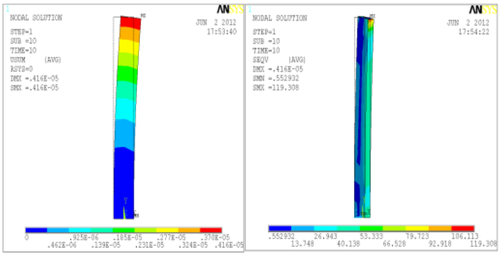
To analysis the force of rack on the lifting jack at different heights, the rack on the lifting jack was divided into three sections based on the distance between the support head and the rail surface, namely 1500mm, 2000mm, and 2500mm. Static analysis was conducted on these three situations, and the deformation diagram and equivalent stress diagram of the rack on the lifting jack at different distances were finally obtained, as shown in figure 4.



(a) Displacement distribution at the distance of 1500mm; (b) Stress distribution at the distance of 1500mm



(c) Displacement distribution at the distance of 2000mm; (d) Stress distribution at the distance of 2000mm



(e) Displacement distribution at the distance of 2500mm; (f) Stress distribution at the distance of 2500mm

Figure 4. Deformation and equivalent stress diagram of the rack.

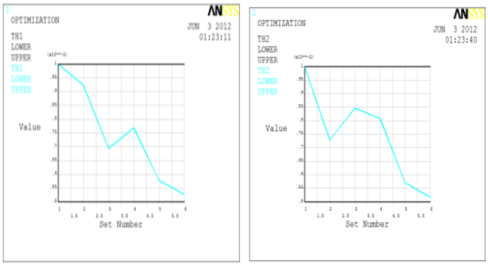
As shown in the figure 4, when the distance between the support head and the rail surface is 1500mm, 2000mm, and 2500mm, the maximum displacement is $0.206\times10^{-5}\,\mathrm{m}$, $0.243\times10^{-5}\,\mathrm{m}$, and $0.416\times10^{-5}\,\mathrm{m}$, respectively. It can be seen that the larger the distance between the support head and the rail surface, the greater the deformation of the rack on the lifting jack. Overall, the deformation of the rack on the lifting jack is relatively small, meeting the requirements. In addition, when the distance between the support head and the rail surface is 1500mm, 2000mm, and 2500mm, the maximum equivalent stresses obtained from the static analysis are $139.126\mathrm{MPa}$, $135.038\mathrm{MPa}$, and $119.308\mathrm{MPa}$, respectively. The maximum stresses are different, but all meet the material requirements, and there is significant optimization space.

4. Structure Optimization of Rack

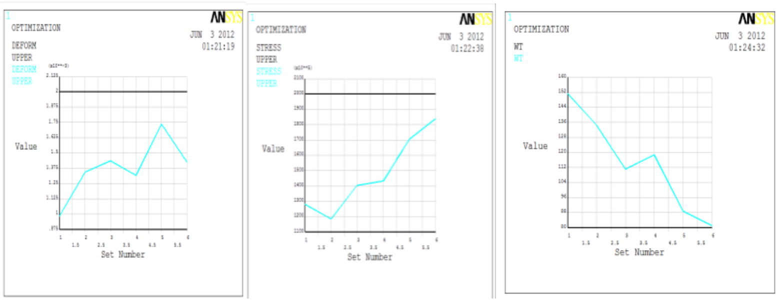
The batch mode and GUI methods can be utilized to realize optimization design. Generally speaking, optimization can be conducted by inputting the commands of the entire optimization file and running in batch mode. This method is more efficient for complex and time-consuming analysis tasks (such as nonlinearity). Additionally, the GUI is more flexible and the results of the loop process can be seen in real-time. When using GUI mode, establish the analysis file of the model at first, and then interactively use the optimization processor to determine the design space for subsequent optimization processing. The initial interactive operations can help users reduce design space and accelerate the optimization process, but GUI operations are very cumbersome. Therefore, command streams are adopted to implement parameter modeling, control, extraction, and other optimization operations. In table 1, the design variable TH1 is the thickness of the rack, and TH2 also represents the thickness of the rack. Two special design variables are set to better optimize the thickness of the rack. STRESS represents the equivalent stress on the rack during operation, while WT represents the mass of the rack. By optimizing and analyzing the design variables, state variables, and objective functions provided in the table 1, the results obtained should ensure that the thickness of the rack is minimized when the maximum equivalent stress does not exceed the yield limit, thereby minimizing weight, saving usage of actual material, and cutting costs. The iterative curves of design variables, state variables, and objective functions are shown in figure 5.

Table 1. Definition of Optimization Variables.

Optimization variables	Variables	Minimum value	Maximum value
Design variables	TH_1(mm)	5	10
	TH_2(mm)	5	10
Objective functions	WT(kg)	80	151



(a) Curve of design variable TH1; (b) Curve of design variable TH2



(c) Curve of displacement of state variable; (d) Curve of equivalent stress of state variable; (e) Curve of objective function WT

Figure 5. Curve of design variables, state variables, and objective functions.

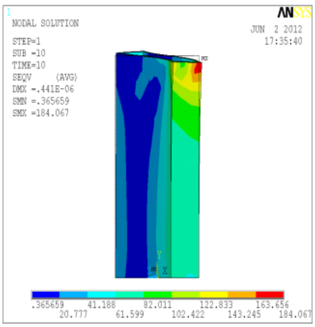


Figure 6. Distribution of stress on the optimized rack.

The optimized thickness of rack on lifting jack *HT* is 8.0896mm, the optimization variable is rounded to 8mm, for convenience to design and process. The maximum node displacement of the rack is 0.480×10^{-5}m, and the maximum equivalent stress received is 184.067MPa, as illustrated in figure 6. The comparisons of various data before and after optimization are shown in table 2.

Table 2. Comparisons of various data before and after optimization.

Optimization variables	Variables	Before optimization	After optimization
Design variables	TH1(mm)	10	8
	TH2(mm)	10	8
State variables	STRESS(MPa)	139.126	184.067
Objective functions	WT(kg)	151	118

5. Conclusion

The three-dimensional model of the basic structure of the lifting jack and the optimal analysis of the key component of rack have been presented in this paper. The results show that the maximum stress is 184.067MPa, which does not exceed the yield limit. Additionally, the thickness of the rack is reduced by 2mm, and the mass is reduced by 21.9%, thereby having saved materials and reduced production costs. Practice has proved that the mobile lifting jack developed based on the optimization method in this paper works well in actual operation.

Acknowledgments

This work was supported by funding from the Innovation Fund for Industry, University and Research in China [grant number 2022BL082].

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