Stress Analysis and Strength Test of 2500 Fracturing Truck Frame

Lei Li, Bin Zhang and Chunming Fan

Baoji Oilfield Machinery Co., Ltd., National Engineering Research Center of Oil and Gas Drilling Equipment, Baoji, China

Abstract. For the fracturing trucks, which is an important member of oil and gas fracturing, the stress and strength of fracturing truck’s frame have a very significant influence on the continuous fracturing operation. This paper takes the frame of 2500 fracturing truck as the research object, analyses its stress condition, and conducts the static strength test and dynamic strength test of the whole frame of fracturing truck, respectively tests the strain of 15 measuring points of the frame under the fully loaded static condition and the right front wheel lifting condition, and finds out the distribution rule of the stress and strain of the frame. The results show that the maximum stress position of the frame under migration condition is at the root of the rear support of the tank, the total stress is 146.76 MPa, the minimum safety factor reaches 2.35, and the strength of measuring point meets the requirements.

1. Introduction

The fracturing truck is the core equipment of the fracturing operation. Its role is to inject high-pressure fracturing fluid with large displacement into oil and gas wells, so as to fracturing oil and gas. The on-site fracturing puts a high standard on the technical performance of the fracturing truck. It is required that the fracturing truck must have large displacement, high pressure, strong abrasion resistance and corrosion resistance [1]. The frame is the main load-carrying component of the fracturing truck. During the fracturing operation, the fracturing pump will generate great vibration to the frame.

In 2005, Zhao Han and Wei Ying applied ADAMS to simulate the dynamics of a passenger car air suspension and then related mechanical analysis of the spring suspension bracket in ANSYS [2]. In 2009, Zhu Sihong and Xiao Zhijin of Nanjing Agricultural University analyzed multi-body dynamics combined with finite element analysis for a certain type of vehicle frame [3]. In 2011, Wang Jun-qiao and others calculated and studied the frame of 2500 fracturing truck. According to the driving and fracturing conditions of fracturing truck, transient dynamic finite element calculation was carried out on the frame to obtain the dynamic stress distribution of the frame under the two working conditions [4]. In 2013, Sang Meng solved the fatigue load spectrum of 2500 fracturing truck under fracturing and migration conditions based on dynamic simulation [5].

Whether it is a random load on the road surface or the simple harmonic excitation load of the fracturing pump, it is possible to cause fatigue damage to the frame. Therefore, it is necessary to calculate the fatigue life and safety factor of the frame under various working conditions to ensure the safety of the fracturing truck’s service. This paper analyzes the strength of various types of working conditions of the 2500 fracturing frame during the fracturing process and conducts strength tests.
2. Finite element static analysis of 2500 fracturing truck frame

2.1. Stress analysis of 2500 fracturing truck frame

In order to analyze the force of the fracturing frame efficiently and accurately, it is necessary to first understand the structure of the truck, analyze the load of the frame, analyze the force of the frame and simplify it, and establish a mechanical model of the frame.

2.1.1. Structural Analysis of 2500 Fracturing Truck. The structure of the 2500 fracturing truck is shown in Figure 1 and the secondary frame and mainframe are combined by connecting plates. The lower part is connected to the axle and wheels by the leaf spring suspension system. The upper part bears the weight of various mounted equipment, which mainly includes the cab, the engine of the truck, the torque converter, the gearbox, and the fracturing pump.

\[ \text{Figure 1 Structure of 2500 fracturing truck} \]

2.1.2. Stress analysis on the frame of model 2500 fracturing truck. Before the statics analysis of the frame, the stress condition of the frame is firstly analyzed and the mechanics model of the frame is established, which will be used as the basis to apply load and boundary conditions in the finite element model of the frame. In order to simplify the frame mechanics model, the following assumptions are made:

1. The frame is a flat structure and the longitudinal beam is treated as a simply supported beam.
2. The left and right sides members of the frame each bear half of the frame load.
3. The load of the top-loading equipment passes through the center of the frame longitudinal section.
4. Due to the small size of the top-loading equipment, the load of the top-loading equipment can be treated as concentrated quality, and the point of action is the position of the center of gravity of each equipment.
5. The main and auxiliary frames are considered as rigid connections, that is the deflection changes synchronously.

The force analysis of the mainframe and secondary frame is shown in Figure 2. According to the system balance conditions, there are:

\[
F_i + F_2 + F_3 + F_4 + F_5 + G = R_{1f} + R_{1b} + R_{2f} + R_{2b} + R_3
\]

\[
F_5((l_{3m} - l_5) + R_{2b}(l_{2b} - l_{3m}) + R_{2f}(l_{2f} - l_{3m}) + R_{3b}(l_{1b} - l_{3m}) + R_{1f}(l_{1f} - l_{3m}) =
\]

\[
F_1(l_{1f} - l_{3m}) + F_2(l_{2f} - l_{3m}) + F_3(l_{3f} - l_{3m}) + F_4(l_{4f} - l_{3m}) + G(l_{G} - l_{3m})
\]

\[
F_5(l_{2b} - l_{3}) + F_4(l_{2f} - l_{3}) + G(l_{2b} - l_{G}) + F_3(l_{2f} - l_{3}) + F_4(l_{2f} - l_{2}) + R_{1b}(l_{1b} - l_{2b}) + R_{2f}(l_{1f} - l_{2b}) + R_{2f}(l_{1f} - l_{2b}) = F_1(l_{1f} - l_{2b}) + R_3(l_{1b} - l_{3m})
\]

Since the tires of the first two bridges are installed at the center of the corresponding leaf spring, there are:
\[ \begin{align*}
R_{1f} &= R_{1b} \\
R_{2f} &= R_{2b}
\end{align*} \] (2)

2.2. Finite element analysis of 2500 fracturing truck frame

Firstly, the model of the fracturing frame is simplified. The body model is built in SolidWorks and then imported into ANSYS Workbench. For the full load static and the right front wheel elevation 120 mm, the finite element statics are respectively carried out. The stress and strain distribution of the frame is obtained.

2.2.1. Modeling of the three-dimensional frame. The fracturing truck has a large vehicle and a complicated structure. The chassis is mainly connected by the main frame and the secondary frame through the connecting plate. Under the conditions of precision, the following assumptions and simplifications are made on the frame model:

1. Processing the frame rails as simply supported beams;
2. This paper mainly considers the overall stress and deformation distribution of the frame, ignores the influence of welding seam, and considers that the force transfer between the main frame and the secondary frame is average [3];
3. This paper mainly analyzes the static frame stress, temporarily do not consider the role of the suspension system;
4. Parts with small mass and low load are removed, such as bolts;
5. To divide the ideal mesh, the small rounded corners in the structure are turned into right angles.

According to the above simplified principle, the solid model of each component of the frame is respectively constructed in three-dimensional mechanical design software SolidWorks. The model of 2500 fracturing truck frame is shown in Figure 3.

![Figure 3](image1.png) Surface model of 2500 Fracturing Truck frame

![Figure 4](image2.png) Meshing for 2500 Fracturing Truck frame

2.2.2. Definition of frame material. The frame of 2500 fracturing truck is made of carbon manganese steel 16MnL, which is a kind of low alloy and high strength structural. Its comprehensive mechanical properties are outstanding.

2.2.3. Application of load and boundary conditions

1. Full load static condition boundary condition
2. Full load static condition boundary condition
3. The right front wheel raises the boundary condition of 120 mm working condition

2.2.4. Frame meshing. The frame structure of fracturing truck is complex, and the two grid generation methods, automatic grid and sweeping grid are combined to improve the dividing efficiency. A total of 122972 grid nodes and 121725 grid cells were obtained in Figure 4.

2.2.5. Results of frame static analysis
(1) Static analysis results of the frame under full load static condition

The static analysis of the 2500 fracturing frame under full load static conditions is shown in Figure 5 and Figure 6. It can be seen that, except for the stress concentration due to the simplification of the boundary conditions, the overall stress level of the frame of the fracturing truck under this working condition is low; there are three main bearing areas on the frame: the engine bearing area on the platform, the front bearing area on the water tank and the rear bearing area on the water tank. The stress range is about \(10\sim30\) MPa. The strain distribution rule of the frame is the same as the stress, and the strain range of the main bearing area is \(1.0\times10^{-5}\sim5.5\times10^{-5}\) mm/mm. In the next chapter, the measuring points of frame strength test will be mainly selected in these three areas.

![Figure 5 The stress of the full-loaded frame](image1)

![Figure 6 Strain of the full-loaded frame](image2)

(2) The results of statics analysis of right front wheel lift frame

The static analysis results of 2500 fracturing truck frame under the condition of 120 mm elevation of the right front wheel are shown in Figure 7 and Figure 8. It can be seen that the overall stress level of the frame of the fracturing truck under this condition is still not high, but a certain increase compared with the full-load static condition. The stress range of the main bearing of the frame is about 30~60 MPa. In addition, the strain range of the main bearing area of the frame is \(7.0\times10^{-5}\sim6.0\times10^{-4}\) mm/mm.

![Figure 7 The stress of the frame under bending and torsion mode](image3)

![Figure 8 Strain of the frame under bending and torsion mode](image4)

3. Strength test of 2500 fracturing truck frame

Static strength test and dynamic strength test were carried out on the 2500 fracturing frame by resistance strain measurement.

3.1. 2500 fracturing truck frame strength test program

3.1.1. Frame strength test program
3.1.2. Strain gauge arrangement and strength test equipment. First of all, according to the statics analysis of the fracturing of the owner's secondary frame, the areas with large surface stress on the upper surface of the sub-frame and under the mainframe are selected as the preliminary position of strain gauge arrangement. Then, according to the operability of pasting strain gauge on-site, the final arrangement scheme of strain gauge is determined. This test adopts the resistance strain measurement method to test the strength of the fracturing truck frame. According to the relationship between stress and strain, the stress value of the measuring point of the truck frame is finally determined.

3.2. Frame strength test results of 2500 fracturing truck

3.2.1. Frame static strength test results. The purpose of the static strength test is to verify the correctness of the finite element model of the frame. The strain information collected in the test can only reflect the strain change of the loading equipment (initial strain). The statics calculation results for comparison can only be the strain increment after subtracting the initial strain form the total strain after raising the right front wheel of the frame. The calculation results of the strain points on the left side of the fracturing truck frame are shown in Figure 11. when the frame is only subjected to a single load of the top-loading equipment, the overall strain is very small; when the right front wheel is raised, the strain increases to different types. In general, the closer to the position of the right front wheel, the greater the strain increase. This is in line with the actual loading situation; the maximum strain increase and the maximum total strain occur at the measuring point 7, 0.000514 and 0.000529, respectively, because the measuring point 7 is closest to the right front wheel and also close to the heavy-duty platform engine.
The comparison between the calculation results of the strain points on the left side of the fracturing truck frame and test results is shown in Figure 12. although there is a certain error between the effective test results and the corresponding calculation results, the overall trend of the two is consistent, that is, the closer to the position of the right front wheel, the greater the strain increase.

3.2.2. Frame dynamic strength test results. When the fracturing truck runs on the off-road at a speed of 30km/h, strain test results of each measuring point on the left side of the frame are shown in Fig.13(a)–(j). It can be seen that among all the effective points, the stress change at the measuring point is the largest, and the peak value reaches 87.54MPa. The possible reason is that the measuring point 3 is located at the root of the cantilever tank support and adjacent to the fracturing pump, which bears a large load in the process of migration. However, both point 4 and point 6 are far away from the main bearing area, and the range of stress variation is the smallest, about -8~8 MPa.

![Measuring point 1](image1)
![Measuring point 3](image2)
![Measuring point 4](image3)
![Measuring point 5](image4)
![Measuring point 6](image5)
![Measuring point 8](image6)
![Measuring point 10](image7)
![Measuring point 13](image8)
![Measuring point 14](image9)
![Measuring point 15](image10)

**Figure 13** Dynamic strength test result of the frame’s left side: \( v = 30 \text{km}/\text{h} \)

It can be seen that when the fracturing truck runs at the test section at a speed of 30km/h, the overall stress level on the left side of the frame is relatively low, about 23.73–146.76 MPa; among them, the total stress at the two-point of measuring point 3 and measuring point 5 is larger. What they have in common is that they are all at the root of the tank support (cantilever structure), so care should be taken to improve the support structure and minimize the length of the boom. The total stress of measuring point 3 is the largest, which is 146.76 MPa and does not exceed the yield limit of the frame material (345MPa), and the safety factor reaches 2.35. Then the measuring point 3 satisfies the strength requirement under this working condition, so other measuring points also meet the requirements.

4. Conclusion

Based on the analysis of the overall structure of the 2500 fracturing truck, this paper extracts the simplified mechanical model of the main and subframes and provides a reference for the selection of the strength test points of the fracturing frame. The static strength test plan of the fracturing frame (120mm right front wheel lift) and the dynamic strength test plan (off-road transport) are designed. Then the strength test of the 2500 fracturing frame was completed, and the strain strength test results of the frame are compared with the strain calculation results, and the error is about 4.69%–33.33% (the average error is only 22.01%). Finally, the maximum stress position of the frame under the moving
condition is measured point 3 (the root of the rear support of the water tank), the total stress is 146.76 MPa, and the minimum safety factor is 2.35. The strength of each measuring point meets the requirements.

Acknowledgments
The researchers gratefully acknowledge the financial support of Shaanxi Post-doctoral Research Funding Project “Research on Key Technologies of Intelligent Control System for Electric Drive Fracturing Device” (Project No.: 2018BSHQYXMZZ04) and Major Engineering and Technology Field Test Projects of CNPC “Integration and field test of 7000hp electric drive fracturing skid and on-line monitoring system for diesel drive fracturing unit” (Project No.: 2019F-30)

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