Fatigue analysis of all-electric shale gas fracturing truck frame

Wanli WANG¹*, Han PANG², Xincheng LI³, Yipeng WU⁴, Xiufu SONG⁵

¹China University of Petroleum (East China)
²China University of Petroleum (East China)
³China Ship Development And Design Center
⁴China Ship Development And Design Center
⁵China Ship Development And Design Center

*Corresponding author: wwli0919@163.com

Abstract—Fracturing truck is the core equipment in shale oil and gas exploitation. The operation environment is harsh. As the main bearing structure of the fracturing truck, the frame should have high efficiency and reliability to ensure the stable operation of the fracturing truck. Therefore, a frame model of the all-electric fracturing vehicle was established in this paper, and the load spectrum of the frame was simulated with white noise load when the fracturing vehicle was running on uneven road surface, and the finite element transient analysis of the frame was carried out. Then, a five-block diagram of fatigue analysis was established by using ncode Design-Life software, and the fatigue analysis results of the fracking truck frame were calculated according to the linear cumulative damage theory and S-N material characteristic curve. The research provides an effective reference for the detection of the fracking truck frame, so as to ensure the running stability of the fracturing truck.

1. INTRODUCTION
Domestic shale gas well fields are mostly located in mountainous areas, far away from highways, and the road environment is very harsh, this increases the damage rate of shale gas fracturing equipment [1]. As the core equipment of the fracturing system, the stability of the all-electric fracturing vehicle directly affects the operation of the entire shale gas fracturing system. Therefore, this paper carried out fatigue reliability analysis on the frame of the fracturing truck under driving conditions, established the calculation model of the frame of the fully electric drive fracturing truck, obtained the load spectrum, carried out finite element transient analysis on the frame, and obtained the stress distribution of the frame under the action of the load spectrum. Then, ncode Design-Life software was used for fatigue analysis of the frame. Reliable fatigue evaluation results were obtained.

2. Establishment of Frame Calculation Model
The all-electric drive fracturing truck is mainly composed of fracturing pump, motor and control unit and other top equipment. The frame is composed of two parts, the main frame and the sub-frame. The main frame is a side beam structure, composed of two longitudinal beams and five beams. The longitudinal beam of the main frame is in the form of groove section, and the inner surface of the longitudinal beam is closely fitted to the lining beam. The connecting plate between the main and sub-
frames is connected by riveting and bolt connection. Since the bolts, threaded holes and other fine geometric features on the frame of the fracturing truck may generate deformed elements when the finite element is used to partition mesh elements, the

![Calculation model of all-electric drive fracturing vehicle](image)

Fig. 1 Calculation model of all-electric drive fracturing vehicle

frame model is simplified on the premise of ensuring the accuracy of calculation. The simplified calculation model is shown in Figure 1.

As the bearing position of the all-electric drive fracturing vehicle, the frame should have good comprehensive mechanical properties, so 16MnL is selected as the material of the all-electric drive fracturing vehicle frame, and its performance parameters are shown in Table 1.

| Material | Poisson's Ratio | Young's Modulus (N/mm²) | Density (kg/mm³) | Yield Strength (MPa) |
|----------|----------------|-------------------------|------------------|---------------------|
| 16MnL    | 0.3            | 2.17×10⁵                | 7.85×10⁻⁶        | 345                 |

3. Finite Element Calculation under Driving Condition

Under driving conditions, the fatigue damage of the frame is mainly due to the displacement change of the top equipment, which produces the inertia random load, resulting in the alternating stress of the frame and the fatigue wear. In this paper, white noise load is used to simulate the inertial random load spectrum of the mounted equipment, and the obtained load spectrum is shown in Figure 2.

![Frame load spectrum under driving conditions](image)

Fig. 2 Frame load spectrum under driving conditions

The finite element calculation under the load spectrum of the frame under the driving condition is as follows:

1. Load is applied to the installation position of the upper equipment on the sub-frame, and the direction of application is vertical to the ground.
(2) In the suspension position of the frame, a displacement constraint of 800mm above the ground is applied perpendicular to the ground, and the freedom in other directions is fully constrained. Through finite element calculation, the finite element transient stress results of the frame under load spectrum are shown in Fig. 3.

Fig. 3 Transient stress distribution diagram of the frame under driving conditions

It can be seen that the maximum stress is located in the connection between the frame of the fracturing truck and the rear suspension, and the maximum stress value is 71.51 MPa. Due to the large dead weight of the fracturing pump installed at the rear of the frame, the position of the maximum stress is consistent with the actual working condition.

4. Frame Fatigue Analysis

4.1. Fatigue Analysis Theory

Fatigue can be divided into high cycle fatigue and low cycle fatigue according to the different cycles experienced before material failure [3]. The alternating stress of the high cycle fatigue material is far lower than the yield limit of the material, and the number of times before fracture is more than $1 \times 10^5$ times. From the stress analysis results, it can be seen that the frame belongs to high cycle fatigue.

The fatigue load of the frame of the all-electric fracturing vehicle is random load, so the fatigue life is estimated by using the fatigue damage accumulation theory and S-N fatigue life curve with the help of materials. According to Palmgren-Miner's theory [4], fatigue damage will occur to materials or parts when they are subjected to stress cycles, and the total damage under actual conditions is equal to the sum of the damage under each stress cycle. Fatigue failure is considered to occur when the total damage of materials or components accumulates to a certain threshold.

4.2. S-N Curve

The S-N curve of the material reflects the relationship between the stress of the material and the fatigue life of the material under the action of the stress cycle. In the S-N curve, N represents the fatigue life of the material, that is, the number of stress cycles the material experiences before fatigue failure occurs. The S-N curve of 16MnL material is shown in Fig. 4, in which $\log_{10}$ is converted to the number of cycles and the alternating stress corresponding to the horizontal and vertical coordinates.
Fig. 4 S-N curve of 16MnL

S-N curve is usually obtained by applying symmetric load to standard specimens. However, under driving conditions, the load on the frame of a fully electric drive fracturing vehicle is random load, and the average stress on the frame is not 0. Therefore, FKM curve is adopted to correct the average stress, so as to improve the accuracy of fatigue life calculation results.

4.3. Rain Flow Counting Method
The main reason that affects the fatigue life of mechanical parts is the amplitude of stress or strain and the number of cycles corresponding to them. Rain flow counting method is currently the most widely used method to deal with the random fatigue load waveform of the frame [5].

Fig. 5 Rain flow load diagram of the frame

Fig. 5 shows the histogram of load amplitude and mean value in a cycle after being counted by rain flow counting method, in which Range represents load amplitude, Mean represents load mean, and Counts represents the frequency of occurrence of different amplitude and mean values in a cycle. The bar chart shows the stress amplitudes of different sizes, their mean values and their respective occurrence times. By querying the S-N curve, the fatigue cycle times N corresponding to each amplitude can be found. Then, when each stress amplitude appears once, 1/N damage will be caused to the frame of the fracturing truck. According to the fatigue damage accumulation theory and the average stress correction, the fatigue damage of the parts in this cycle can be calculated, so as to calculate the fatigue life of the frame at this position.

4.4. Calculation of Fatigue Life of Frame
Through finite element transient analysis, the stress distribution of the frame can be obtained. Import it
into the ncode Design-Life software, and import the load spectrum of the fracking truck frame to obtain the fatigue analysis results of the frame. Fig. 6 is the fatigue life cloud map of the frame under driving conditions.

It can be seen from the figure that the position of fatigue failure of the frame is mainly distributed at the front and rear suspension under driving conditions, and the position of maximum fatigue failure is the connection between the frame and the rear suspension, with the shortest life of $1.376 \times 10^7$ times. The driving speed of the all-electric fracturing vehicle on uneven road surface is about $10m/s$, and the finite element simulation period is $16.5s$. Therefore, when the all-electric fracturing vehicle is driving on uneven road surface, the mileage that the frame can travel before fatigue damage occurs can be calculated as:

$$S = v \cdot T \cdot n = 10 \times 16.5 \times 7.607 \times 10^5 = 139462km$$

5. CONCLUSION
The paper uses finite element analysis software to analyze the frame of the all-electric drive fracturing truck under driving condition. Then, combining the results of finite element analysis, white noise load and S-N curve of materials, the fatigue life of the frame under driving conditions was obtained by using ncode Design-Life software. It was calculated that fatigue failure would occur after the frame of the all-electric drive fracturing vehicle was driven on the uneven road surface for 139462km. The fatigue damage of the frame is located in the connection between the frame and the rear suspension.

References
[1] Fan Kaiyun, Rong Shuang, Zhou Jin, et al. Application of electric fracturing pump in shale gas fracturing[J]. Drilling process, 2017,40(5):81-83.
[2] Li Junwen. Study on fatigue performance of high power fracturing truck frame[D]. Dalian University of Tech-nology, 2014.
[3] Wei Enxiang. Fatigue Life Prediction of a Tractor Frame Based on Random Vibration[D]. Chongqing University, 2017.
[4] Liu Xiaofen, Wu Zhou, Song Ming, et al. Based on the theory of the Miner Fatigue Damage of Fuzziness Analysis and Mathematical Modeling[J]. Applied Mechanics and Materials, 2013,2773 (437):124-128.
[5] Zhao Xiaopeng, Jiang Ding, Zhang Qiang, et al. Application of rain flow counting method in load spectrum analysis of whole vehicle[J]. Tech review, 2009(3):67-73.