Research on Fatigue Life Prediction Method of Tractor Frame

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Abstract. Aiming at the phenomenon of a certain type of tractor frame batch fatigue damage during the three-package period, the fatigue point and damage life of frame are predicted based on finite element method and linear fatigue damage theory in this paper. The stress at each node of the frame structure is acquired through the inertial release analysis of finite element model. The correction coefficient of the simulation model is determined by correlating the virtual strain of the frame with the measured strain. Based on the measured road load, finite element analysis results and material S-N curve, the fatigue life of the frame is calculated, and the severe fatigue damage area is obtained. The simulation results are consistent with the actual statistical results.

1. Introduction
The tractor frame bears various complex dynamic loads when it is running under full load for a long time, which is easy to cause frame fatigue damage. The damaged frame prevents the vehicle from driving normally and even leads to a traffic accident. Therefore, it is very important to predict the fatigue life of the frame under actual working conditions. At present, most scholars use the combination of finite element simulation and fatigue analysis software to predict the fatigue life of automobile frames. Hui Y B discussed the main cause of fatigue cracking in the frame of a light passenger car by using inertial release analysis in MSC Nastran and fatigue life analysis in the MSC Fatigue [1]. Sun Y L established the finite element model of commercial vehicle frame and carried out modal analysis, and used the modal stress recovery method to perform fatigue analysis in MSC fatigue to obtain the fatigue life result and damage position of the frame [2]. Li C L conducted static strength analysis on the frame in ANSYS and performed fatigue life analysis in FE-SAFE software in order to solve the problem of cracks frequently appearing in the frame of the semi-trailer tractor [3]. The fatigue life analysis process based on finite element has certain practical significance. But the existence of model error affects the finite element results, which make the fatigue calculation inaccurate. So it is necessary to correct the simulation model.

At first, the unit force inertia release model of the tractor frame is established, which eliminates the influence of boundary conditions on structural deformation and stress state [4-6]. The simulation model is modified by correlating the frame virtual strain and the measured strain to reduce errors such as geometric mesh and iteration calculate. Then, the load spectrum of the measuring points of the frame on the bad section and finite element simulation results are taken as the fatigue analysis input, and the frame fatigue life is calculated based on nCode software. Finally, the frame fatigue weakness
points are identified and the fatigue life is predicted based on the fatigue simulation results, which provides a theoretical basis for the next step of structural optimization design.

2. Finite element analysis of tractor frame

2.1. Establishment of the finite element model
The vehicle frame model is pre-processed based on the Hypermesh software. The model is simplified by ignoring components that have little effect on the simulation, for instance, hydraulic tubing and pins, etc. The parts such as the cab, fuel tank and engine are equivalent to the concentrated mass point, and the centroid position is provided by the relevant manufacturer. The cross beam and longitudinal beam of the frame are thin stamping parts, which are simulated by shell elements. The rear axle and leaf spring mounting base are casting that are replaced with solid elements. The bolt connection of the vehicle frame is expressed by the “Beam+Rbe2” unit. The welding unit is directly applied to the spot welding structure. As shown in Figure 1.

![Figure 1. Finite element model of tractor frame.](image)

2.2. Inertial release analysis
The balance force system can be constructed by adding the inertial force obtained by calculating the acceleration under the unbalanced external force to the finite element unit node, and then the static analysis can be performed.

For the finite element model of n nodes, the equivalent load of the external load at the center of gravity is

\[
F = \begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} f_{x,i} \\ \sum_{i=1}^{n} f_{y,i} \\ \sum_{i=1}^{n} f_{z,i} \\ \sum_{i=1}^{n} m_{x,i} + \sum_{i=1}^{n} (f_{y,i} \Delta z_i - f_{z,i} \Delta y_i) \\ \sum_{i=1}^{n} m_{y,i} + \sum_{i=1}^{n} (f_{z,i} \Delta z_i - f_{x,i} \Delta y_i) \\ \sum_{i=1}^{n} m_{z,i} + \sum_{i=1}^{n} (f_{x,i} \Delta z_i - f_{y,i} \Delta y_i) \end{bmatrix}
\]

(1)
Where \( f \) is the load concentrated force, \( m \) is the moment, \( i \) represents the \( i \)-th node, \( x, y, \) and \( z \) indicate load direction, \( \Delta x_i, \Delta y_i \) and \( \Delta z_i \) are the distance respectively between the \( i \)-th node and the center of gravity.

If the vehicle frame quality is \( m \) and the matrix of the moment of inertia relative to the center of gravity is \( I \), the overall translational acceleration \( \delta_t \) and the rotational acceleration \( \delta_r \) are

\[
\delta_t = \begin{bmatrix}
F_x / m \\
F_y / m \\
F_z / m
\end{bmatrix}
\]

\[
\delta_r = I^{-1} \begin{bmatrix}
M_x \\
M_y \\
M_z
\end{bmatrix}
\]

The acceleration of the \( i \)-th node is

\[
\delta = \begin{bmatrix}
\delta_t + r_i \times \delta_r \\
\delta_r_i
\end{bmatrix}
\]

Where \( r_i \) is the coordinate vector of the \( i \)-th node to the center of gravity.

The node inertia force is

\[
\{F_i\} = -[M] \{\delta\}
\]

Where \([M]\) is the mass matrix, \(\{\delta\}\) is the node acceleration vector. The frame structure stress under the unit load of the measuring point can be calculated by applied inertia load to the finite element node reversely.

### 2.3. Correction of simulation model

The simulation model is corrected by associating Virtual strain with measured strain at the same position. Four strain gauges R1, R2, R3, R4 are applied to test the strain on the second beam of the frame. The measured strain position and the position of the virtual strain gauge are shown in Figure 2.

![Figure 2](image1.jpg)

(a) Measured strain (b) Virtual strain gauge

The strain at the position of the strain gauge on the second beam is calculated based on the measured load and the finite element calculation results. The strain simulation results are compared with the measured strains, and the virtual strain is basically matched with the measured strain by adjusting the load coefficient to eliminate the influence of factors such as grid density on the model. Taking R1 and R2 as the example, the comparison between the virtual strain and the measured strain at R1 and R2 is shown in Figure 3. In the figure, the red strain spectrum is the virtual strain and the blue strain spectrum is the measured strain. As can be seen from the figure that the virtual strain...
change trend of the two measuring points is consistent with the measured strain, and the average relative error is small.

![Comparison of virtual strain and measured strain](image1.png)

**Figure 3.** Comparison of virtual strain and measured strain at (a) R1 and (b) R2 positions.

### 3. Simulation analysis of vehicle frame fatigue life

#### 3.1. Collection of the frame measuring point load spectrum

Through the test tractor, the external load is collected on the section where the batch fatigue damage often occurs, and the signal data of each measuring point of the frame of about 100 kilo-meters is obtained. The collected signals are processed such as noise eliminating, de-zero drift, de-burring, etc. As shown in Figure 4.

![Signal collection and processing](image2.png)

**Figure 4.** (a) Signal collection and (b) processing.

#### 3.2. Fitting of material S-N curve

According to the fatigue test data of the tractor frame material, the material high cycle fatigue S-N curve is fitted based on nCode software. The S-N curve of the frame material is shown in Figure 5.
3.3. Fatigue life calculation of the frame

The tractor is in a stable state during normal driving, and the components of the frame are generally in the elastic range, and the fatigue load is almost in the HCF zone. Therefore, the fatigue life of the frame is evaluated based on the linear damage theory and the local stress method. The damage area and fatigue life of the structure are calculated by the S-N solver in nCode-DesignLife on the basis of input FE finite element model, the problematic pavement measured load spectrum and the material S-N curve. The simulation process is shown in Figure 6.

Figure 6. Simulation flow chart of frame fatigue life.

The fatigue life damage cloud image of the tractor frame and the weak fatigue life area are shown in Figure 7. Regardless of the units and nodes within the Rbe2 grab range near the hole, the distribution of the top 10 dangerous points with the lowest fatigue life is counted in Table 1.

Figure 7. Damage cloud map of the frame under problem road conditions.
Table 1. Location and life of fatigue weak points

| Damage areas                        | Dangerous point | Damage areas                        | Dangerous point |
|-------------------------------------|-----------------|-------------------------------------|-----------------|
|                                     | fatigue life (cyc) |                                     | fatigue life (cyc) |
| Near the saddle                     | 548             | Near the second                      | 579             |
| connection plate                    |                 | crossbeam                           | 636             |
|                                     | 568             |                                     | 649             |
|                                     | 642             |                                     | 649             |
|                                     | 693             |                                     | 703             |
|                                     | 766             | near the wing beam                   | 702             |

It can be seen from the table that the frame damage is mainly distributed near the saddle and near the second cross beam. The weakest point of fatigue is located near the saddle, and the number of cycles is 548, about 54,800 kilo-meters.

4. Comparison of simulation results with actual statistics

According to statistics, the fatigue fracture of the frame often occurs between 43,000 km and 57,000 km, and the cracking position is concentrated on the second crossbeam and the side of the saddle connection plate. The simulation results show that there are dangerous points on the side of the saddle connecting plate and the upper end of the saddle connection. At the same time, there are also potential weak points on the second crossbeam and the longitudinal beams near the second crossbeam, which are consistent with the actual cracking area of the frame. The fatigue life calculation result of the frame is about 54,800 kilo-meters, which is similar to the actual life of the frame. The simulation results are basically in keep with the actual situation.

5. Conclusion

1) The cumulative error such as grid density and algorithm iteration can be effectively reduced by modifying the finite element model with the measured strain and virtual strain, and the finite element simulation results are more accurate.

2) The driving life is about 54,800 kilometers and the fatigue point of this type of tractor frame is mainly distributed near the saddle and near the second crossbeam which basically matches the actual break position of the frame and the number of kilometers traveled.

References

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