The Failure Evaluation and Reliability Life Prediction Technique of Complex Artillery Equipment

Dalin WU¹, Jian HE¹, Yuliang YANG¹*, Yue LI¹ and Lei DONG²
¹Shijiazhuang Campus of Army Engineering University, Shijiazhuang, China
²66069 Army, Luoyang, China
*Corresponding author’s e-mail: yyl_liang@sina.com

Abstract. To accurately predict and master the actual combat capacity of the weapon system, the paper took a self-propelled artillery as the research subject and built the completely artillery system virtual prototype based on the dynamic theory. Extracted the dynamic characteristics of firepower system, running system and drive system, the performance variation and failure mechanism of the artillery system were studied by using the method of theoretical analysis, simulation and physical experiment. The paper built the fault evaluation and life prediction model in the process of shooting and driving by combining data fusion, deep learning, etc. The performance evaluation and the prediction of fault of the full artillery system were realized. It can provide references for the life evaluation and prediction of complex equipment system.

1. Introduction
Self-propelled artillery is a new artillery weapon of our army. It combines the firepower system of traditional artillery with the armoured chassis. It integrates machine, light, electricity and liquid. It has many advantages such as good manoeuvrability and high degree of automation. It will bear in future emergency operations. The main tasks of medium and long-range strikes and fire suppression are one of the important main battle equipment in modern warfare. However, the failure rate of self-propelled artillery installed in recent years is relatively high, and the use and management personnel of the troops have little control over the integrity of the artillery. It is unclear what faults may occur. The main reasons for the above problems are:

(1) Self-propelled artillery mission profile is complex, often driving on sand, paddy fields, loach and various non-grade roads, working conditions are very harsh, combat loads, impact loads and friction and wear and other complex random loads, on the artillery system The damage to the parts is particularly serious;

(2) Almost all of the self-propelled artillery equipment installed in the army has not been tested for full-life reliability in the true sense, resulting in a lack of reliability data for the self-propelled artillery system, and the fault law is unclear;

(3) Conventional and traditional technical means cannot scientifically study the failure law of the firepower system. The existing spare parts financing and maintenance support schemes have not been systematically tested and tested in wartime.

Therefore, mastering the failure rules of self-propelled artillery, the laws of spare parts consumption, the scientific development of spare parts financing plan and the maintenance guarantee program have become important factors for the self-propelled artillery to play an effective operational effectiveness.
In order to accurately predict and grasp the actual combat power level of weapons and equipment, this paper takes a self-propelled artillery as the research object, builds a complete virtual prototype model of artillery system based on dynamics theory, and extracts the dynamics of its firepower system, transmission system and walking system. The paper studied the quality variation law and failure mechanism of the artillery system by combining theoretical analysis, simulation calculation and physical experiment.

2. Self-propelled artillery virtual prototype modelling

First, solid modeling was performed in the Pro/E environment according to the actual size and dynamics of the guns. A constraint (binding force) is imposed on each of the bodies that make up the artillery system. On this basis, the solid model was transformed into a solid model with dynamic parameters in the ADAMS environment. Combine the Fortran language to compile a user-defined program, and obtained a virtual prototype model that can simulate the dynamic characteristics of the gun in the ADAMS environment. The virtual prototype model of a certain type of self-propelled gun is finally shown in Figure 1. The virtual prototype has 249 rigid bodies and 1267 degrees of freedom.

3. Failure assessment and life prediction of self-propelled artillery

Here, the self-propelled artillery was divided into a firepower system, a transmission system and a walking system according to its structural composition, and the failure assessment and reliability life prediction of each subsystem critical parts were carried out.

3.1 Barrel system

In the barrel system, there are three main forms of wear: the cam surface wear of the irregular profile, the cylindrical wear and the step wear. Taking the cam surface wear of the irregular profile as an example, the wear threshold calculation and life prediction of the baffle arm and its toggle arm (as shown in Figure 2) were calculated.

3.1.1 Wear theory research

For the cam surface wear of irregular contours, firstly, the working load spectrum and relative motion speed of the friction components are obtained through the established virtual prototype, and then the wear law obtained by the test is reflected to the parts corresponding to the number of times of the switch. The change of the outer contour of the transfer motion (reconstruction of the outer contour), and then the new load spectrum, relative motion speed, hardness and other indicators, and then use the wear law, ..., so repeated until the friction parts If the motion cannot be transmitted or the motion is not transmitted, the wear depth of the component is the wear threshold. The number of times the switch latch is the wear life of the friction component. In view of the current research on the impact force, it is still used here. An approximate estimation method: firstly, through the cam profile reconstruction,
the wear failure threshold is obtained by simulation, and then the wear life is estimated by the single
wear amount obtained for the initial profile.

3.1.2 Simulation load acquisition
Through the virtual prototype simulation, the cam collision force and the relative motion speed for the
initial contour when extracting the automatic switch latch are as shown in Figure. 3 and 4 respectively.

3.1.3 Wear and failure life calculation
Firstly, the baffle shaft and the baffle plate arming arm are evenly worn inward along the starting
contour into the virtual prototype, and the movement of the cartridge is simulated. It can be seen that
the surface of the two cams is grounded to a total depth of 3.5 mm. Left and right, the baffle will block
the pump. The load spectrum obtained by the simulated initial surface profile and the kinematic
parameters are substituted into the wear law of the material, and the profile change of the two cams
after a single wear can be obtained. The armature shaft and the toggle shaft arm can be calculated. The
wear and tear life of the automatic switch latch is about 2700 times.

3.2 Transmission system
In view of the complicated shape of the self-propelled propeller transmission member, the fatigue life
prediction process shown in Figure 5 is adopted.

3.2.1 Gear contact finite element model
The established finite element model of the gear contact is shown in Figure 6.

3.2.2 Extracting the stress history
The time history of the maximum stress point of the root by simulation is shown in Figure 7.
3.2.3 Determine the S-N curve of the gear material

The material of the drive train gear is 20Cr2Ni4A. Since there is no fatigue data of gear bending and contact of the material, the fatigue curve of the material is also corrected on the basis of the above smooth sample when calculating the fatigue life. Then the fatigue curve of the modified 20Cr2Ni4A is shown in Figure 8.

3.2.4 Determine the S-N curve of the gear material

When the pressure angle is 20°, the theoretical stress concentration factor at the root of the root is:

\[ K_r = 0.18 + \frac{1}{(\frac{\rho}{2b})^{0.15} \left(\frac{h}{2b}\right)^{0.45}} \]

where \( \rho \) is Root radius, \( h \) is distance from point C to point L, \( b \) is tooth width.

Used the modified linear cumulative damage criterion, the life of the gear is calculated, and the bending and contact fatigue life of the gear under multi-condition driving conditions at 50% and 99% reliability are shown in Table 1 and Table 2.

| Road Velocity | Level B | Level C | Level D | Level E | Level F | Level G |
|---------------|---------|---------|---------|---------|---------|---------|
| Second        | 0%      | 0%      | 0%      | 0%      | 0%      | 0%      |
| Third         | 0%      | 0%      | 0%      | 0%      | 0%      | 0%      |
| Fourth        | 0%      | 0%      | 0%      | 0%      | 0%      | 0%      |
| Five          | 0%      | 0.104   | 0.104   | 0.415   | 0.415   | 0.415   |

| Road Velocity | Level B | Level C | Level D | Level E | Level F | Level G |
|---------------|---------|---------|---------|---------|---------|---------|
| Second        | 0%      | 0%      | 0%      | 0%      | 0%      | 0%      |
| Third         | 0%      | 0%      | 0%      | 0%      | 0%      | 0%      |
| Fourth        | 0%      | 0%      | 0%      | 0%      | 0%      | 0%      |
| Five          | 8.73    | 1.88    | 6.244   | 6.058   | 6.058   | 6.058   |

3.3 Walking system

The torsion shaft is used to reduce the impact of the ground on the car body when the self-propelled gun is running. The torsion shaft is a solid steel solid round rod. The two ends of the shaft are respectively formed with long and short splines. The short spline is inserted into the small hole spline of the support to fix the torsion shaft, the long spline and the balance in the elbow shaft. When the road wheel is subjected to an impact, the balance elbow swings to twist the torsion shaft, and the
torsional deformation thereof acts as an elastic suspension. Take the suspension torque axis in the walking system as an example.

3.3.1 Determination of dangerous parts and acquisition of stress time history

The investigation shows that the fatigue fracture part of the torsion axis is in the thin rod part of the torsion axis, and the removal of the splines at both ends can ensure the better unit quality, so the spline modelling of the two ends of the torsion shaft is omitted in the solid modelling. The 3D solid model of the torsion axis was established by MSC. Patran, and the finite element mesh was divided. In order to ensure the calculation accuracy, the cell meshing has a higher density. The torsion axis model has a total of 13575 nodes and 13320 solid elements, of which 2664 are Wedge6 units and 10656 are Hex8 units. The finite element mesh of the torsion axis is shown in Figure 9.

![Figure 9. Twisted shaft part finite element mesh](image)

After the necessary material properties and element properties are set, the finite element static stress analysis of the torsion axis is performed using the Nastran solver. The figure below shows the shear stress cloud diagram of the torsion axis in the x-y direction under the torque of 8617 N\(\cdot\)m in the two-dimensional design torque spectrum. It can be seen from the Figure 10 that the maximum shear stress is 460 MPa and occurs in the middle of the torsion axis. The outer surface is also the most dangerous part of the fatigue failure of the torsion shaft. The maximum shear stress occurs uniformly on the outer surface of the torsion shaft working section (ie, the intermediate elongated section). Therefore, any part of the outer surface of the working section is a dangerous part of the torsion axis, and the stress time history is processed by the simple loaded member.

![Figure 10. Torsional axis shear stress cloud](image)

3.3.2 Fatigue performance of torsion shaft material

Apply the MM criterion to correct the part below the fatigue limit of the P-S-N curve.

Let the slope of the straight part of the finite life part of the PSN curve under a certain reliability in the double logarithmic coordinates (the logarithmic stress amplitude is the ordinate and the logarithmic cycle number as the abscissa) be k, and the slope of the horizontal section of the OM criterion For \(k_1=0\); the MM criterion takes the slope of the portion below the fatigue limit, which is equivalent to the two-parameter power function expression becoming partially under the fatigue limit; the EM criterion will be the finite life portion The slope k is directly extended below the fatigue limit, and the slope of the portion below the fatigue limit is considered to be \(k_3 = k\), as shown in Figure 11.

In the figure, \(S_E\) is the fatigue limit, and \(N_E\) is the number of cycles corresponding to the stress amplitude when the fatigue limit is reached. It can be seen from the figure that the MM criterion is between the OM criterion and the EM criterion, and the estimated fatigue life of the OM criterion is more dangerous than the EM criterion and the MM criterion. The OM guidelines are now largely
unincorporated. The EM guidelines are primarily used in the aircraft industry, and the MM guidelines have been adopted by many European industry standards.

3.3.3 Two-dimensional fatigue stress spectrum for each single working condition
The three-peak valley value processing is performed on the stress time history under the limited life condition, and the distribution parameters of the load cycle counting result are estimated. For various distribution forms, the K-S test is used for testing. The results of various tests are analyzed and compared. It is found that the mean value of the load obeys the normal distribution and the load amplitude obeys the lognormal distribution.

3.3.4 Fatigue life of each single working condition
The dangerous part of the torsion shaft is at the thin rod, which is a regular cylindrical shape, and the fatigue notch coefficient is taken as 1. The dimensional correction factor is 0.8025, and the surface quality coefficient is 0.856 with reference to the torsion axis. The fatigue stress is corrected, and the fatigue life estimation is carried out by the MTPMiner criterion. The fatigue life histogram of the torque axis reliability of 50%, 90%, 95%, 99% and 99.9% under each single working condition is shown in the Figure 12.

![Figure 12. Logarithmic fatigue life histogram of the torsion axis](image)

References
[1] WU Dalin, MA Jisheng, LI Yadong, etc. Model and simulation of a self-propelled gun chassis[J]. Journal of System Simulation. 2004.16 (11) :1153~1155.
[2] TANG Qinhuong, MA Jisheng, JIA Changzhi. Establishment of two-dimensional stochastic fatigue load spectrum in multiple-loading case for torsion shaft[J]. Journal of Vibration and Shock. 2007,26(2):105~106.
[3] DU Xiuju. Research on dynamic simulation and life prediction of self-propelled gun’s drive system[D]. Shijiazhuang: Ordnance Engineering College, 2005.
[4] DU Zhonghua, WANG Xinggui, DI Changchun. Study on shell stop mechanism abrasion in xx breech system based on virtual prototype technology[J]. Acta Simulata Systematica Sinica, 2002,14(9):1168~1170.
[5] WU Dalin, MA Jisheng, DU Zhonghua. Calculation and analysis on fatigue life of torsion shaft link for self-propelled gun on enhancement road[J]. Computer Simulation, 2012,19(12):30-33.
[6] China Society of Mechanical Engineering Materials Society. Fatigue failure analysis [M]. Beijing: Mechanical Industry Press, 1987, 10.
[7] ZHANG Yaou, MA Jisheng, WU Dalin. Modeling and simulation of road roughness based on the method of reverse fourier[J]. Journal of Hebei University of Technology, 2005.34(12): 66~69
[8] Armored tracked vehicle material handbook -metal materials[M]. Beijing: National Defense Industry Press 1985.7: 481 ~ 483