Shearer’s quadratic curve unloading torque shaft fracture characteristics numerical simulation

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Abstract. The type of Shearer’s cutting part torque shaft unloading groove has a significant impact on the fracture characteristics and reliability. Shearer’s flexible virtual prototype coupling model was established, combined with the actual working condition, loads of the torque shaft were obtained by ADAMS, the quadratic curve unloading groove of torque shaft crack finite element model was established, combined with fracture mechanics, FRANC3D was used to do numerical simulation and crack propagation analysis, the torque shaft crack’s stress intensity factor was obtained, quadratic curve unloading groove of torque shaft’s stable propagation were obtained, was 2.2333e5. Combined virtual prototype technology with fracture mechanics, provides a new technology and data support in the design and research of Machinery and equipment parts.

1. Introduction
The shearer’s cutting part torque shaft connects the motor and the driving system of cutting part through the external spline of involute, which plays an important role in the power transmission, elastic buffering and overload protection during the working process of shearer. When the shearer is running in overload, the torque shaft breaks to protect the key parts from failure due to overloading [1]. The unloading groove has an important impact on the fracture characteristics and reliability of the torque shaft. Reference [2] parameterized the quadratic curve unloading groove of torque shaft and conducted the modal analysis. The simulation showed that the optimized torque shaft avoids the resonance phenomenon [2]. References [3-4] studied the influence of main structural parameters and loads of the shearer’s cutting part torque shaft on its torsion characteristics, providing reference for the structure design of the torque shaft [3-4]. Reference [5] used the finite element ANSYS to perform a static analysis on the shearer’s cutting part torque shaft, and obtained the optimized structure of safety groove by combining the safety coefficient of torsion static strength [5]. To sum up, the research on the torque shaft of shearsers focused on the finite element analysis, and the fracture characteristics were not studied. Based on the flexible virtual prototype coupling technology and combined with the theory of fracture mechanics, the establishment of the quadratic curve unloading groove of torque shaft crack finite element model are introduced. With the application of FRANC3D numerical simulation on the torque shaft fracture properties, the quadratic curve unloading groove of torque shaft’s crack’s stress intensity factor was obtained. By running the numerical simulation on the crack propagation, the crack propagation trajectory and the crack stable propagation fatigue life were obtained.

2. Theoretical Background

2.1 Fracture Mechanics Theory
In fracture mechanics, the force-deformation of cracked components can be divided into three basic types, namely opening type, sliding type and tearing type \(^6\), as shown in figure 1:

![Type of Crack Diagram](image)

Fig.1 Type of crack

Assuming that the crack exists in an infinite plate, the calculation of the stress field and displacement field of the crack can be concluded as follows:

\[
\sigma_r = \frac{K_f}{\sqrt{2\pi r}} f_r(\theta) \tag{1}
\]

\[
u_i = K_i \sqrt{r} g_i(\theta) \tag{2}
\]

where \(\sigma\) is the stress component; \(\nu\) is the displacement component; \(f(\theta)\) and \(g(\theta)\) are the functions of polar coordinates; the corner mark I denotes the opening type crack, II denotes the sliding type crack and III represents the tearing type crack.

2.2 Fatigue life prediction theory based on fracture mechanics

The fatigue life calculation method based on fracture mechanics theory is more accurate and reliable than the linear fatigue loss accumulation theory \(^6\). The commonly used fatigue life method of fracture mechanics is Paris formula. The crack fatigue growth rate is:

\[
\frac{da}{dN} = C(\Delta K)^m \tag{3}
\]

where \(C\) and \(m\) are material characteristic constants; \(a\) is the length of the crack, mm; \(N\) is the number of cycles of the load; \(\Delta K\) is the difference between the maximum and minimum stress intensity factor.

The number of cycles from crack to fracture \(N_p\) is:
\[ N_p = \int_{a_0}^{a_c} \frac{da}{dN} \]  

(4)

where \( a_0 \) is the initial crack length, mm; \( a_c \) is the critical crack length, mm; \( N_p \) is the number of cycles from crack to fracture.

Paris formula is the basic formula of fatigue fracture problem, but due to the existence of threshold value in the process of material fracture, Donahue revised Paris formula \(^7\) and proposed the following generalized formula:

\[ \frac{da}{dN} = C(\Delta K - \Delta K_m)^m \]  

(5)

The number of cycles from crack growth to fracture \( N_p \) after correction is:

\[ N_p = \int_{a_0}^{a_c} \frac{da}{C(\Delta K - \Delta K_m)^m} \]  

(6)

3. Establishment of flexible virtual prototype coupling model of shearer’s torque shaft

Use ANSYS to establish the torque-axis modal neutral file, select Solid8node45 unit to divide the grid, set real constants, assign material properties and execute other operations, then establish its finite element model and external connection points required by simulation, and finally generate the modal neutral file required by ADAMS simulation \(^8\), as shown in fig.2.

![Fig.2 The modal neutral file of shearer torque shaft](image)

Based on the shearer load simulation program that the project team developed, the calculation of the working condition of the coal load is performed under the conditions that the front rocker arm roller dinting maximum angle is 3.51°, the rear rocker arm roller uplift maximum angle is 22.85°, the coal consistence coefficient \( f \) is 2.0, the cutting depth is 800 mm, the roller speed is 58 r/min, and the traction speed \( v \) is 10 m/min. Adding constraints, drives and loads in the ADAMS, the flexible virtual prototype coupling model of the shearer is obtained, as shown in figure 3.
4. Numerical simulation of torque shaft fracture mechanical properties

4.1 Numerical simulation of torque shaft crack stress intensity factor

In order to accurately simulate the stress intensity factor of crack front, the author generated 14 wedge elements with 16 nodes on the crack front and normalized them. The arc length was expressed as the ratio between the arc length from the start point to a certain point on the crack front and the arc length of the entire crack front, as shown in figure 4.

Fig.4 Crack front mesh

Establish the quadratic curve unloading groove of torque shaft crack finite element model in ANSYS. The normal crack is introduced at the torque shaft unloading groove [9-11]. Numerically simulate the unloading groove torque shaft after introducing the crack. The stress intensity factor results of type I, II and III are as shown in figure 5.

Fig.5 The torque shaft stress intensity factor

The figure 5 shows that the stress intensity factor of the quadratic curve unloading groove of torque shaft of type III is greater than the stress intensity factor of the I and II type, mainly for tearing type crack. The maximum stress intensity factor of III type is 2533MPa·mm1/2, and the minimum value is -1351MPa·mm1/2.
4.2 Numerical simulation and life prediction of torque shaft crack growth

The crack with a torque shaft radius of 2mm expanded by FRANC3D, the crack growth trajectory of the torque shaft is shown in figure 6.

![Image of crack propagation path]

Based on the crack growth analysis, formulas 4-6 were used to calculate the crack stable propagation fatigue life and unstable propagation fatigue life of the quadratic curve unloading groove of torque shaft. The fatigue life was $2.2333 \times 10^5$ times when the crack was stable to expand, and the fatigue life was $2.4752 \times 10^5$ times when the crack was unstable to expand.

5. Conclusion

Based on the fracture mechanics theory, using the flexible virtual prototype coupling technology, the fracture characteristics of the quadratic curve unloading groove of torque shaft were simulated numerically with the combination of micro dynamic fatigue and 3D crack growth analysis software FRANC3D. The conclusion is as follows:

(a) Based on the simulation results of the flexible virtual prototype, the fracture characteristics of the quadratic curve unloading groove of torque shaft were analyzed with FRANC3D software, and the stress intensity factor of the crack front was obtained. Besides, the torque shaft crack is mainly tearing type crack.

(b) The crack growth numerical simulation was performed by using FRANC3D software, and the fatigue life of the quadratic curve unloading groove of torque shaft based on fracture mechanics theory was obtained at $2.2333 \times 10^5$. The combination of virtual prototype technology and fracture mechanics provides a new technical and data support for the parts design and research in mechanical equipment.

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