Fatigue Life Analysis of Automotive Glass Regulator Based on ABAQUS and FE-SAFE

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Abstract: Taking automotive glass regulator (glass regulator for short) as investigative object, fatigue life of glass regulator in top dead center locked-rotor condition is analyzed by adopting the combined simulation of ABAQUS and FE-SAFE. Firstly, calculation criterion of fatigue life of glass regulator and the combined simulation steps of analyzing fatigue life of glass regulator are investigated. Afterwards, HYPERMESH is used to generate mesh of glass regulator and ABAQUS is used to finite element analyze glass regulator. Then, stress condition is obtained. Finally, stress condition, material fatigue property, loading spectrum are imported into FE-SAFE for analyzing fatigue life, and fatigue life nephograms are gained. Fatigue life nephograms suggest that fatigue life of plate curved part on slider, flanging on guide rail, the part near the mounting hole of guide pulley are short, on which risk of fatigue failure exists. This method provides theoretical basis for design of fatigue life of glass regulator.

1. Introduction

As a functional component for adjusting glass lifting of door, working condition of glass regulator affects comfort and safety of driver [1]. When glass regulator is locked-rotor on top dead center, slider and guide rail bear a large force, and there exists risk of fatigue failure on glass regulator. In order to avoid fatigue failure of glass regulator during working, fatigue life design of the parts prone to fatigue failure should be carried out. Risk of glass lifter fatigue failure is low within the designed fatigue life. Before design of fatigue life of components prone to fatigue failure, stress analysis and fatigue life analysis are needed to provide theoretical basis. At present, some scholars have studied fatigue life analysis of mechanical equipment and mechanical components. [2-6] used FE-Safe, ABAQUS and ANSYS software to carry out finite element analysis on fatigue life of different types of cranes, and identified the parts and fatigue conditions that are prone to fatigue failure on the cranes. [7-10] carried out finite element analysis on stress, strain and fatigue life of hydraulic connecting rod, axle and pick cutter and other mechanical parts. However, few scholars have studied fatigue life analysis of glass regulator. In this paper, ABAQUS and FE-SAFE are used to carry out the combined simulation analysis of fatigue
life of locked-rotor glass regulator on top dead center. Fatigue life nephogram obtained from analysis shows that fatigue life of slider shrapnel bending and guide rail flanging and guide pulley around the mounting hole is low, and there exists risk of fatigue failure on glass regulator. This method provides theoretical basis for design of fatigue life of glass regulator.

2. Calculation criteria and analysis procedures of fatigue life

2.1. Fatigue life calculation criteria
There are six criteria for calculating fatigue life of materials: principal stress criterion, principal strain criterion, maximum shear strain criterion, equivalent strain criterion, Brown-Miller strain criterion and Brown-Miller strain criterion under average stress correction.

(1) Principal stress criterion
Principal stress criterion takes maximum principal stress as standard of fatigue failure and calculates fatigue life by taking amplitude of maximum principal stress fluctuation under specific load spectrum into S-N curve. This method is only applicable to brittle metallic materials such as cast iron and high strength steel.

(2) Principal strain criterion
According to principal strain criterion, fatigue crack initiation occurs in plane with maximum amplitude of principal strain fluctuation. Calculation equation of principal strain fatigue life is shown in Eq. (1):

$$\frac{\Delta \varepsilon_1}{2} = \frac{\sigma'_{f}}{E} (2N_f)^b + \varepsilon'_{f} (2N_f)^c$$

Where $\Delta \varepsilon_1$ is dominant strain amplitude. $\sigma'_{f}$ is fatigue strength coefficient; $E$ is elastic modulus of material; $N_f$ is fatigue life of material; $\varepsilon'_{f}$ is fatigue ductility coefficient of material; $b$ is elastic fatigue index of material; $c$ is plastic fatigue index of material.

Principal strain criterion is applied on brittle metallic materials such as cast iron and high strength steel. This criterion can also be used for high cycle fatigue of ductile metal materials.

(3) Maximum shear strain criterion
Maximum shear strain criterion considers that fatigue crack initiation occurs in plane with maximum shear strain fluctuation amplitude. Calculation equation of shear strain fatigue life is shown in Eq. (2):

$$\frac{\Delta \gamma}{2} = (1+\mu_e) \sigma'_{f} (2N_f)^b + (1+\mu_p) \varepsilon'_{f} (2N_f)^c$$

Where $\Delta \gamma$ is tangent strain fluctuation amplitude; $\sigma'_{f}$ is fatigue strength coefficient; $E$ is elastic modulus of material; $N_f$ is fatigue life of material; $\varepsilon'_{f}$ is fatigue ductility coefficient of material; $b$ is elastic fatigue index of material; $c$ is plastic fatigue index of material. $\mu_e$ is poisson ratio of elastic material, and empirical value is 0.3. $\mu_p$ is poisson ratio of plastic material, and empirical value is 0.5. Eq. (2) can be simplified as Eq. (3):

$$\frac{\Delta \gamma_{max}}{2} = 1.3 \frac{\sigma'_{f}}{E} (2N_f)^b + 1.5 \varepsilon'_{f} (2N_f)^c$$

(4) Equivalent strain criterion
Equivalent strain criterion considers that fatigue crack initiation is caused by equivalent strain fluctuation. Calculation equation of equivalent strain fatigue life is shown in Eq. (4):

$$\frac{\Delta \varepsilon_{eff}}{2} = \frac{\sigma'_{f}}{E} (2N_f)^b + \varepsilon'_{f} (2N_f)^c$$

Where $\sigma'_{f}$ is fatigue strength coefficient of material; $E$ is elastic modulus of material; $N_f$ is fatigue life of material; $\varepsilon'_{f}$ is fatigue ductility coefficient of material; $b$ is elastic fatigue index of material; $c$ is plastic fatigue index of material; $\Delta \varepsilon_{eff}$ is equivalent strain fluctuation amplitude, and its calculation equation is shown in Eq. (5):
Equivalent strain criterion is difficult to correspond with experimental data, especially the multiaxial stress state where principal stress direction changes constantly.

(5) Brown-Miller strain criterion

Brown-miller criterion considers that principal shear strain of fatigue is in plane, but shear strain and positive strain are considered in failure. Brown-miller criterion is particularly suitable for ductile metal materials. It is recommended that this criterion (plastic fatigue) is used for fatigue of ductile guides.

(6) Brown-Miller strain criterion under mean stress correction

Mean stress correction Brown-Miller criterion is derived by introducing mean stress under Brown-Miller criterion. This criterion takes into account the influence of average stress and is more accurate.

2.2. Fatigue life analysis procedures

When glass regulator is locked-rotor on top dead center, fatigue life analysis steps of slider and guide rail are as follows:

(1) Stresses of slider and guide rail are finite element analyzed by ABAQUS.

(2) Import finite element analysis results of slider stress and guide rail stress into finite element analysis file window of FE-Safe.

(3) Determine parameters of slider and guide rail material in material data window of FE-Safe.

(4) Import load spectrum into data file window of FE-Safe.

(5) Set fatigue life algorithm in FE-Safe. Fatigue life algorithm is mainly related to material fatigue failure properties of slider and guide rail. Guide rail steel (especially when plastic deformation occurs) is low carbon steel with good toughness. Fatigue failure is mainly caused by joint action of shear Strain and positive Strain. Its fatigue Life algorithm is set as Biaxial Strain Life Brown Miller: -Morrow algorithm. Slider is a plastic part, and fatigue failure is in the form of tensile Principal Stress failure. Fatigue Life algorithm is set as Biaxial Stress Life Principal Stress: -Goodman algorithm.

(6) In analysis setting window of FE-Safe, set life nephogram as output.

3. Fatigue life analysis of slider

According to geometric dimensions and relevant parameters of a type of rope-wheel glass regulator in Wuhan Donghuan Body System company, slider finite element model was established by ABAQUS, shown in Fig. 1. Main stress and contact areas on slider are separately partitioned and divided into hexahedral mesh elements (C3D8R mesh elements), while rest areas are divided into automatic mesh elements (C3D4 mesh elements). Slider is made of plastic, its elastic modulus is 2600Mpa, poisson ratio is 0.38, and its density is 1.45e9t /mm³.

Fig.1. Mesh division of slider.

When glass regulator is locked-rotor on top dead center, stress nephogram of slider is shown in Fig. 2. Maximum stress is on shrapnel of slider, and maximum stress is 80.6mpa.
Fatigue failure of slider is mainly stress fatigue failure. According to data provided by enterprise, the S-N curve of slider material is shown in Fig. 3. According to the S-N curve of slider material, it can be found that fatigue life of slider material is highly sensitive to stress.

In FE-safe, SN Curve_Sample, the material provided by SAFE, is adapted. S-N curve is modified. Principlestress-Goodman criterion is selected to calculate fatigue life of slider material. In addition, fatigue load spectrum is shown in Fig. 4. Contact part of slide block and bending part of shrapnel mainly bear unidirectional load. Value of unidirectional load is between 0 and 1.

Stress, material fatigue properties and load spectrum of slider are introduced into FE-SAFE for fatigue life analysis, and fatigue life nephogram is obtained, shown in Fig. 5. Contact part of slider and bending part of shrapnel are prone to fatigue failure under given load spectrum, and fatigue life of bending part of shrapnel is less than $10^4$ times.
4. Fatigue life analysis of guide rail

Finite element model of guide rail is established by ABAQUS, shown in Fig. 6. Overall element size of guide rail is 2mm, element size at local stress concentration is 1mm, material of guide rail is DX54D+Z100 (Galvanized steel plate), and elastic modulus is 210Gpa, poisson ratio is 0.3, and density is 7.83e³t /mm³.

When glass regulator is locked-rotor on top dead center, stress nephogram of guide rail is shown in Fig. 7. Stress is concentrated on the upper flanging point A, where stress value is 240.1Mpa.

In FE-SAFE, SAE_950C-Manten is selected. Brown-miller criterion under average stress correction is selected as fatigue life calculation criterion of guide rail material. In addition, strain criterion fatigue load spectrum is shown in Fig. 4. Unidirectional load is applied on guide pulley, load spectral stress varies between 0 and 1.

Stress, material fatigue properties and load spectrum of the guide are introduced into FE-SAFE for fatigue life analysis, and fatigue life nephogram is obtained, shown in Fig. 8. Upper flanging of guide rail and around guide pulley mounting hole have low fatigue life under given load spectrum, about 2×10⁵ times.
5. Conclusions
In this paper, mesh division and finite element analysis of glass regulator are carried out by using HYPERMESH and ABAQUS. Afterwards, stress, material fatigue properties and load spectrum of glass regulator are introduced into FE-SAFE for fatigue life analysis. Several conclusions can be obtained:

1) When glass regulator is locked-rotor on top dead center, maximum stress is on shrapnel of slider, and there exists risk of stress fatigue failure.

2) When glass regulator is locked-rotor on top dead center, the contact part on slider and bending part of shrapnel have low fatigue life under the given load spectrum, and fatigue failure is easy to occur.

3) When glass regulator is locked-rotor on top dead center, stress is concentrated on the upper flanging of guide rail, and there exists risk of stress fatigue failure.

4) When glass regulator is locked-rotor on top dead center, fatigue life of the upper flanging of guide rail and installation hole of guide pulley is low under the given load spectrum, and fatigue failure is easy to occur.

Analysis of fatigue life of automobile glass regulator in this paper provides theoretical basis for fatigue life design and structure optimization of glass regulator. This paper provides reference for investigation of other types of regulators.

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