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Fatigue Analysis and Optimization of a Conductive Slip Ring with Finite Angle of Rotation

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Fatigue Analysis and Optimization of a Conductive Slip Ring with Finite Angle of Rotation

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Abstract. In this paper, according to the working environment characteristics and technical requirements of the conductive slip ring of a two-dimensional space tracking and aiming system, the power and control signal transmission between two relative rotating mechanisms is realized by using flexible circuit board, and a precise conductive slip ring with limited rotation angle is designed and optimized. The fatigue life performance of the conductive slip ring is verified and analyzed by testing and testing.

1. Introduction

In the space two-dimensional tracking and aiming system, the conductive slip ring is a precise electromechanical device to transmit power and control signals from the fixed mechanism to the rotating mechanism. With the rapid development of satellite, manned spacecraft, space station and other space applications, conductive slip ring is the key component of space two-dimensional tracking and pointing system, which determines the reliability and working life of the tracking and pointing system. Once the conductive slip ring fails, it will directly affect the whole tracking and pointing system. Therefore, the fatigue life of the conductive slip ring is very long. Life and reliability put forward higher requirements.

2. Structural design of conductive slip ring

Rotary finite angle precision conductive slip ring is composed of inner ring, outer ring, retaining ring, flexible circuit board (FPC) and other auxiliary components. The flexible circuit board (FPC) is arranged in the slip ring in a rotary way, and a goose-neck is formed between the inner and outer rings. The inner and outer rings realize power and control signals through flexible circuit board (FPC). Transmission. Compared with the spiral structure, it has the advantages of positive and negative torque consistency, stable working torque and so on. The structural diagram of the conductive slip ring is shown in Figure 1.

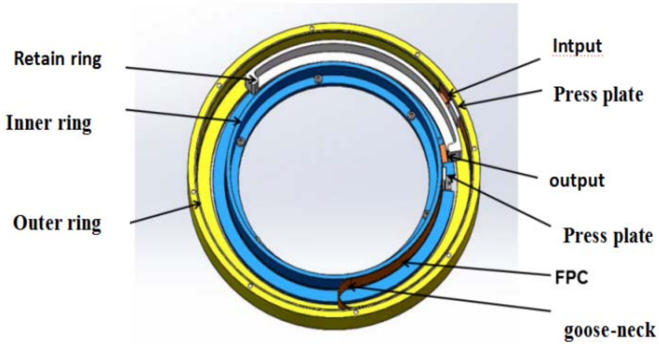


Fig. 1 Structural diagram of rotary finite angle conductive slip ring

3. Fatigue analysis of conductive slip ring

3.1. Fatigue analysis theory

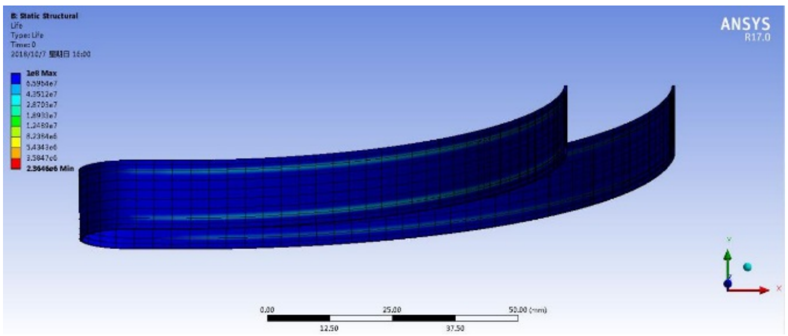
Fatigue refers to the phenomenon of fracture failure of members under alternating stress. There are many factors causing fatigue failure of conductive slip rings, including stress concentration, number of cycles, stress magnitude, structural size and other factors. Nominal stress method, local stress-strain method and fracture mechanics method are widely used to estimate fatigue life. Nominal stress method is used to predict the fatigue life of conductive slip rings.

In this paper, the power function formula is used as the empirical formula of S-N curve. According to the stress and life data table of calendered copper, as shown in Table 1, the S-N characteristic curve of calendered copper can be fitted, which provides a basis for software fatigue life simulation analysis[1].

Tab. 1 Three Scheme comparing

Stress/M.Pa	130	117	104	90
Life N/cycle	20000	41600	86000	218000
Stress/M.Pa	78	65	52	
Life N/cycle	595000	2250000	12000000	

3.2. The results of the analysis



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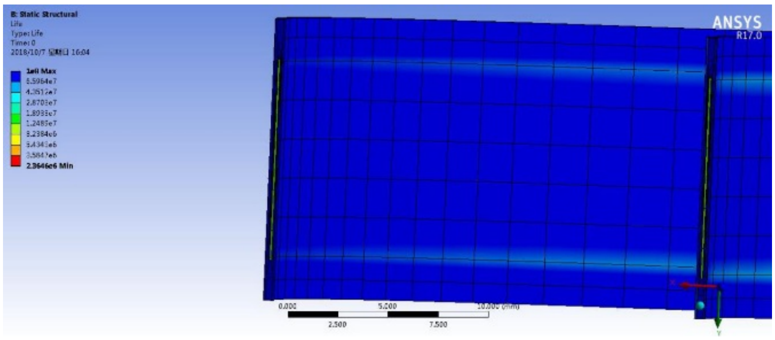

Fig. 2 Simulation results of fatigue life

As shown in Figure 2, under the condition of small angle reciprocating rotation, we can confirm that the fatigue life of the rotary finite angle conductive slip ring is 2.364E+06cycle. The fatigue life cannot meet the actual working conditions, and the conductive slip ring needs to be optimized. And the copper layer of the gooseneck of the flexible circuit board (FPC) is the first to fail, so the rotary finite angle conductive slip ring can be equivalent to the copper layer of the gooseneck of the flexible circuit board (FPC).

4. Optimization analysis of conductive slip ring

4.1. Optimization analysis setup

Based on the purpose of improving the fatigue life and stability of conducting slip ring, the fatigue life of conducting slip ring and the deformation amount of flexible circuit board were selected. These two parameters were optimized and the objective function was defined as [4]:

max： y1=f1(x) =f1 (Q1, Q2)

Min: y2=f2(x) =f2 (Q1, Q2) = {19 * GB2 * MERGEFORMAT}

s.t. E(x)=(x1,x2,x3...xn)

Where, the fatigue life of y1 conductive slip ring;Y2 is the deformation of flexible circuit board;Q1 is the bending radius of flexible circuit board;Q2 is the working radius of the goose neck with conducting slip ring;E (x) is the optimization constraint, which determines the value range of the optimization variable.

4.2. Optimization analysis results

After 300 generations of evolution, the Pareto solution set of multi-objective optimization of conductive slip ring is obtained, as shown in figure 3.

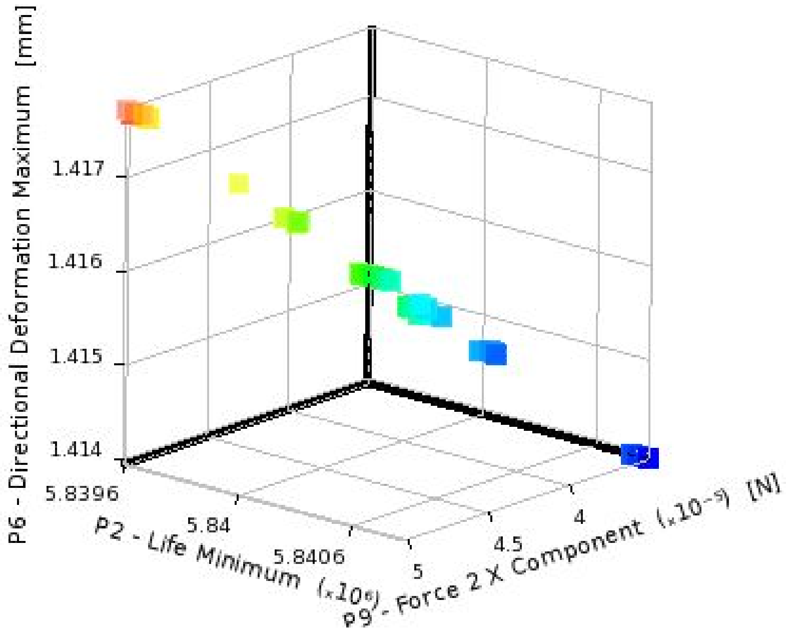

Fig. 3 Pareto solution set of conductive slip ring to target optimization

It can be seen from figure 4 that the fatigue life of conductive slip ring decreases with the increase of deformation amount of flexible circuit board.After finishing, the final optimization results were obtained for 3 alternative optimization results, whose parameters were shown in the table.

Tab. 2 Optimize the result parameter data

Variable	Optimization of 1	Optimization of 2	Optimization of 3
Working radius of goose neck Q2/mm	86.471	80.187	99.582
Bend radius Q1/mm	8.5872	8.5762	8.5724
Fatigue life y1/cycle	5.8408E+06	5.8407E+06	5.8404E+06
Flexibility y2/mm	1.4139	1.4139	1.4151

Comparing three groups to optimize data, found that the fatigue life of the first group of conductive slip ring and the deformation of flexible circuit boards of comprehensive optimization effect is best, the fatigue life analysis and computation of relative to the initial fatigue increased by 147%, adagio deformation decreased by 19% relative to the initial amount of calculation, theory can meet the demand of actual working condition, so choose the first set of numerical optimization design parameters were optimized.

5. Fatigue life test of conductive slip ring

In order to verify the high reliability and high life of the conductive sliding ring, the fatigue life test of the conductive sliding ring was carried out.

5.1. Fatigue life test plan

According to the IPC-TM-650 series standard [6], the failure judgement conditions are as follows:

1. Copper foil short circuit, circuit break, or its resistance value or current value changes more than 10%, line voltage changes more than 10%.

2, obvious fatigue cracks, fracture or adhesive layer failure occurred in visual inspection.

5.2. Fatigue life test results

After 17 days of fatigue life test, the cumulative cycle number reaches 5.86E+06cycle. The test device is shown in the figure 4. During the fatigue life test, the resistance of the conductive slip ring circuit was tested. It can be seen from the diagram that the maximum resistance is 0.192_, and the resistance growth is not more than 10% of the initial value. The results show that the resistance of the conductive slip ring can still meet the requirements after the fatigue test of 5.86E+06cycle and has a higher fatigue life.

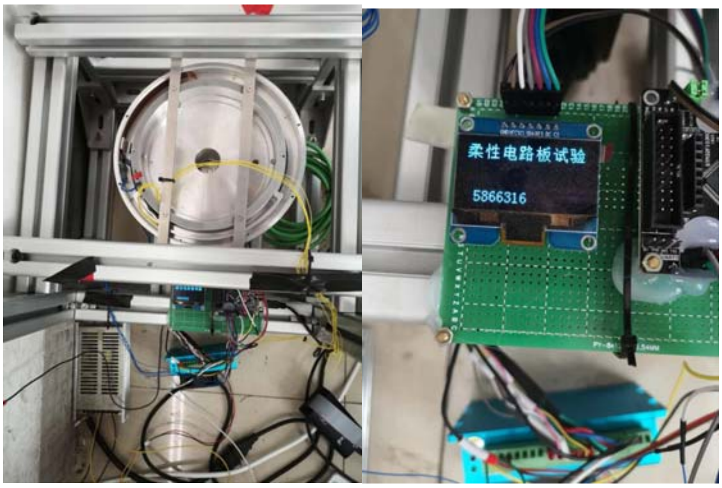

Fig. 4 Fatigue testing equipment

6. Conclusion

In this paper, the fatigue life of conducting slip-ring is analyzed, and the multi-objective genetic algorithm is applied to the optimization design of conducting slip-ring, so that Pareto solution set can be obtained from a large range of search solution space, providing a basis for the design of conducting slip-ring.Through fatigue life test, the accuracy of analysis is verified, and the advantage of high reliability and long life of conductive slip ring is determined.

Acknowledgments

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