Simulation Analysis of Mechanical Performance of the Broadband Coaxial Step Attenuator

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Abstract. In this paper, the structure and performance of broadband coaxial step attenuator are studied by simulation. Through the finite element static structure simulation, the stress and strain of the internal structure of the step attenuator are analyzed. The contact pressure, contact state and contact stability between the reed and the attenuation unit are analyzed. The theoretical analysis and calculation of the fatigue life with the nominal stress method are carried out. At the same time, the structure of the reed is optimized and improved for better performance. Then the dynamic mechanical properties of the structure are analyzed. The finite element simulation results show that the maximum stress is 395.53MPa. Due to the high stress in the contact area between the reed and the ejector rod, there will be micro cracks at these stress concentration positions under the constant impact of the ejector rod on the reed. The micro cracks gradually grow up and finally form the macro cracks, which lead to the reed fracture.

Keywords: Simulation, Mechanical performance, Reliability.

1. Introduction
Attenuator is a kind of device commonly used in test system[1-2]. Due to the limitation of the amplitude of the received signal at the receiving end of the precise testing instrument, therefore the input signal often needs to be attenuated by using an attenuator in the test, in order to make the amplitude can reach the requirement by the measured instrument[3-5]. At the same time, the step attenuator can also improve the impedance matching and make the load impedance more stable[6-7]. Due to its high-precision and good impedance matching, it has been widely used in RF and microwave technology. Because the signal attenuation of the step attenuator is realized by a lot of opening and closing actions, the structure and performance of the step attenuator will have an impact on its accuracy, especially the mechanical properties have a significant impact[8-10]. In this paper, the structure and performance of broadband coaxial step attenuator are studied by simulation in order to analyse the effect on the reliability of the step attenuator.

2. Simulation Analysis of Static Performance of the Step Attenuator
The step attenuator have several attenuation units which can provide different attenuation amplitude. One of the attenuation units is modeled as shown in Fig.1 and Fig.2. The reed is simplified into a cantilever beam, and the cantilever beam is affected by two concentrated forces. The static simulation results of the model are shown in Fig.3, it shows that the stress is mainly concentrated at the fixed end of the reed and the contact area of ejector rod and the reed. The stress in these locations is relatively high because the reed is bent and produce a high stress or the impact of the ejector rod on reed.
simulation results show that the maximum stress is 395.53Mpa, and the maximum stress is located at the connecting end between the reed and the fixed stage. Under the impact of the ejector rod, the stress concentration of the reed appears at the contact area between the ejector rod and reed. At the same time, the reed are constantly bent and deformed in the actual working process. Because spring works under dynamic load for a long time, it will lead to fatigue failure, so the nominal stress method is usually used to estimate the fatigue life of structures. The nominal stress method is based on the S-N curve of material or structure, compared with the nominal stress of specimen or structure, combined with fatigue damage accumulation theory, to estimate the fatigue life. The theoretical analysis and calculation of the reed fatigue life are carried out, the result is shown in Fig.4. The theoretical calculation shows that the fatigue life of spring decreases with the increase of spring stress. If the reed works under high dynamic stress for a long time, the stress concentration will cause micro cracks [11].

Figure 1. Single attenuation element model.

Figure 2. Theoretical model of the attenuation element.

Figure 3. The stress distribution diagram of attenuation unit.
3. Optimization Simulation of Reed Structure and Size

Figure 5 shows the structure size of the original attenuation unit, which can meet the requirements of a certain frequency. However, with the increase of switching frequency, the structure size of the reed of the broadband coaxial step attenuator needs to be reduced to meet the requirements. After the structure improvement, the coaxial step attenuator becomes narrower and thinner. The width is reduced from 1.12 mm to 0.62 mm, and the thickness is reduced from 0.06 mm to 0.04 mm. As the reed becomes thinner and thinner, the stiffness of the reed structure will be significantly reduced. According to the existing design requirements, it is necessary to change the length of the reed and the distance between the fixed end to the ejector rod to improve the reed stiffness. In order to improve the reliability, the positive pressure between the reed and the attenuator should be kept at 0.04N, so the length of the reed should be shortened. It is necessary to ensure that the maximum stress value of the reed is within the allowable range of its fatigue life, and the positive pressure between the reed and attenuation unit should be kept stable. Therefore, changing the length of ‘\(a\)’ while ‘\(l\)’ remains unchanged, the maximum stress of reed decreases and the stiffness increases. According to the previous analysis of the simulation results, it is necessary to design the length of the reed between 4mm and 5mm, if the positive pressure between the reed and the attenuation unit is 0.04N.

The length of the reed is set as 5mm, 4.5mm and 4mm respectively. For each length of reed, different distances from the ejector rod to the fixed end are selected to analyze and compare the maximum stress and the maximum positive pressure of contact interface. The results are shown in Fig.6~ Fig.8. It shows that when the length of the reed is 5mm, the positive pressure between the reed and the attenuator unit cannot meet the requirement of 0.04N, so the length of the reed needs to be further shortened. When the length of the reed is 4mm, the maximum stress is 1130Mpa. Under this stress, the fatigue life of the reed will be greatly reduced. When the length of the reed is 4.5mm and the distances from the ejector rod to the fixed end is 3.6mm, the positive pressure between the reed and the attenuator is 0.04N and the maximum stress value of the reed is 449.74mpa, which both can meet the requirements.
Figure 6. The maximum normal stress and positive pressure for the different $a$ when $l=5mm$.

Figure 7. The maximum normal stress and positive pressure for the different $a$ when $l=4mm$.

Figure 8. The maximum normal stress and positive pressure for the different $a$ when $l=4mm$.

4. Structural Dynamics Simulation of the Broadband Coaxial Step Attenuator

Transient dynamic analysis is a dynamic response analysis method used to determine whether the system can withstand time-varying load, so as to predict the displacement, stress and strain under time-varying load. The broadband coaxial step attenuator also bear the time-varying load from the ejector rod. The ejector rod of the step attenuator is a variable acceleration motion driven by the relay. It is simplified into a uniform acceleration to simulate the impact of the ejector rod on the reed.

The overall stress distribution diagram of the model is shown in Fig. 9. The stress concentration position is basically the same as the result of structural static simulation analysis, which are respectively located at the fixed end and the contact area between the ejector rod and the reed. The maximum stress slightly increases to 396.39Mpa. Figure10 shows the ten points of the reed, with an average value of 365Mpa. Due to the high stress in the contact area between the reed and the ejector rod, there will be micro cracks at these stress concentration positions under the constant impact of the ejector rod on the reed.
Figure 9. The stress distribution diagram of dynamic simulation analysis.

(a) Stress distribution of the fixed end

(b) Stress distribution of the contact area between the ejector rod and the reed

Figure 10. Stress distribution of the fixed end and the contact area.

The contact area between the reed and the ejector rod was analyzed by SEM, as shown in Fig. 11. The rectangle area in the figure shows the impact trace produced by tens of thousands of impacts during the operation of the ejector rod. Meanwhile, some metal debris is produced during the process, which contains some metal oxides. If it enters the contact interface, it will lead to the increase of contact resistance.
Figure 11. SEM morphology of the contact area between the reed and the ejector rod. Under the push of the ejector rod, the reed will accelerate its movement. When the reed and the attenuator unit are in contact, the contact state is line contact. The reed has a great impact on the coating of the attenuator unit. Then, the impact effect was weakened and the contact state will change from line contact to surface contact. There will be the relative sliding between the reed and the attenuator coating until the final stable contact state was reached. The coating of the attenuator unit was analyzed by SEM, and the indentation of the coating was produced under the impact of the reed, as shown in Fig. 12. In the process of impact, because the impact is strong and the gold plating is soft, the coating material will flake off locally. The coating material in the contact area will become thinner, which will directly affect the contact resistance and reduce contact reliability. The contact pressure between the reed and the attenuator unit has great influence on the contact resistance and contact reliability. Fig. 13 shows the change curve of the contact pressure with time in the transient dynamic analysis. From the curve, the contact pressure is 0.04N in the final stable contact, which meets the design requirements.

Figure 12. SEM morphology of contact area

Figure 13. Change curve of contact pressure between reed and attenuator unit
5. Conclusion

(1) Through the finite element simulation, the maximum stress is 395.53MPa and the maximum stress is located at the connecting end between the reed and the fixed stage. The theoretical calculation shows that the fatigue life of the reed decreases with the increase of spring stress.

(2) When $L = 4.5 \text{mm}$, $a = 3.6 \text{mm}$, the maximum normal stress and the positive pressure between the reed and the attenuator unit both can meet the design requirements.

(3) There will be micro cracks at these stress concentration positions under the constant impact of the ejector rod on the reed. The micro cracks gradually grow up and finally form the macro cracks, which lead to the reed fracture.

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