Optimal design of sealing structure of vehicular radar case door

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Abstract—The quality of antenna array environment control technology directly affects the reliability and service life of vehicular radar. The structure design of case door sealing is an important part of the environmental control technology of vehicular radar. The stress distribution analysis of case door sealing structure of vehicular radar antenna is carried out in this paper. Maximum stress of double-peaked sealing ring and stress distribution and deformation of case door panel are investigated through finite element analysis based on ABAQUS. In order to increase the reliability of sealing structure, the section size of double-peaked sealing ring and the spacing length of fasteners are optimized by the way of co-simulation optimal design method using ISIGHT. Through radial basis function neural network surrogate model, which is built based on Latin hypercube sample algorithm, the sensitivity of each optimization variable is analyzed. Meanwhile the optimal section size of double-peaked sealing ring and spacing length are obtained through non-dominated sorting genetic algorithm.

1. Introduction
Higher integration and mobility is required with the development of vehicular active phased array radar. A large number of electronic equipment and devices are installed in the highly integrated radar antenna array, while high-mobility brings more severe environmental test. Therefore, the quality of antenna array environment control technology directly affects the reliability and service life of radar. The structure design of case door sealing is an important part of the environmental control technology of the antenna array. Failed sealing structure exposes the electronic equipment and devices to the harsh environment, which will not only cause device failure, ignition, insulation resistance reduction, corrosion and other phenomena due to water leakage, but also seriously affect the service life and product image of radar, and increase the workload of maintenance.\textsuperscript{[1-2]} Based on an engineering application example, the modeling and calculation of the stress distribution of the case door sealing structure of the antenna array are carried out in this paper. The value of maximum stress of double-peaked sealing ring and stress distribution of case door panel are obtained by finite element analysis.

Based on the results of finite element analysis, a co-simulation optimal design method is provides in this paper to obtain the optimal section size of double-peaked sealing ring using ISIGHT. Firstly, the radial basis function neural network is chosen as surrogate model, which reflects the nonlinear relationships between the optimization objectives and variables. Secondly the surrogate model is built based on Latin hypercube sample algorithm. Lastly, the size of the sealing ring section is optimized by this surrogate model through non-dominated sorting genetic algorithm.
2. Finite element analysis of sealing structure

2.1 Modeling of sealing structure

The sealing structure of case door of a typical vehicular radar antenna is shown in Fig. 1. The case door sealing structure is composed of hinge, case door panel, sealing ring and fastener. Under the condition of locked, the door panel is preloaded by the fasteners. The rubber sealing ring produces elastic deformation under the action of preload and fills the gap between the door panel and the case, which achieves the purpose of sealing.[3]

![Fig. 1. Case door and sealing structure](image)

The solid 3D model of case door is built in CREO. The model is imported to ABAQUS for finite element analysis. The key point of finite element analysis of seal structure is the accurate establishment of seal ring model. Different from metal material which have a certain elastic modulus, the material of sealing ring is silicone rubber. Silicone rubber belongs to super elastic material. Therefore, the material parameters of silicone rubber are important parameters for the reliability of finite element simulation. The constitutive model of silicone rubber is a parameter model reflecting its stress-strain relationship. Mooney-Rivlin model with two parameters is widely used in engineering application. Mooney-Rivlin model is chosen to reflect the nonlinear stress-strain relationship in this paper. The parameters are shown in Table.1.[4]

| Structure       | Material parameters     | Value   |
|-----------------|-------------------------|---------|
| Sealing ring    | Elasticity (M-R model)  | C_{10} 0.42 |
|                 |                         | C_{01} 0.035 |
|                 |                         | D       0   |
|                 | Density (g/cm³)         | 0.87    |
|                 | Elastic modulus (GPa)   | 68.9    |
| Door panel      | Poisson's ratio         | 0.33    |
|                 | Density (g/cm³)         | 2.7     |
| Hinge/Fastener  | Rigid body              |         |

The friction contact is adopted between the box and the sealing ring, and the friction coefficient of rubber material and aluminum is set as 0.3. The sealing ring and door panel are meshed as hexahedron.

2.2 Stress distribution analysis of sealing ring

The relative displacement is applied to both sides of the seal groove. The double-peaked seal ring is compressed in the width direction to simulate the precompression state of the seal ring. Based on this step, the longitudinal compression is applied to the double-peaked seal ring until the seal ring is completely compressed into the groove, which simulates the compression of the door panel. The stress nephogram of the sealing ring in the whole sealing process is shown in the Fig.2.
The stress nephogram shows that the maximum stress of double-peaked seal ring appears in the middle hollow during the compression process. The value of maximum stress is 2.58MPa. Also the reaction force of sealing ring during compression process is shown in Fig.3, the value of force increases with the increase of the compression value, which reflects the nonlinear relationship. And the maximum value of reaction force is 1.75N when the sealing ring is completely compressed into the sealing groove.

2.3 Stress distribution analysis of door panel

Based on the analysis results of section 2.2, the door panel is subjected to a greater reaction force during the compression process. The material of the door panel is aluminum alloy sandwich layer structure, so the larger reaction force may cause the deformation and damage of the door panel. So the stress distribution of door panel is also analyzed through finite element simulation.

A displacement load which equals to the compression value of sealing ring is applied to the 6 fasteners’ position on the door panel. The stress nephogram and displacement nephogram of door panel is shown in Fig.4.

The value of maximum stress shown in the Fig.4. is 18.9Mpa. The maximum displacement occurs in the fasteners’ position, the value of which is 2.2mm. The minimum displacement of the door panel
appears in the middle of the two locks on the transverse side, where the displacement is 2.0 mm. Based on this result, the door plate is deformed due to the preload, and the flatness of the door plate increases by 0.2. The deformation of door panel causes some area of the sealing ring is not completely compressed, which will increase the risk of water leakage.

3. Optimal design of the sealing ring size

3.1 Surrogate model of the optimization

Based on the results of finite element simulation analysis, the Height H and width W of double-peaked sealing ring and the spacing length L of two fasteners on the transverse edge of the door panel are chosen as optimization variables. The maximum stress of sealing ring S and the maximum deformation of door panel D are chosen as optimization objectives. The calculation of finite element model cost tremendous amounts of time. So surrogate model is built for optimization iteration based on co-simulation software ISIGHT[5] in this paper. The principle and method of surrogate model is shown in Fig. 5.

![Fig. 5. Optimization method based on ISIGHT](image)

The Latin hypercube sample algorithm is chosen as sampling algorithm. Radial basis function neural network is chosen as surrogate model to reflect the nonlinear relationships between the optimization objectives and variables. The design variables of the optimization are the Height H and width W of double-peaked sealing ring and the spacing length L of two fasteners on the transverse edge of the door panel. The mass of the sealing ring M must be less than the mass m before optimization. So the constrains of optimization is shown by Eq. (1).

\[ M \leq m \] (1)

The range of variables are shown in Table.2.

| Variables          | H(mm) | W(mm) | L(mm) |
|--------------------|-------|-------|-------|
| Initial value      | 6.3   | 5.8   | 260   |
| Minimum value      | 5.0   | 4.6   | 208   |
| Maximum value      | 7.6   | 7.0   | 312   |

3.2 Results of the optimization

Based on the Latin hypercube sample data, the sensitivity of each parameters is analyzed, which is shown in Fig.6. The most critical parameter to the maximum stress of sealing ring is the height of ring section. Also the result shows the maximum stress has no relevance with the spacing length L of two fasteners. Because the sealing ring is completely compressed at the locked position which is not affected by the spacing length. Meanwhile the height of ring section is the most critical parameter to the deformation of door panel.
Fig. 6. Sensitivity of parameters

The non-dominated sorting genetic algorithm with 60 generation and 35 samples of each generation is carried out in this optimization model. The aim of the optimization is to reduce the maximum stress of sealing ring and the maximum deformation of door panel. The results of this multi-objectives optimization are Pareto solutions, which is shown in Table.3.

| H(mm) | W(mm) | L(mm) | S(Mpa) | Reduction(%) | D(mm) | Reduction(%) |
|-------|-------|-------|--------|--------------|-------|--------------|
| 5.8   | 6.0   | 254   | 2.11   | -18.2        | 0.14  | -30          |
| 6     | 5.4   | 240   | 2.20   | -14.7        | 0.12  | -40          |
| 6.4   | 4.9   | 243   | 2.03   | -21.3        | 0.15  | -25          |

4. Conclusions

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) The finite element simulation based on ABAQUS is carried out in this paper to analyze the stress distribution of sealing structure of vehicular radar case door. Based on the analysis, the maximum stress of double-peaked sealing ring and the maximum deformation of door panel are obtained.

(2) The section size of double-peaked sealing ring and spacing length of fasteners on the door panel are optimized through surrogate model and multi-objectives optimization method based on ISIGHT. The maximum stress of sealing ring is reduced by 14.7% after optimization. Meanwhile, compared with the door panel before optimization, the maximum deformation of door panel is reduced by 40%. The reliability of sealing structure of vehicular radar case door is improved through optimal design.

References

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