Finite Element Analysis of Antenna Array of Large Meter Wave Height Mobile Dual Polarization Radar based on NASTRAN

JinWei Wang, YeQing Gu and BaoFu Tang
Nanjing Research Institute of Electronics Technology, Nanjing 210039, China
13913365261@139.com

Abstract. A large-scale meter wave high maneuvering dual polarization radar is designed with a cantilever folded beam. In order to realize the high tolerance spread of its dual polarization antenna, it is necessary to ensure that its folded spread antenna array has high plane stiffness. Firstly, the finite element model is established according to the geometrical model of the antenna array. Secondly, the corresponding load conditions are determined according to the material parameters of the antenna array, different wind loads and temperature fields. Then, the mechanical calculation and analysis of the antenna array are carried out by using NASTRAN software, and the deformation, stress and deformation of the antenna array element and folded beam under different conditions are obtained Square root value. The results show that the array can meet the requirements of stiffness and strength.

1. Introduction
With the gradual deployment of F-22, F-35 and other aircrafts around China, the demand of high mobility meter wave radar for long-range, medium and high altitude surveillance of stealth aircrafts in the region, mobile supplementary network, strong network and emergency air situation support tasks is becoming more and more urgent [1]. Due to the limitation of wavelength and warning task, the scale of meter wave radar antenna is large. In order to ensure the stable operation of its overall radar system, the mechanical structure of its antenna array surface needs to have sufficient rigidity and strength under complex working conditions [2]. Therefore, during the design of radar antenna array, it is usually carried out simulation calculation [3]. At present, in view of the radar antenna array design and analysis, the main of antenna array the whole skeleton model of finite element model is established, and the corresponding just strength calculation by finite element software, but in this way the calculation is often the result of the reaction is the stress level and change trend of the antenna array [4], there's no other response matrix surface to the stress of the key components and the deformation tendency.

In this paper, a reasonable finite element analysis model is established for a large-scale meter wave high maneuvering dual polarization radar. Based on this, NASTRAN is used to analyze the antenna array, antenna element, folding beam and other key components of the radar under multiple working conditions, check the deformation and stress values, calculate the corresponding deformation root mean square value, and verify the whole array and related components Structural safety. The results show that the stiffness and strength of the antenna array can meet the corresponding requirements.
under complex working conditions, which can provide reference for the design and calculation of similar structure antenna array.

2. Array structure and establishment of finite element model

2.1. Array structure
The radar antenna array studied in this paper is mainly composed of antenna beam, folding beam, antenna unit blade, reflection net, roller and connecting bolt. For the finite element analysis of the whole structure of the antenna array, it is necessary to establish the corresponding structural model of the whole antenna array. However, due to the complexity of the actual structure, it takes a lot of time to model and calculate. The actual model is simplified into a reasonable structure model for calculation to ensure that the calculation results are similar to the actual test results. Figure 1 shows the simplified antenna structure model.

2.2. Establishment of finite element model
In order to ensure the accuracy and reliability of the finite element analysis results, this paper first focuses on the basic composition of the radar array structure, the stress characteristics of key components, material performance, boundary conditions and external loads and other major factors, to determine the reasonable element type, material characteristics, constraints, connection relationship and load distribution, etc., to reduce the calculation knot as much as possible. The error between the result and the actual result. The finite element model of the whole radar antenna array mainly includes:

1) element type: due to the complex structure of the antenna array, in order to reduce the finite element model and calculation amount of the whole array, the parts on the crossbeam are represented by solid elements, and the other plate and shell structures, including crossbeam, reflection net, antenna element blade, are represented by shell elements.

2) unit property: according to the stress characteristics, material properties and use requirements of different structural parts in the radar antenna array, the materials used for the antenna beam, folding beam, reflection net, roller, sleeve and connecting bolt are steel, and the materials used for the antenna unit blade are aluminum. The elastic modulus of steel is 210000 MPa, Poisson's ratio is 0.3, and density is 7.9e-9 (t/mm³). The elastic modulus of aluminum is 72000 MPa, Poisson's ratio is 0.33, density is 2.7e-9 (t/mm³).

3) grid division: Figure 2 is the grid model of the antenna, which is based on the geometric model to ensure the quality and centroid remain unchanged, and the grid size is 30mm. The parts on the crossbeam are modeled by solid elements. The other plate and shell structures are expressed by shell element, and the grid treatment is carried out by the middle surface. In figure 2, X: antenna deployment direction; Y: gravity direction; Z: vertical antenna blade direction. figure 3 is the mesh model of antenna element. Based on the geometric model, the middle plane is extracted for mesh processing to ensure the quality and centroid remain unchanged, and the mesh size is 15 mm.
2.3. Connection problem
According to the connection relationship of the main components on the antenna array, the connection relationship of the main components in the process of finite element modeling is as follows: the reflection network on the adjacent folding beam creates an Rb2 on both sides respectively, so that the Rb2 center points of the reflection network on the adjacent side coincide, creates an Rb2 at the center point, connects two coincident nodes, and releases the degree of freedom around the Y axis, as shown in figure 4. It is shown. The antenna crossbeam and the reflection network are connected by hinges. Rb2 connection is established at the hinge rotation axis, and the freedom of rotation around the Y axis is released. Other freedom constraints are shown in figure 5. Rb2 is set up through bolt holes to connect the reflector support and beam, and fixed connection is shown in figure 6. The blade is bolted to the epoxy plate (the blade and the epoxy plate share the joint), and the blade and the hinge are bolted (the blade and the hinge share the joint), as shown in figure 7.

3. Calculation condition and load
There are many loads on the radar antenna array in the outdoor working environment, including dead weight, wind load, ice and snow load, inertial load and temperature load when the antenna moves. Considering the actual working environment, this paper focuses on the analysis of the stiffness and strength of the antenna array under the combined action of gravity field and wind load, as well as the analysis of the stiffness and strength under the combined action of gravity field and temperature field. The basic equation of structural analysis is shown in formula (1) [5]:
\[
[K][U] = \{F\}
\]  

(1)

Where, \([K]\) is the overall stiffness matrix of the structure; \([U]\) is node displacement array; \([F]\) is the node load array.

According to the working status and load bearing of antenna array situation faced by working condition, to calculate the wind load is divided into front and back to the antenna array antenna is surface, which is opposite with his back to the antenna array surface wind velocity of 25 m/s respectively, 30 m/s and 35 m/s, consider the corresponding wind speed at the same time the antenna surface of the centrifugal force, were set to 0.1 r/s, 0.05 r/s, 0 r/s, when the angular velocity is defined to antenna actual center of rotation axis rotation.

The effects of gravity field and temperature field on the antenna array face are set as two working conditions, namely, working condition 1 is considering the dead weight, and the ambient temperature is 20°C, reducing to -40°C. In working condition 2, considering the dead weight, the ambient temperature is 20°C and rises to 60°C.

4. Loading and constraint

4.1. Connection problem

Because the wind speed does not change regularly at any time, the wind load is a kind of dynamic load. This paper mainly considers that the structure of the antenna array is a large rigid structure with a large overall mass and the wind will not cause great vibration to the structure. Therefore, the wind load is considered as static load in the simulation calculation. The calculation formula of wind load is shown in (2)

\[
F = C_{Fq}A
\]  

(2)

Where, \(C_{Fq}\) is the wind pressure value and \(A\) is the characteristic area of the object.

When the wind load is divided into the front face of the antenna, the wind load is evenly distributed on the reflective network, the beam and the parts on the surface of the beam. After calculation, the wind pressure corresponding to the wind speed of 25m/s, 30m /s and 35m /s is 0.0003949 MPa, 0.0005924 MPa and 0.0007899 MPa respectively. When the wind load is divided into the array facing the back of the antenna, the wind load is evenly distributed on the surface of the reflective network and the beam. The wind speed is 25m/s, the wind pressure corresponding to 30m /s and 35m /s is respectively 0.0003686 MPa, 0.0005528 MPa and 0.0007371 MPa.

For the gravity load of the antenna array, only the value of gravity acceleration needs to be specified, and the load can be completed through NASTRAN.

4.2. Constraints

According to the actual test situation, 6 degrees of freedom are constrained at the binding of the folded beam and the inner sleeve before calculation, as shown in figure 8

![Figure 8. Antenna constraints](image-url)
5. Calculation results and analysis
One of the main mechanical indexes of the antenna array surface is the precision of the reflection surface [6], and what affects the performance of the antenna array is the error condition of the whole reflection surface, which is measured by the root mean square value of the normal phase error of each node on the reflection surface. In this paper, the stress of the antenna array under different working conditions and the related deformation results are obtained through calculation and analysis, and then the RMS value of the reflection network model is obtained through calculation based on the obtained deformation results. Among them, the antenna array surface under the corresponding working conditions under the combined action of wind load and gravity field, the stress cloud diagram of folded beam and the displacement cloud diagram are extracted, as shown in figure 9, figure 10, figure 11 and figure 12 respectively. Through calculation, the deformation, stress and corresponding root mean square planting of antenna element and folded beam in antenna array face under different wind load conditions are obtained, as shown in table 1.

| Wind speed | The direction of the wind | Antenna unit blade (aluminum) | Folding beam (steel) | Antenna array displacement | Antenna element displacement in Z direction | Z direction displacement of blade | Y direction displacement of folded beam | Reflection network | Antenna element blade |
|------------|---------------------------|------------------------------|----------------------|---------------------------|------------------------------------------|---------------------------------|----------------------------------------|-------------------|----------------------|
| 25m/s      | Facing the antenna array  | 151.37                       | 249.23               | 65.02                     | 32.86                                    | 29.98                           | 55                                      | 3.8294            | 3.1201               |
|            | Back to antenna array     | 135.68                       | 266.33               | 61.3                      | 29.31                                    | 26.8                            | 54.92                                  | 3.9610            | 3.2111               |
| 30m/s      | Facing the antenna array  | 138.06                       | 222.83               | 61.82                     | 27.45                                    | 27.45                           | 55.2                                   | 3.8285            | 3.3409               |
|            | Back to antenna array     | 126.49                       | 235.88               | 60.41                     | 25.14                                    | 25.14                           | 55.1                                   | 3.8753            | 3.4712               |
| 35m/s      | Facing the antenna array  | 136.49                       | 216.39               | 62.55                     | 29.77                                    | 27.18                           | 55.41                                  | 4.0590            | 3.5832               |
|            | Back to antenna array     | 131.61                       | 230.47               | 60.68                     | 26.15                                    | 26.15                           | 55.27                                  | 4.0614            | 3.7432               |
The displacement cloud images of the antenna array surface extracted under working conditions 1 and 2 under the action of temperature field and gravity field are shown in figure 13 and figure 14 respectively. The mean square deformation values of the corresponding reflection network and blade are calculated as shown in table 2.

![Figure 13. Antenna array displacement cloud map of working condition 1](image1)
![Figure 14. Antenna array displacement cloud map of working condition 2](image2)

| Working condition | RMS value of reflection network deformation | Root mean square value of antenna element blade deformation |
|-------------------|---------------------------------------------|--------------------------------------------------------|
| Working condition 1 | 4.9132                                      | 4.4808                                                  |
| Working condition 2 | 4.2566                                      | 4.0990                                                  |

Combined with the calculation results, it can be seen that under the action of gravity field and wind load, the larger the wind load is in the positive direction, the smaller the centrifugal force is, and the smaller the z-direction displacement of the blade is. When the wind speed is 25M/S and the wind direction is positive, the displacement of the antenna array is the largest in the Z direction, and the largest displacement is located on the reflection network, and the displacement reaches 32.86mm. When the wind speed is 25M/S and the wind direction is in the lee direction, the stress value of the folded beam is the maximum. The maximum stress is located at the connection between the roller and the folded beam, and the maximum stress is 266.33mpa, which is less than the yield limit of the material, and the structure is safe. The working state of the antenna, in the combination of gravitational field and temperature field of conditions, when the environment temperature reduces to 60 degrees, the antenna unit maximum displacement is 60.01 mm, deformation of blade root mean square value is 4.4808, reflecting mesh deformation root mean square value is 4.9132. The environment temperature 40 degrees, antenna unit maximum displacement is 60.39 mm, deformation of blade root mean square value is 4.0990, reflecting mesh deformation root mean square value is 4.2566.

6. Conclusion
1) In this paper the design of large wave high motor dual polarization radar antenna array face reasonable finite element analysis model is established, and according to the antenna array the material parameters and different wind load, temperature load cases, determine the corresponding application NASTRAN again in the gravity field of the antenna array surface and just under the action of wind load strength analysis, and in just strength under the action of gravity field and temperature field analysis, checking on the surface of the antenna array deformation and stress, verify the front of the whole structure of security.
2) The calculation results show that the larger the wind load is, the smaller the centrifugal force is and the smaller the z-direction displacement of the blade is. When the wind speed is 25M/S and the wind direction is opposite, the stress value of the folded beam is the maximum. Among them, the maximum stress is at the connection between the roller and the folded beam, and the maximum stress
is 266.33mpa, which does not exceed the yield strength of the material, and the structure is safe. In addition, under the action of gravity field and wind load, the maximum root mean square value of the reflection network of the antenna array face is 4.0614, and the maximum root mean square value of the blade is 3.7432, which meet the corresponding requirements.

3) The working state of the antenna, the environment temperature by 60 degrees, the maximum displacement is 60.01 mm, antenna unit deformation of blade root mean square value is 4.4808, reflecting mesh deformation root mean square value is 4.9132. The environment temperature 40 degrees, the maximum displacement is 60.39 mm, antenna unit deformation of blade root mean square value is 4.0990, reflective mesh deformation root mean square value is 4.2566, meet the corresponding requirements.

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