Design and Simulation Analysis of Deployable Structure of a Single-unit Radar

JinWei Wang, XiFang Zhao and BaoFu Tang
Nanjing Research Institute of Electronics Technology, Nanjing 210039, China
zxfang203@sohu.com

Abstract. The deployable structure has the characteristics of polymorphism, and it appears as the function of the mechanism during the deployment process, and as the function of the structure during the deployment and locking stage. Since the 21st century, it has been increasingly adopted by the military field. Based on the tactical requirements of individual radars for rapid withdrawal, off-road marching, rapid erection, and light weight in the war, a soldier radar with an expandable structure consisting of several active linear array antennas arranged uniformly on the circumference to form a cylindrical antenna array is designed. In order to ensure a smooth and reliable deployment of the deployable structure, a link mechanism design with hinge gap is used. According to the corresponding technical requirements, the rigidity of the single-armor radar's cylindrical box and antenna unit panel was simulated and calculated. The results show that the single-armor radar can meet the technical requirements under the corresponding working conditions without damage.

1. Introduction

At present, the collection of circular array radar array carried by individual soldiers at home and abroad mainly adopts separate installation and folding, which has a lot of process and slow speed. There is still a large gap between the requirements of rapid collection and cross-country March from the combat readiness state of one position to another position for quick installation and transition to combat readiness state [1]. For example, the TPQ-48 single soldier radar in the United States is installed separately in pieces, with a weight of 55kg. It takes about 10min for two to three people to set up and spread the radar, and the speed of frame collection is slow. In order to meet the needs of rapid response in modern war, a new type of single soldier radar array structure is urgently needed.

In order to solve the problem of slow collection speed of single soldier radar array, it is necessary to design a developable structure to realize the rapid installation and precise positioning of active linear array antenna with the cooperation of two people, so as to greatly improve the efficiency of collection; at the same time, aiming at the problem of heavy weight and poor portability, a new lightweight material is adopted to control the weight of the product within 50kg on the premise of meeting the rigid strength of the product. In this paper, the rapid development and retraction of the single radar array is realized by using the shear hinge structure, the lightweight materials and weight reduction design are adopted, and the finite element analysis is combined to ensure that the whole radar meets the requirements of lightweight quality and stiffness under the corresponding working conditions, which can provide certain reference for the design of similar radars.
2. The design of deployable structure of individual radar

In order to meet the technical requirements of rapid unwheeling and simple unwheeling process of single round array radar, the whole radar array is designed with shear hinged structure [2] [3]. As shown in Figure 1, the radar is mainly composed of a cylindrical box, a bottom plate, a scissor hinged deployable array surface, a hanging plate, etc. The shear hinged deployable array is composed of the upper hinged deployable structure, the lower deployable structure and the pin shaft of the connecting plate. The antenna unit is installed on the connecting plate in a circular distribution, forming a cylindrical antenna array. In addition, the corresponding reflective cloth is installed on the outside of the two connecting plates, which can expand and collapse with the array surface. As shown in figure 2 and figure 3, the bottom plate with reserved mounting holes is buckled to the corresponding predetermined position at the bottom of the cylindrical box. After the deployable structure is expanded to the corresponding position, the hanging plate is installed on the bottom plate through the fixed scissor hinge, so that the bottom of the deployable array is fixed. Then, the top cover plate and the hanging plate on the upper part of the cylindrical box are hinged to form a whole. When the individual radar is in working state, the upper and lower parts of the deployable structure are in developing state. The stability of the array is ensured by fixing the hanging plate and the scissor hinge. In addition, in order to ensure the technical requirements of the whole radar, such as light weight, good portability, etc., the material used for the radar is mainly aluminum, and the weight reduction design is adopted for the parts with small force, so as to ensure the radar's quality is below 50kg.
3. Establishment of finite element model

On the premise of satisfying the lightweight of the whole radar, it is also necessary to verify the mechanical performance of the radar under the corresponding working conditions. According to the design requirements, it is necessary to ensure that the individual radar can work normally under the wind speed of 15 m/s, that is to say, when the individual radar is deployed, the cylindricity of the box and the evenly distributed antenna unit panel in the circular state shall be less than 1.5 mm. Under the wind speed of 30 m/s, the whole array will not be damaged. In order to ensure the accuracy and reliability of the finite element analysis results, this paper mainly analyzes the stress characteristics, material properties and external load conditions of the whole cylinder box and the array panel when the individual radar is working, and determines the reasonable grid elements and load conditions to reduce the error between the calculation results and the actual results [4].

3.1. Model simplification

There are many components and complicated structures in the single soldier radar. If the real antenna structure model is used, it will lead to a great amount of calculation. Therefore, it is necessary to simplify the model of the whole single soldier radar and reduce the calculation amount [5]. After analysis, the wind load on the antenna mainly acts on the circular array facing the wind direction cylinder surface, and finally acts on the cylinder box through the conduction of force, which has no effect on the structure and position of components inside the cylinder. Therefore, the cylinder body with equal volume and mass is used to replace the actual model of the cylinder box inside the antenna for simulation calculation. In addition, because the reflection cloth between the two adjacent antenna elements is in the expanded state when the whole single soldier radar is in the expanded state, and the external wind load directly acts on the reflection cloth, the reflection cloth outside the cylinder is simplified into a film cloth structure with equal volume and mass when the model is simplified. The simplified single soldier radar model is shown in figure 4, which is mainly composed of outer membrane cloth, antenna unit panel, cylinder box, etc.

3.2. Unit type and attribute

After simplification, the whole radar consists of three parts: outer membrane, circular uniform antenna unit panel and cylinder box. The outer membrane is shell unit, and the antenna unit panel and cylinder box are solid unit. According to the structural design requirements, stress characteristics and material requirements of the individual radar, the material of antenna unit panel and cylinder box is aluminum, the material of outer membrane is tin membrane, and the material of antenna unit blade is aluminum. The elastic modulus of aluminum is 72000 Mpa, Poisson's ratio is 0.33, and density is 2.7e-9 (t / mm³). The elastic modulus of Tin film is 106000 Mpa, Poisson's ratio is 0.25, and density is 3.7e-9 (t / mm³).

3.3. Grid division

The small holes in the model do not affect the overall calculation results of the structure to be omitted, the rigid element equivalent treatment is used for hinge connection, and the mesh division of the cylindrical box and the antenna unit panel is carried out automatically by software. According to the
different structures, the mesh is automatically divided into tetrahedral and hexahedral mesh as shown in figure 5 and figure 6, and the maximum size of the mesh is 3 mm. The outer membrane structure is represented by shell element, and the middle surface is used for mesh processing. The results show that the grid accuracy can meet the analysis requirements

4. Loads and constraints
The load of the single soldier radar in the working state mainly comes from the wind load. The load directions of the individual radar and the antenna unit array of the single soldier radar in the working state are shown in figure 7 and figure 8 respectively. In the actual situation, the wind load moves irregularly with time [6]. According to the design requirements, the individual radar needs to work normally under the wind speed of 15m / s and not be damaged under the wind speed of 30m/s. Therefore, in the simulation calculation, the wind load is calculated and checked according to the static load, taking the wind speed of 15m/s and 30m/s respectively. The calculation formula of wind load is shown in (1)

\[ F = C_{Fq} A \]  

(1)

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

After calculation, when the wind speed is 15m / s, the surface load on the outer membrane material is 0.302 KN/m². When the wind speed is 30m / s, the surface load on the outer membrane material is 1.208 KN/m². After loading the corresponding load, according to the actual test situation, the lower surface of the cylindrical box is set as a fixed constraint, and finally the solution is calculated.
5. Calculation results and analysis
Through calculation and analysis, the deformation results of the cylindrical box and the antenna array panel of the single soldier radar under the wind speed of 15m/s and 30m/s are obtained, and the displacement nephogram of the cylindrical box and the antenna array panel under the corresponding working conditions are extracted respectively, as shown in figure 9, figure 10, figure 11 and figure 12. The deformation of cylinder box and antenna unit panel under different wind load conditions are shown in table 1.

![Figure 9. Cloud chart of cylindrical box displacement under the wind speed of 15m/s](image)

![Figure 10. Cloud chart of cylindrical box displacement under the wind speed of 30m/s](image)

![Figure 11. Cloud chart of antenna unit panel displacement under wind speed of 15m/s](image)

![Figure 12. Cloud chart of antenna unit panel displacement under wind speed of 30m/s](image)

Table 1. The deformation of cylinder box and antenna unit panel under different wind load conditions

| Wind speed | X-direction displacement of cylindrical box | Z-direction displacement of antenna unit panel |
|------------|---------------------------------------------|----------------------------------------------|
| 15m/s      | 0.37                                        | 1.06                                         |
| 30m/s      | 1.41                                        | 4.25                                         |

Combined with the calculation results, it can be seen that under the wind load of 15m/s, the maximum displacement of the cylindrical box in X direction is 0.37mm, and the maximum displacement of the antenna array in Z direction is 1.06mm. The cylindricity of the box and the evenly distributed antenna unit panel in the circular state can be ensured to be less than 1.5mm, which can meet the requirements of normal work Requirements in working state. When the wind speed is 30 m/s, the maximum displacement of the cylindrical box in X direction is 1.41 mm, and the maximum
displacement of the antenna array in Z direction is 4.25 mm. The whole single radar will not be damaged. To sum up, the design of individual radar can meet the corresponding design requirements.

6. Conclusion
Combined with the calculation results, it can be seen that under the wind load of 15 m/s, the maximum displacement of the cylindrical box in X direction is 0.37 mm, and the maximum displacement of the antenna array in Z direction is 1.06 mm. The cylindricity of the box and the evenly distributed antenna unit panel in the circular state can be ensured to be less than 1.5 mm, which can meet the requirements of normal work requirements in working state. When the wind speed is 30 m/s, the maximum displacement of the cylindrical box in X direction is 1.41 mm, and the maximum displacement of the antenna array in Z direction is 4.25 mm. The whole single radar will not be damaged. To sum up, the design of individual radar can meet the corresponding design requirements.

References
[1] Wang Jinwei, Tang Baofu, Zhao Xifang, et al. Error analysis of deployable structure of a single radar [J]. Modern radar, 2014, 36 (4)
[2] Zhang Shujie. Design of deployment mechanism and thermal structure coupling analysis of semi-rigid solar array in space laboratory [D]. 2004
[3] Cui Qifeng, Ni Bo, Shanghai Institute of aerospace systems engineering, Shanghai. Topological characteristics analysis of space articulated extension mechanism [J]. 2009 joint academic exchange meeting of space electromechanical and space optics Professional Committee and space materials professional committee of Chinese society of space science, 2011
[4] Yan Rongjun, Li Weitian. Stress analysis of a simple radar structure [J]. Naval Electronic Engineering (8)
[5] Structural design of light antenna for man on back radar [J]. Fiber composite, 2011 (3): 36-39
[6] Gao Yanlong. Research on numerical simulation method of wind load characteristics of radar antenna [D]. University of Electronic Science and technology, 2009