Research on the influence mechanism of assembly stress on reliability of space deployable mechanism

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Abstract. The on-orbit performance of spaceborne SAR satellite mainly depends on the unwrapping precision of antenna panel, which is determined by its supporting pole system. The assembly stress of the pole system affects the antenna deployable precision in the assembly process of SAR antenna deployable mechanism. Aiming at this problem, this work presents an efficient method that the three-dimensional model of the deployment mechanism of SAR antenna is established, and the method of finite element simulation analysis is adopted. Prestress is applied to the pole system to simulate its assembly stress, and then we study the deformation law of the antenna panel under different assembly stress combinations of the mast system, and the mapping relationship is determined between the mast system and the flatness of the antenna panel. The most sensitive pole affected by the antenna panel deformation is obtained. The results show that the flatness of the antenna panel is related to the dimensional tolerance and position of the pole system, especially large dimensional tolerance results in large deformation of antenna panel. In addition, the deformation area of antenna panel is determined by the assembly stress of different pole combinations. According to this research, it is concluded that the poles which should be controlled are obtained in the assembly process of the antenna deployable mechanism, which lays a theoretical foundation for the high precision assembly of the truss space deployable mechanism.

1. Introduction

The antenna deployable mechanism is an important part of SAR satellite. Its assembly performance affects antenna flatness, deployable reliability and connection reliability, and directly determines the observation precision of antenna. During the assembly process, the assembly stress is caused by the restraint deformation of parts. When operating in space, the stress is gradually released, resulting in the antenna performance changes, can not meet the requirements of orbital use. Therefore, the assembly stress analysis and control are of great significance to the assembly of the antenna deployable mechanism [1-3]. It's shown in figure 1.
In the manufacturing process of large aircraft wing box, Junhao Chang et al. studied the influence of different tightening sequences and torques on the assembly stress distribution of bolts with clearance through tests. Unreasonable tightening operations will also affect assembly quality. Both tightening sequence and torque will cause local stress concentration, especially at the first place where gaps appear. Gaskets must be made to achieve the best assembly quality [4]. Shijie Wang et al. used the finite element analysis to carry out the static loading test on the composite reinforced rib panel structure. And the bolt loading load to the working condition to realize the load preservation test, which is in good agreement with the test results. The effects of assembly stress are obtained on the failure of the truss skin bonding surface and the lamination of the truss lower edge. The influence of assembly stress was studied on the failure mechanism of girder panel structure [5]. Hai Deng et al. established the finite element model of steel truss bridge with ANSYS. On the bridge, vehicles with different load and speed carried out numerical stress analysis on different poles. By comparing with the test data, the test stress values of key parts were obtained, thus providing a basis for the optimal design of steel truss bridge structure [6].

2. Assembly stress modeling and analysis

2.1 Model establishment
The structure of the deployable mechanism of SAR antenna is complex. The pole system is long and coupled in size, including the antenna inner plate, the antenna outer plate, the support truss pole, the drive assembly and the hinge. The support truss pole is supported by the connection of the pole and the hinge. In order to facilitate the calculation and ensure the precision of the results, the finite element model is simplified as shown in figure 2.

2.2 Setting of simulation conditions
As there are many poles of different lengths in the antenna deployment mechanism, the tolerance values of the poles with different lengths are different. According to GB/T 19804 standard, the tolerance values of the poles are shown in table 1.
| Table 1. Dimension tolerance of pole member.  |
|---------------------------------------------|
| Range of nominal dimensions L.              |
| The length of the pole | >400~1000 | >1000~2000 | >2000~4000 |
| The tolerance range    | ±2.5      | ±5         | ±6         |

During the assembly process, the dimensional tolerance of the pole will lead to the assembly stress in the pole. The calculation of assembly stress is derived from strain and stress formula.

$$\sigma = E \cdot \frac{L - L_0}{L_0}$$

Type:
- $L_0$ — the original length of the member;
- $L$ — maximum tolerance of the pole;
- $\varepsilon$ — Longitudinal strain;
- $E$ — modulus of elasticity;
- $\sigma$ — Tensile (compressive) stress.

The size of the longest pole is 3263mm. According to the above calculation, the maximum stress in the pole can be: $\sigma = 128.7 \text{ MPa}$, The stress is an integer $\sigma = 130 \text{ MPa}$.

The conditions of finite element simulation analysis are set as follows: For multiple poles subjected to assembly stress, in order to facilitate the analysis of the force between poles, 20MPa is taken as the simulation numerical interval and the variation interval is from -130Mpa to 130Mpa during the finite element simulation analysis.

2.3 Finite element analysis of different assembly stresses

The plane diagram of the pole system of the deployable mechanism is shown in figure 3, where the left antenna plate is called the inner plate and the right antenna plate is called the outer plate. The labeled pole in the figure is the one with assembly stress.

Figure 3. Schematic diagram of mechanism plane.

Through the simulation analysis of prestress on the No. 1, 2 and 3 poles, the influence law of the poles under different assembly stress state on the assembly precision of the antenna plate was studied. The poles 4, 5 and 6 are the symmetrical arrangement of the poles 1, 2 and 3 in the figure 3.

The combination of multiple poles is divided into five cases. Prestress is mainly applied to two or three poles to simulate the assembly stress in the assembly process. Through finite element analysis of the deployable mechanism, the deformation of the antenna panel is obtained, and the influence law of the pole on the deformation of the antenna panel is analyzed. Furthermore, the influence of the complex pole system with assembly stress on the assembly performance of the SAR antenna is obtained.

(1) The assembly prestress of 130Mpa was applied to the poles 1 and 2, and the antenna panel deformation was obtained, as shown in figure 4. Positive and negative values are denoted by deformation upward and deformation downward.
Figure 4. Deformation of antenna panel.

Figure 5(a) and 5(b) show the situation where two poles are under tension at the same time. Figure 6(a) and 6(b) show the situation where one pole is under tension and the other is under pressure.

Based on the above simulation data, it can be concluded that with the increase of assembly stress in both tension and compression, the antenna plate deformation tends to increase. The comparison of deformation in figure 5(a) and 5(b) are under tension. It can be seen that under the action of assembly stress of pole 1 and pole 4. The deformation of the inner and outer plates of the antenna is very large, but the difference between the two plates is not much different. Pole 3 and pole 6 have the greatest influence on the outer plate of the antenna, and the deformation of the outer plate is far greater than that of the inner plate. And the deformation of the inner plate is infinitely approaching 0. The length of pole 2 and pole 5 is short, and the deformation of antenna panel is small. Pole 1 and pole 4 have the greatest influence. The comparison of deformation in figure 6(a) and 6(b) show that under the state of two poles, one pulling and one pressing. Pole 1 and pole 2, pole 2 and pole 4, pole 1 and pole 3, pole 1
and pole 6 have a great influence on the antenna inner plate under the state of assembly stress, but the deformation of pole 2 and pole 4 to the antenna plate is negative. Pole 1 and 3, pole 1 and 6, pole 2 and 4, pole 3 and 5 have great influence on the outer plate of the antenna, but the deformation of pole 2 and 4 to the antenna panel is negative.

(2) The deformation of the inner and outer panels of the antenna panel is shown in figure 7 when 130Mpa prestress is applied to pole 1, 2 and 3 at the same time for assembly.

![Deformation of antenna panel](image1)

Figure 7. Deformation of antenna panel.

Figure 8(a) and 8(b) show the situation where three poles are under tension at the same time. Figure 9(a) and 9(b) show the situation where one pole is under tension and two are under pressure.

![Deformation of antenna panel under tension](image2)

Figure 8. Deformation of antenna panel under tension.

![Deformation of antenna panel with one antenna under tension and two antennas under pressure](image3)

Figure 9. Deformation of antenna panel with one antenna under tension and two antennas under pressure.

Based on the above simulation data, the comparison of deformation in figure 8(a) and 8(b) show that the plate deformation tends to increase with the increase of assembly stress when the three poles are under tension. Pole 1, 3 and 4 has the greatest influence on the inner plate of the antenna, which is positive. However pole 2, 3 and 6 has the greatest influence on the outer plate of the antenna, which is negative. In general, pole 1, 3 and 4 and pole 1, 2 and 4 have more obvious deformation to the antenna panel.
plate, and the deformation to the antenna plate is positive. The comparison of deformation in figure 9(a) and 9(b) show that under the state of tension and compression of the three poles, the deformation of the plates tends to increase with the increase of assembly stress. Pole 1, 2 and 5 has the greatest influence on the inner plate of the antenna, while pole 1, 3 and 6 has the greatest influence on the outer plate of the antenna. In general, 1, 3, 6 pole and 1, 2, 3 pole, 1, 3, 5 pole and 1, 2, 5 pole and 2, 3, 4 pole have more obvious deformation on the antenna plate.

(3) As for the other three pole combinations, only 130Mpa assembly stress was used for finite element analysis, and the deformation data of the antenna panel was obtained for reference only, as shown in table 2.

| Pole combination | Inner plate deformation (mm) | Outer plate deformation (mm) |
|------------------|------------------------------|------------------------------|
| 1, 2, 3, 4       | 8.6017                       | 8.4074                       |
| 1, 2, 3, 5       | 2.1912                       | 2.1116                       |
| 1, 2, 3, 6       | 3.6062                       | 7.215                        |
| 1, 2, 4, 5       | 6.605                        | 10.686                       |
| 1, 2, 4, 6       | 8.2325                       | 8.2785                       |
| 1, 2, 5, 6       | 2.3398                       | 2.5832                       |
| 1, 3, 4, 6       | 9.6338                       | 9.6172                       |
| 1, 3, 5, 6       | 3.9441                       | 7.0499                       |
| 2, 3, 5, 6       | 3.0089                       | 12.215                       |
| 1, 2, 3, 4, 5    | 6.6971                       | 6.8949                       |
| 1, 2, 3, 4, 6    | 8.3251                       | 8.2948                       |
| 1, 2, 3, 5, 6    | 2.2687                       | 7.2426                       |
| 1, 2, 3, 4, 5, 6 | 6.6147                       | 6.5878                       |

According to the above data, under the action of assembly stress, multiple poles are not simple numerical superposition of individual poles. When two poles in the outer plate have assembly stress, the deformation of the antenna plate is greatly affected. And the deformation of the outer plate is greater than that of the inner plate. When the two long poles in the inner plate are stressed at the same time, the two long poles in the outer plate will produce resistance, resulting in the deformation of the inner plate and the outer plate of the antenna is close to each other. When the two short poles are stressed at the same time, the deformation of the antenna panel is relatively small. Therefore, it can be concluded that the longer the pole is, the greater the influence on the antenna plate will be: pole 3, pole 1 and pole 2 in sequence.

### 3. Conclusion

The research conclusions are as follows:

(1) During the assembly process, the deformation of antenna panel increases with the increase of assembly stress. And the longer the length of the pole, the greater the influence. The assembly precision of SAR antenna deployable mechanism is difficult to meet the product performance.

(2) In the case of assembly stress of multiple poles, the influence of assembly stress of poles on the assembly precision of plates is also determined by the position relationship between poles and plates in addition to the length of poles.

(3) Antenna panel deformation results obtained by simulation analysis of complex pole system. It is concluded that in the assembly process of SAR antenna, considering assembly stress, pole 3, 6, 1 and 4 should be mainly controlled, which provides a theoretical basis for the high-precision assembly of the truss spatial deployable mechanism.
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