Design of Pre-stressed Cable Rod Radar Array Structure Based on Finite Element Analysis

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Abstract. In recent years, with the increasingly high requirements of radar thinness, the radar array appears thinner and thinner, which is easy to make the stiffness of the radar array is not enough, leading to serious deformation of the radar array, and thus affecting the work of the radar and the whole machine life. As a new type of space structure with light weight and high strength, the pre-stressed cable-stayed structure can play a good role in replacing the traditional front structure. According to the overall design requirements of a radar and the RMSE requirements for the plane flatness, the pre-stressed cable-stayed structure of the radar array is preliminarily designed, and the finite element analysis results are used to optimize the design and finally meet the design requirements.

1. Introduction
Radar array is one of the most important and complex components of phased array radar. Due to the increasingly high requirements on radar thinness in recent years, the radar array appears to be thinner and thinner, which often leads to the insufficient stiffness of the radar array. The bending and deflection of the radar array seriously affect the work and overall life of the radar [1]. Pre-stressed cable-stayed structure is a new type of space structure, through the adoption of cable-strut structure system to achieve to support the back of the radar antenna, the poles against the side panel for direct support to resist deformation to panel under load conditions, with lightweight, high strength characteristics [2-3], has become a traditional frame type phased array radar antenna structure one good alternative forms.

According to the overall design requirement of a radar and the RMSE requirement of flatness required for electronic communication of the front panel, the preliminary design of the pre-stressed cable- stayed front structure of the radar front is carried out, and the simulation calculation of the radar structure front is carried out by using ABAQUS software to verify the rationality of the structure design. Then the model layout is optimized and adjusted, and the fish-belly layout is considered. The calculation results show that the fish-belly layout of the pre-stressed cable- stayed radar front structure can meet the design requirements, which can provide a reference for the radar front design of the pre-stressed cable- stayed structure.

2. Pre-stressed cable bar array structure design

2.1. Preliminary design of pre-stressed cable strut structure
In order to meet the requirements of radar electronic communication, it is required to ensure that the RMSE value of the panel flatness is less than 0.5 under various working conditions. Considering that the working condition of the radar front is mainly wind load working condition, the 8 wind load in the direction of the vertical panel is analyzed and calculated during design, and the wind speed of the 8 wind is about 17.2-20.7 m/s. The basic wind pressure and wind load of the 8th grade wind are as shown in equation (1) and formula (2).

\[ w_0 = \frac{1}{2} \times 0.001 \times 20.7^2 = 0.214 \text{kN/m}^2 \]  
\[ w_k = \beta \mu \mu w_0 = 1.0 \times 1.0 \times 1.4 \times 0.214 = 0.23 \text{kN/m}^2 \]

According to the structure of a whole radar system design requirements, the radar antenna using pre-stressed cable-stayed structure of front of parallel design, as shown in figure 1, the structure is mainly composed of skeleton line-rod and the front panel, cable-pole skeleton adopts parallel line layout, by the steel bar 1, 2, 3, line 4, 5, support bar support bar and support panel 6 through ball ground connection. The steel rod 1 has a diameter of 40 mm, the steel rods 2 and 3 have a diameter of 25 mm, the cable 4 has a diameter of 5 mm, the support rod 5 has a diameter of 10 mm and a length of 100 mm, and the support panel 6 has a size of 1500 × 1500 × 10 mm.

2.2. Establishment of finite element model
In order to improve the efficiency and accuracy of analysis, the surface model is simplified as follows:

1) the intersecting parts are connected through a common point, and the intersecting between the two cables is regarded as independent and independent;

2) the mass of TR components and antenna units fixed before and after the support panel 4 in the real radar is loaded by increasing the density of panel 4.

3) due to the large stiffness of the side beam, simplified analysis was carried out in the preliminary design. In figure 1, steel rod 1, 2 and 3 were omitted and the cable end was hinged for analysis. Strut bar 5 density =7850 kg/m³, elastic modulus =2.06 × 1011 N/m², Beam188 beam element is adopted. Cable 4 density =7300 kg/m³, elastic modulus =1.9 × 1011 N/m², linear expansion coefficient =1.1 × 10-5/℃, using rod unit Link10; Support panel 6 density rho =8100 kg/m³, elastic modulus EX=7×1011 N/m², shell unit Shell93. The boundary condition is that the four vertices of the cable-arch skeleton are completely constrained.

The pre-stress applied by the "cooling method" has the same effect as the natural frequency of the pre-stressed string calculated by the finite element vibration mechanics theory [4-5]. In this analysis, the pre-stress of the cable-stay structure is applied through the temperature field. The temperature was
lowered by 100 degrees, the pre-stress was applied 209 MPa, and the analysis results were shown by magnification 50x.

2.3. Analysis of simulation results
The pre-stress condition of the whole front is pre-stressed, and the pre-stress + eight-level wind load condition is simulated. The vertical displacement cloud map of the obtained array is shown in figure 2 and figure 3 respectively. The RMSE of the plane flatness is shown in figure 4.

It can be seen from figure 2, figure 3 and figure 4 that under the condition that only the pre-stressing force is applied to the front surface, the displacement of the front panel at the middle is the largest, and the displacement is 0.275 mm. Under the condition of pre-stressing + eight-stage wind load on the front, the displacement at the center of the panel is the largest, the displacement is 4.652 mm, and the RMSE of the front panel is 1.477 mm, which cannot meet the design requirements. According to the theoretical analysis, the stiffness of the lattice structure can be increased by increasing the length of the struts. Therefore, the length of the struts 5 in the array is sequentially increased from the original 120 mm to 140 mm and 160 mm, respectively, and the simulation
calculations are performed respectively. The results obtained from the simulation of the working conditions were counted as shown in Table 1.

**Table 1. Comparison of maximum displacement under various working conditions**

| Category                    | Max displacement / mm | RMSE/mm |
|-----------------------------|-----------------------|---------|
| Panel 10mm, struts 120mm. No wind load | 0.275 | \   |
| Panel 10mm, struts 120mm. Eight wind load | 4.652 | 1.4777  |
| Panel 10mm, struts 140mm. Eight wind load | 4.590 | 1.4618  |
| Panel 10mm, struts 160mm. Eight wind load | 4.512 | 1.4434  |

It can be seen from Table 1 that the entire array has almost no effect on the stiffness of the entire array structure by increasing the length of the struts under the eight-stage wind load condition, and the RMSE of the front panel cannot meet the design requirements. The design of the cable-stay structure is invalid, and the failure analysis and optimization of the entire structure are required.

### 3. Failure analysis of pre-stressed cable rod front structure

According to the above simulation calculation results, the deformation side view of the structure under the eight-level wind load is selected for analysis, as shown in figure 5. According to figure 5, it can be seen that the outer ring of the outer surface of the cable is short due to the cable of the outer ring, and the load of the edge equivalent to the strut is small, so the displacement of the outermost ring is small, and there is almost no deformation. The outer ring cable bar structure is more reasonable. There is almost no relative deformation of the middle span cable, and the deformation is concentrated on the side spanning cable bar, showing a parallelogram deformation state.

![Figure 5. Deformation side view of parallel cable-stay model](image)

Since the equivalent load on the edge portion of the outer ring cable rod is small and the deformation amount is relatively small, it can be concluded that the force analysis is shown in figure 6. The outer ring cable rod can be equivalent to the support, and the rest of the cable rods are at the junction. Equivalent to the articulation, and then the force of each span cable is approximated to the force model shown in figure 7 below for simulation analysis.
Figure 6. Force analysis of the edge cable to save space. Justify the caption.

Figure 7. Simplified force model

As can be seen from figure 7, because of the unbalanced force, the cable-stay structure of the front is a transient system, and the transient system is extremely unstable when subjected to external loads, and the increase of the length of the brace will not change the force mode of the whole structure, so the stiffness of the cable-strut front structure cannot be increased by changing the length of the brace.

Further demonstration and analysis were carried out to extract the single trusses for analysis. With double cable design and unit load, the pre-stress is 209 MPa. The single truss structure is uniformly modeled as shown in figure 8 below.

Figure 8. Single trussed parallel cable layout

In addition, on the basis of the original single truss structure with the strut length of 120mm, the strut length was set to 140mm and 160mm for simulation analysis, and the resulting displacement cloud map (all magnified 1000 times) was shown in figure 9, 10 and 11 respectively.

Figure 9. 120mm displacement of a single trussed parallel cable + strut FIG. U3 (1000x)

Figure 10. 140mm displacement of a single trussed parallel cable + strut FIG. U3 (1000x)
As can be seen from figure 9, 10 and 11, when the length of the bracing rod is 120mm, 140mm and 160mm respectively, the maximum displacement of the single trusses parallel cable structure is located in the middle span, and the maximum deformation is 0.0569 mm. Therefore, it is further explained that the layout of the rod-rod structure of the array is designed as a transient system. By increasing the length of the strut, the stress mode of the overall structure will not be changed and the stiffness of the rod-rod array structure cannot be increased. Therefore, it is necessary to optimize and improve the layout of the rod-rod array structure.

4. Optimization design of pre-stressed cable strut structure

In order to avoid the pre-stressed cable-stay front structure system of transient condition affects the whole stiffness matrix surface, integrated the advantages of the stomach type design [6], against the cable-stay structure optimization, using the stomach type is shown in figure 12 single cross structure modeling, applying unified unit load at the same time, the pre-stress is 209 MPa, at the same time, the length of the strut is respectively 120 mm, 140 mm, 160 mm under the conditions of the simulation analysis, the displacement nephogram obtained as shown in figure 13, 14, 15 respectively.
As can be seen from figure 13, 14 and 15, when the length of the strut is 120mm, 140mm and 160mm respectively, the maximum displacement of the single trusses parallel cable structure is located in the middle span, but the maximum deformation is 0.02301mm, 0.01084mm and 0.007708mm respectively. This indicates that with the increase of the strut length, the rigidity of the single trussed parallel cable structure is larger, which can ensure the rigidity requirement of the whole pre-stressed cable-stay array structure, thus controlling the deformation of the array panel.

According to the calculation results of a single trussing fish-bellied parallel cable structure, the structural layout of model 1 (figure 1) was optimized, the cable layout was adjusted and the fish-bellied layout was adopted. The specific model layout is shown in figure 16.

After the layout of the model is determined, the specific material parameters of the model are adjusted, and the design is carried out according to the requirements of the overall design of the radar and the corresponding simulation analysis. The specific parameters are defined as follows:

- The cable adopts stainless steel wire rope, with a diameter of 5mm, a minimum breaking tension of 14.7 kN, and an elastic modulus of 110GPa.
- The support rod adopts stainless steel S316, the diameter is 10mm and the thickness is 2mm round rod, the elastic modulus is 195GPa.
- The panel adopts aluminum plate with thickness of 10mm, 1.5m x 1.5m, and elastic modulus of 70GPa.
- The rest are made of Q345b steel.
Under the eighth wind load condition, 117MPa is applied to the prestressed element. The finite element analysis results are shown in figure 17 and 18. The maximum displacement is in the middle span of the front panel, the maximum displacement is 1.158mm, and the RMSE is 0.4253, which meets the design requirements of the front panel.

5. Conclusion

In this paper, according to the request of the overall design of a radar and electronic communications required against surface panel flatness RMSE requirements of the radar antenna using prestressed cable-stay front structure to the preliminary design, and through the application of ANSYS software to the simulation calculation of the radar antenna structure, verify the rationality of the structure design, the results show that the member structure exists transient system, it is difficult to guarantee the integral structure stiffness and RMSE of front panel flatness requirement. To avoid transient system, adopting the new belly type structure of prestressed cable-strut radar antenna structure optimization design and simulation calculation verification, the results of the surface of pre-stressed cable-stay radar antenna structure using the stomach type decorates can ensure the stiffness of the front structure and make the front panel flatness RMSE value less than 0.5, can meet the design requirements, can be designed for radar antenna pre-stressed cable-stay structures provide a reference basis.

References

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