Dynamic analysis of the effect of mesh tension on the deployment process of loop antenna

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Abstract: In orbit deployment and profile maintenance are the most important functional requirements in the development of loop antenna. If the antenna cannot be deployed in orbit, it will lose the signal transmission function, and the profile in orbit holding function is related to whether the antenna can stably transmit electromagnetic signals. The mesh tension (main mesh tension, rear mesh tension and tension arrays tension) is the key means to maintain the profile stability in orbit. At the same time, it is also closely related to the rod load and the maximum motor driving force in the process of antenna deployment. Based on the theory of flexible multi-body dynamics, the dynamic modeling of the deployment process of ten meter loop deployable antenna is established in this paper. On this basis, the influence of mesh tension on the deployment dynamics of loop antenna is analyzed by using the control variable method, and its related variation law is obtained. This study can provide guidance for the tension adjustment in the profile adjustment stage of the ring antenna, so as to shorten the development cycle, and can also predict the deployment of the antenna in orbit.

1 Introduction

The loop deployable antenna is mainly composed of loop truss, main mesh, rear mesh, metal mesh and the tension arrays, as shown in Figure 1. The loop truss is mainly composed of quadrilateral units as shown in Figure 2. During the deployment process, the motor drives the driving rope running through the diagonal bars of the quadrilateral, so that the quadrilateral units are changed from the folded to the deployed state. The main mesh and the rear mesh are fixed on the hinges of the loop truss through the connecting devices.

Fig.1 Loop antenna sketch map
The main purpose of the loop deployable antenna is to send and receive electromagnetic information in space. Therefore, in order to ensure that the antenna can work normally in space, the main mesh, the rear mesh and tension arrays should satisfy certain tension requirements, so as to ensure that the antenna metal mesh can own certain rigidity to ensure the antenna has sufficient stability for sending and receiving electromagnetic signals. Through the ground test and simulation analysis, it is found that the tension of the mesh surface has a great influence on the deployment process of the loop deployable antenna. Therefore, revealing the dynamic influence of the mesh tension on the deployment process of the loop antenna not only has a predictive effect on the deployment of the antenna in space, but also has certain guiding significance for the adjustment of the mesh tension during the profile adjustment in the ground development process. In this paper, based on the flexible multi-body dynamics theory, the dynamic modeling and simulation of the ten-meter-level loop deployable antenna are carried out, influence on the deployment process of the loop antenna is described in this paper.

2. Dynamic modeling of the antenna deployment process

The deployment process of the loop antenna involves hundreds of flexible rods and thousands of flexible cables moving in a wide range, and the rods and cables are deformed in a large range during the movement. In terms of modeling flexible parts for large deformation and large-scale motion, the current mainstream directions include absolute nodal coordinate method [1][2] and geometrically accurate beam theory [3][4][5][6]. Tao Cheng et al. [7] analyzed the asynchrony of the loop antenna deployment based on the absolute node coordinate method, and Zhao Zhihua et al. [8] carried out dynamic modeling and simulation of the loop antenna based on the geometrically accurate beam theory. The above two modeling methods have their own advantages and disadvantages in terms of computational efficiency, singularity resolution, strain objectivity, and programming implementation [9]. In terms of programming, the absolute node coordinate method is easier to implement, but in terms of accuracy and calculation speed, the geometrically precise method is more dominant. For this reason, this paper adopts the geometrically accurate beam theory to carry out dynamic modeling of flexible members and cables.

The dynamic modeling of the loop antenna deployment process adopts the first type of Lagrangian equation as shown in Equation 1 as the system dynamics control equation:

$$\frac{d}{dt} \left( \frac{\partial T}{\partial q} \right) - \frac{\partial T}{\partial q} + \frac{\partial V}{\partial \dot{q}} + \Phi^T \lambda = Q$$

$$\Phi(q, t) = 0$$

where $T$ is the kinetic energy, $q$ is the generalized coordinate, $\dot{q}$ is the generalized velocity, $V$ is the elastic potential energy, $\Phi$ is the constraint equation, $\lambda$ is the Lagrange multiplier, and $Q$ is the generalized external force.

The modeling of flexible members, dynamic ropes and cable nets can be found in the literature, the modeling can be found in the literature [10][11], and the constraint modeling can be found in the literature [12].

3. Analysis of the influence of mesh tension on the deployment dynamics

The most concerned factors in the deployment process of the loop antenna are the driving force of the motor and the maximum bending stress of the vertical rod (compared with the horizontal rod and the inclined rod, the vertical rod is most likely to be damaged), destruction of rope and bars will directly
cause the antenna to fail to deploy smoothly.

In the research process, the control variable method was used to analyze the average tension of the outer part cables of the main and rear mesh, and the average tension of the tension arrays. To compare and analyze the deployment driving force and the maximum bending stress of the longitudinal bar. Considering that for the loop antenna system, after its deployment is stable, the main mesh, rear mesh, and tension arrays satisfy a certain balance relationship, and their changes have a certain coupling phenomenon; therefore, when the simulation process analyzes the influence of a variable on the dynamics of the deployment process, other tension variables Changes will occur. In order to analyze effectively and reasonably, ensure that other forces do not change by more than 5%.

3.1 Analysis of the influence of outer part main mesh cables on the dynamics of the deployment process

When analyzing the influence of the average tension of the outer part cables of the main mesh on the deployment dynamics, the variation range of the average force of the rear mesh is 8.70Kg-8.90Kg, and the change rate is 2.3%; the average tension of the tension arrays vary from 2.98N to 3.12N, with the change rate of 4.6%. The influence of the average tension of the outer part cables of the main mesh on the maximum motor driving force is shown in Figure 3. The average tension of the outer part cables of the main mesh gradually increases, and the the maximum motor driving force increases too; the average tension of the outer part cables of the main mesh increases from 2.6Kg to 4.6 Kg, the maximum motor driving force is increased from 18.94Kg to 30.33Kg, and the maximum motor driving force is increased by 60.1%.

Fig 3. Relationship between average tension of main net side rope and maximum dynamic change of motor deployment

Figure 4 shows the effect of the average tension of the outer part cables of the main mesh on the bending stress of the vertical rod. The average tension of the outer part cables of the main mesh has little effect on the maximum bending stress of the vertical rod. The average tension of the outer part cables of the main mesh changes from 2.6Kg to 4.6Kg, the maximum bending stress of the vertical rod changes in the range of 215.99MPa-224.04MPa, and the maximum change is only 3.7%.
3.2 Analysis of the influence of outer part rear mesh cables on the dynamics of the deployment process

When analyzing the influence of the average tension of the outer part cables of the rear mesh on the deployment dynamics, the average force of the outer part cables of the rear mesh varies in the range of 3.75Kg-3.91Kg, and the change rate is 4.2%; the average tension of the tension arrays vary from 2.98N to 3.12N, with the change rate was 4.6%. The influence of the average tension of the outer part cables of the rear mesh on the maximum motor driving force is shown in Figure 5. As the average tension of the outer part cables of the rear mesh gradually increases, the maximum motor driving force increases and the increase is larger; the average tension of the outer part cables of the rear mesh increases from 7.8Kg to 10.8Kg, the maximum motor driving force is increased from 21.5Kg to 29.05Kg, and the rate is increased by 35.11%.

Fig 5. Relationship between average tension of side rope of auxiliary mesh and maximum dynamic change of motor deployment

The influence of the average tension of the outer part cables of the rear mesh on the maximum bending stress of the vertical rod is shown in Figure 6. The average tension of the outer part cables of the rear mesh has little effect on the maximum bending stress of the vertical rod. The average tension of the outer part cables of the rear mesh increases from 7.8Kg to 10.8Kg, the maximum bending stress of the vertical rod varies from 219.16MPa to 224.28MPa, and the maximum variation is only 2.3%.
3.3 Analysis of the influence of the tension arrays on the dynamics of the deployment process

When analyzing the influence of the average tension of the tension arrays on the deployment dynamics, the variation range of the average force of the outer part cables of the main mesh is 3.75Kg-3.91Kg, and the change rate is 4.2%; the average force of the outer part cables of the rear mesh is 8.68Kg-9.10Kg. The rate was 4.6%. The influence of the average tension of the tension arrays on the maximum motor driving force is shown in Figure 7. As the average tension of the tension array increases, the maximum motor driving force shows an overall upward trend, but the increase is small. When the average tension of the tension array increases from 3N to 4N, the maximum motor driving force increases from 24.43Kg to 27.98Kg, and rate is 14.53%.

The effect of the average tension of the tension array on the bending stress of the vertical rod is shown in Figure 8. The average tension of the tension arrays has little effect on the maximum bending stress of the vertical rod. The average tension of the tension array increases from 3N to 4N, the maximum bending stress of the vertical rod varies from 215.58MPa to 224.04MPa, and the maximum variation is only 3.9%.

Fig. 6. Variation relationship between average tension of side rope of auxiliary mesh and maximum bending stress of vertical rod

Fig 7. Relationship between average tension of tension array and maximum dynamic change of motor deployment

Fig 8. Relationship between average tension of tension matrix and maximum bending stress of vertical bar
4. Conclusion
During the development of the loop antenna, the profile adjustment work occupies a long period of time in the development cycle. Through the above research and analysis, it can be concluded that within a certain range, the mesh tension has little influence on the load of the rod. As for the maximum motor driving force, when the average tension of the tension arrays and the tension of the outer part cables of the rear mesh remain unchanged, increasing the tension of the outer part cables of the main mesh will also increase the deployment power, and the increase is obvious; when the average tension of the outer part cables of the main mesh and the tension arrays remain unchanged, increasing the tension of the outer part cables of the rear mesh, and the the maximum motor driving force will also increase; when the average tension of the outer part cables of the main mesh and the average tension of the outer part cables of the rear mesh remain unchanged, increasing the average tension of the tension arrays, and the maximum motor driving force will increase as a whole. trend, but the increase is small.

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