A Novel Tolerance Design Method for a Spaceborne Active Phased Array Antenna

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1. Introduction

The spaceborne phased array antenna is an important monitoring and communication device in space, as shown in Fig. (1). The performance of the spaceborne phased array antenna is determined by the position, amplitude and phase of the discrete element[1], as shown in Fig. (2). The geometric error, especially the position error of the elements, seriously affects the performance[2].

To constrain the position error, several tolerance design methods have been proposed. The empirical tolerance design method based on the Ruze equation[3] has been widely used. However, it always leads to the too strict tolerance zone. Wang[4] established the multi-field coupling model to describe the relation between the performance and the position errors, this method could not deal with the rest tolerances, such as the flatness of the reflection plate. Peng[5] proposed a new sensitivity analysis method considering interval variables and random variables. Anselmi[6] derived the performance interval of the antenna with geometric error based on the interval method. These methods are computationally complex and expensive for the spaceborne phased array antenna. Sa[7] proposed a region-division based tolerance method to optimized the position tolerance of the discrete elements and the subarray splicing structure simultaneously.

Based on the previous work, a novel tolerance design method considering the performance requirements was proposed in this paper.

2. Body of abstract

The tolerance propagation model from the base plate to the discrete elements was established first. Then the accumulative geometric error of the elements was calculated based on the propagation model. All the discrete elements were treated as points since only the position error are considered here. And the continuous plates were simulated by the NURBS surface, as shown in Fig. (3). The realistic position of the elements was calculated by assembling all the parts thought the matrix method.

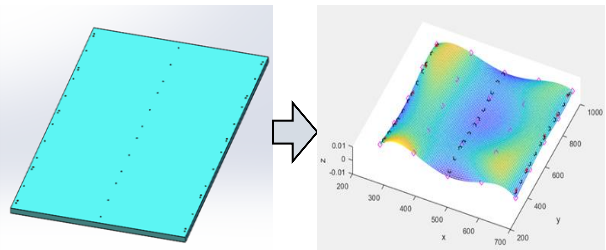

Fig.3 The NURBS model of the base plate

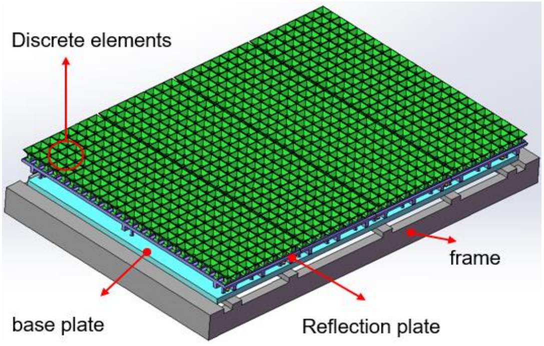

Fig.1 The CAD model of the array antenna

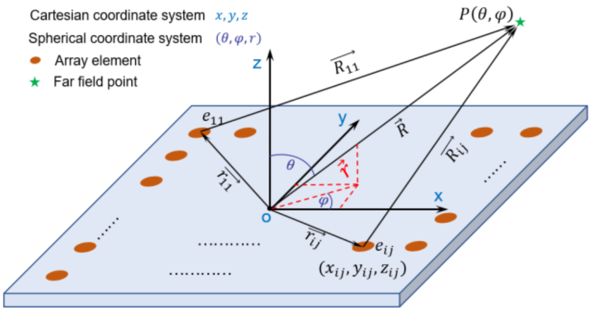

Fig. 2 The performance calculation

The correlation function between the antenna performance and the accumulative geometric error was established based on the Taylor expansion.

$$P^e = P + \sum_{i=1}^{m}\sum_{j=1}^{n}\left\{\frac{\partial P}{\partial x_{ij}}\Delta x_{ij} + \frac{\partial P}{\partial y_{ij}}\Delta y_{ij} + \frac{\partial P}{\partial z_{ij}}\Delta z_{ij}\right\} \quad (1)$$

Then all the tolerances affecting the realistic position $\{x_{ij}, y_{ij}, z_{ij}\}$ of the elements were integrated into the correlation function based on the probability integral transform theorem[8], as shown in Fig. (4).

$$\Delta P = \sum_{i=1}^{m}\sum_{j=1}^{n}\Delta_{ij}\nabla_{ij}(\theta,\varphi),\ \Delta_{ij} = [\Delta x_{ij}, \Delta y_{ij}, \Delta z_{ij}]$$
$$\nabla_{ij}(\theta,\varphi) = \left[\frac{\partial P}{\partial x_{ij}}, \frac{\partial P}{\partial y_{ij}}, \frac{\partial P}{\partial z_{ij}}\right]^T \quad (2)$$

Finally, all the tolerances were optimized by the global sensitivity analysis method. Simulation experiments demonstrate the effectiveness and efficiency of the proposed method.

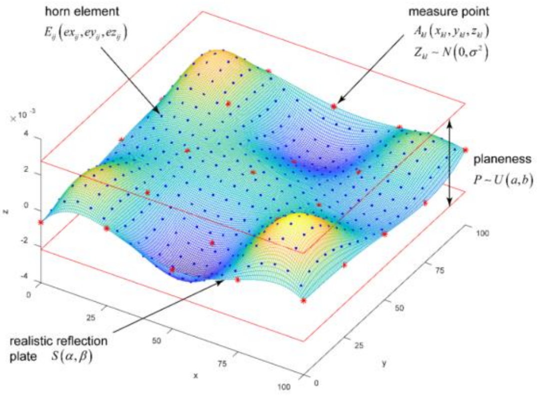

Fig. 4 The performance calculation

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