Electromechanical Coupled Analysis of large broad band Reflector Antennas

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1. Introduction

At present, in the electromechanical coupled analysis of reflector antennas, software for structure analysis is used firstly, such as ANSYS; and then the data from ANSYS is imported to software for electromagnetism analysis, such as FEKO; at last FEKO is used to calculate electromagnetism performance of the antenna. A FEM mesh is necessary in structure analysis. Another mesh is also requested by electromagnetism analysis; the side length is generally less than third of wavelength. The two meshes are independent, and do not match with each other. Especially for broad band antennas, different frequencies need different meshes; different meshes need independent electromagnetism analysis. So the efficiency of the electromechanical coupled analysis of broad band reflector antennas is low.

Generally, there are two methods for the mismatching problems of structure mesh and electromagnetism mesh. The first one, A new surface of reflector is fitting from structure mesh, and electromagnetism mesh is obtained form the new surface[1,2]. In this way, new error will be bringer on in surface fitting. The second one, the data of structure mesh is imported to software of electromagnetism analysis directly. But A complex process include mesh refinement and uniform is necessary for structure mesh, because the mismatching of two meshes, especially for large antennas. For the problem of meshes in different frequencies, the mesh of high frequency could be obtained by thinning mesh of low frequency. The process is also very complex.

For the problems above, electromechanical coupled model of reflector antennas has been modelled by GO method. An improved Gaussian formula has been used to calculate the model. A transformation matrix between structure mesh and Gauss points has been deducted. The Gauss points have been chose form structure mesh instead of complex mesh process. The number of the Gauss points is determined by antenna frequency, more points for higher frequency. Compared with FEKO software and tradition method, the method in this paper is accurate and effective, could be used in the electromechanical coupled analysis of large broad band reflector antennas. At last the method in this paper is used in a 40m reflect antenna, the result is accord with practice engineering.

2. Electromechanical coupled model of reflector antennas

The Reflector distortion leads to phase difference and influence far field parameter of antennas ultimately. The formula of far field parameter is following[2]:

$$T = \iint_A f e^{j\delta} e^{jk\rho' \sin(\theta)\cos(\phi-\phi')} \rho' d\rho' d\phi' \tag{1}$$

In formula(1), T means field value in some point at infinity distance, $f = f(\xi,\phi)$ is a distribution function of aperture field, $e^{j\delta}$ embody the error of reflector distortion; $\delta = 4\pi/\lambda Z(\rho',\phi')\cos^2(\xi/2)$, $Z(\rho',\phi')$ is axial displacement in reflector surface; $k = 2\pi \cdot freq/c$,c is velocity of light; freq is frequency. All the variables are shown in fig 1. Structure analysis and electromagnetism analysis are concatenated by introducing phase difference which embody structure deformation to formula of far field parameter.

We do not solver the double integral in formula (1) directly. By fitting, get a new surface; and introducing Bessel function to predigest, at last a form of series accumulate will be done[1、 2].For the reason that fitting will induce error, so numerical integral is a normally method[3-5] by partition the integral area to N cells, as following formula:

$$T = \sum_{i=1}^{N} T_i = \sum_{i=1}^{N} f\left(x_i, y_i\right) e^{j\varphi\left(x_i, y_i\right)} e^{j\delta_i} \Delta x \Delta y \tag{2}$$

Trapezoidal integral is in common use[3-5]. But the number of cells requested this way is very large, especially for large reflector antennas in high frequency. So an improved Gaussian formula has been used to calculate formula (1).

For the integral T_i in each triangle cell, use area coordination, and the formula $dA = 2AdL_1dL_2$, the following formula could be gotten[6、7]:

$$T_i = \iint_A f\left(L_1, L_2\right) dA = \int_0^1 \int_0^{1-L_1} 2\mathrm{S} f\left(L_1, L_2\right) dL_1 dL_2 \tag{3}$$

S is the area of the triangle cell. The integral formula in triangle cell is constructed[9]:

$$T_i = \iint_A f\left(L_1, L_2\right) dA = \sum_{k=1}^{n\times m} 2\mathrm{S} \omega_k f\left(L_{1k}, L_{2k}\right) \tag{4}$$

$$\left[\omega_k\right]_{n\times m} = \left[\frac{1-\alpha_i}{8} A_i\right]_n' \left[A_j\right]_m, \quad \left[L_{1k}\right]_{n\times m} = \left[\frac{1+\alpha_i}{2}\right]_n' [1,\cdots,1]_m, \quad \left[L_{2k}\right]_{n\times m} = \left[\frac{1-\alpha_i}{2}\right]_n' \left[\frac{1+\beta_j}{2}\right]_m \tag{5}$$

α_i, β_j and A_i, A_j are Gaussian points and weights in stand Gaussian integral form, $i = 1 \sim n,\ j = 1 \sim m,\ k = 1 \sim n \times m$, n, m is the number of Gaussian points in α, β directions.

Substitute formula (4) to formula (2), we can finish the calculation of far field parameter.

3. Transformation matrix between mesh and Gauss points

The base idea of mesh transformation is: project 3D structure mesh to 2D mesh in aperture surface, choose Gauss points on 2D mesh by transformation matrix, determine the number of points by frequency. So different frequencies analysis based on only one mesh could be realization.

So a matrix $[A]$ is supposed as following:

$$\Omega_2 = \Omega_1 [A] \tag{6}$$

Structure mesh Ω_1: contain n triangle cells and coordinate of three vertex of each triangle cell. Ω_1 could be written as a $[J]_{n\times 3}$ matrix.

Coordinate of Gauss points Ω_2 for electromagnetism analysis: contain *n* triangle cells and *k* points for electromagnetism analysis in each triangle cell. Ω_2 could be written as a $[E]_{n\times k}$ matrix. The number of points is determined by frequency of antennas, higher frequency, more points.

So matrix *A* in formula (6) is a $[L]_{3\times k}$ matrix. Formula (6) could be written down:

$$[E]_{n\times k} = [J]_{n\times 3} \times [L]_{3\times k} \tag{7}$$

$$E_{ij} = J_{i1}L_{1j} + J_{i2}L_{2j} + J_{i3}L_{3j} \quad i = 1, 2, \cdots, n \ ; \quad j = 1, 2, \cdots, k$$

In antenna aperture, J_{i1}, J_{i2}, J_{i3} denote the 2D coordinate of three vertex of the *i*th cell respectively, as $\left(x_1, y_1\right), \left(x_2, y_2\right), \left(x_3, y_3\right)$, make E_{11} has the form $\left(Lx_1, Ly_1\right)$,and then:

$$\begin{aligned} Lx_1 &= x_1L_{11} + x_2L_{21} + x_3L_{31} \\ Ly_1 &= y_1L_{11} + y_2L_{21} + y_3L_{31} \end{aligned} \tag{8}$$

$\left(L_{11}, L_{21}, L_{31}\right)$ and $\left(Lx_1, Ly_1\right)$ are area coordination and Cartesian coordination of one point in the cell.

Through formula (5), points in rectangle could be mapped to triangle. L_3 could be computed by characteristic formula $L_1 + L_2 + L_3 = 1$ of area coordination. And area coordination of every node in one triangle cell is here:

$$N_k = \left[L_1, L_2, L_3\right]', \quad k = 1 \sim n \times m \tag{9}$$

So matrix A could be written down $\left[N_1, \cdots, N_k\right]$.

The construction of element in matrix A depends on the method calculating formula (1). Except the method above, Hammer integral formula is also a possible method[8、9]. But only server number of integral points is provided in Hammer integral form, in some condition the points is not enough and the result is not accurately.

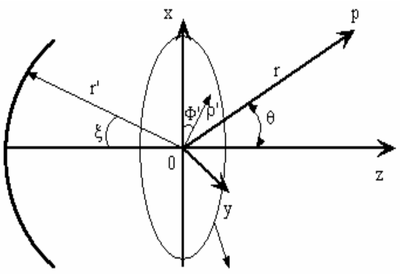

Figure 1.Variables in reflector antennas schematic diagram

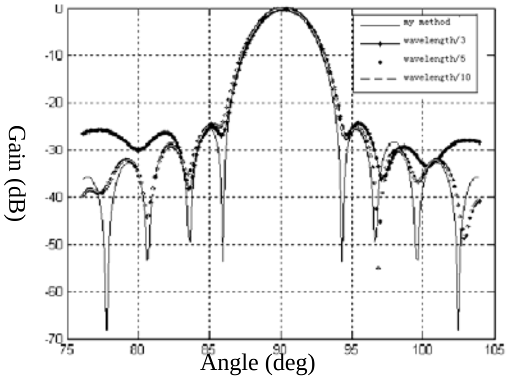

Figure 2. The far field parameter using FEKO software in different mesh and method in this paper

4. Simulation example

A stand reflector antenna is analyses. Diameter is 3m. Frequency is 2GHz. The number of triangle cells in structure mesh is 5400. Side length is about 5cm, which is third of wavelength. The size of cell satisfies the minimum requirement of FEKO software. Method in this paper and FEKO software are used to compute the same antenna as a contrast. Except the mesh number 5400, other two mesh number 25980 and 102344 is also used. Three kinds of side lengths are respective third, one fifth and one tenth wavelengths.

The results are shown in fig 2, the third wavelength mesh has large error, and the others are much more accurate. Fig 2 also shows that the result of method in this paper is similar with the result of FEKO.

5. Engineering Application

A 40m reflect antenna in Kuming of China is used as an applied object. The antenna can be seen in fig 3. Antenna diameter is 40m ; focus is 13.2m ; working wind speed is 20m/s ; maximum wind speed is 40m/s; frequencies are 2GHz and 12GHz.

In practical working, it is important to research the effect of electromagnetism performance induce by gravity, wind and temperature. In this paper four conditions have been computed. The structure analysis is done by ANSYS software. Antenna model of ANSYS is shown in fig 4. After structure analysis, method in this paper is used for electromagnetism analysis, and the result is shown in table 3.

Figure 3. Picture of the 40m reflector antenna

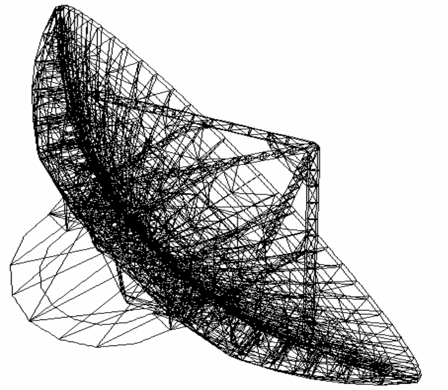

Figure 4. ANSYS model of the 40m reflector antenna

In table 3, ideal condition means that there is no effect by gravity and wind. You can see from table 3, because wind and gravity cause the distortion of reflector, the gain decrease , side lobe increase. For high frequency, the effect of electromagnetism performance is more sensitive for the same distortion condition. This computed result basically tallies with the experience of engineering.

Table 3. compute results of the 40m antenna in 6 different conditions

Work condition	Work frequency 2GHz			Work frequency 12GHz		
	Gain (dB)	L-side lobe(dB)	R-side lobe(dB)	Gain (dB)	L-side lobe(dB)	R-side lobe(dB)
ideal condition	57.397	-24.642	-24.642	57.397	-24.642	-24.642
$\theta = 90^o$ and gravity	52.189	-21.032	-21.032	51.114	-20.056	-20.056
$\theta = 90^o$ and wind 20m/s	52.257	-20.447	-21.671	50.220	-12.415	-13.485
$\theta = 0^o$ and gravity	52.308	-21.533	-21.569	49.411	-20.968	-20.779
$\theta = 0^o$ and wind 20m/s	52.223	-20.524	-20.620	46.506	-11.86	-13.240

Using the method in this paper, the time is about 10 minutes, even in high frequency. But using FEKO, a complex mesh process is necessary for each frequency and it takes mach more time. In fact, for 40m antenna in 12GHz frequency, it is hard to compute by FEKO, because of the limit of computer memory.

6. Conclusion

For the problems in the electromechanical coupled analysis of large broad band reflector antennas, such as the structure mesh is not matching with the electromagnetism mesh, and different frequencies need different meshes. Aperture method is used to constitute the electromechanical coupled model; an improved Gaussian formula has been used to calculate the model; a transformation matrix between structure mesh and Gauss points has been deducted. The Gauss points have been chose form structure mesh instead of complex mesh process. The number of the Gauss points is determined by antenna frequency. Compared with FEKO, a complex process of mesh is avoided, and much compute time is saved. The examples show that the method in this paper is accurate and effective, could be used in the electromechanical coupled analysis of large broad band reflector antennas. At last the method in this paper is used in a 40m reflect antenna, the result is accord with practice engineering.

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