The Effect of Structural Deformation of Metal Space Frame Radome on Electrical Performance *

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Abstract - In the simulation of electrical performance of metal space frame radome, the effect of structural deformation of the radome is studied. Firstly, structural deformation of the radome under wind load and weight load is analyzed. Secondly, far field of antenna is obtained by adding the far field transmitted through skin to the scattering field generated by elements. Then the effect of the deformed radome on electrical performance is analyzed. The simulation results of some 20m metal space frame radome show that structural deformation greatly affects electrical performance. Further research on the effect of skin and elements separately indicates that deformation of the skin is the main factor in the degradation of electrical performance.

Index Terms - Radome; Metal space frame; Dielectric sandwich; Structural deformation; Electrical performance.

1. Introduction

Reflector antenna plays a significant role in deep-space probing and manned space flight. Nowadays the work band of reflector antenna can be as high as Ka band which places great demands on the surface precision of reflector[1]. Metal space frame radome(MSF radome) is widely used to protect antenna from environmental loads which contribute a lot to surface distortion of reflector[2].

To protect the inner antenna, radome itself has to bear the environmental loads. Structural deformation emerges when wind load and weight load are applied. Wind pressure distribution on the outer surface of radome is studied in Ref. [3]. In Ref. [4] a simulation of some 25m radome under wind load and weight load is made using ANSYS in which the maximum equivalent stress in radome is 37.7MPa, far less than the allowable stress and the maximum deformation is 55.3mm..

Fig.1 Metal space frame radome

In the simulation example of Ref.[4], strength and stiffness requirements of the radome are fulfilled. However, as the radome is deformed, does the electrical performance still meet the requirement? The electromagnetic wave incident on a MSF radome(Fig. 1) will either be scattered[5][6] or transmitted[7] by different components. The scattering performance and the transmitting performance would both be changed if the radome is deformed. Then, a problem arises: how much will the electrical performance be affected by the deformation?

To solve these problems, firstly, the far field under the impact of both elements and skin is obtained. Then, computing the structural deformation of radome under loads, the effect on electrical performance of the deformed radome with different skin types and at different work frequencies is analyzed. Lastly, the effect of skin and elements separately on electrical performance is studied and the results are discussed.

2. Analysis method of MSF radome

When wind blows a radome, wind pressure emerges on the outer surface. The equivalent force on the nodes can be calculated based on the wind pressure and the weight of elements. Then the deformation of the radome can be obtained using a commercial software such as ANSYS.

MSF radome, belonging to electrically big structure, is usually analyzed using ray-tracing method [2]. MSF radome consists of a large number of elements, hubs and windows which we shall call "units". Elements and hubs scatter the electromagnetic field incident upon them while the scattered field of the hubs are much less than that of the elements, thus being ignored[5]. Windows are formed by single-layered or multi-layered skin through which electromagnetic field can be transmitted[2]. The transmitting performance of skin is usually analyzed using equivalent transmission line theory[8]. Adding the far field transmitted through skin to the scattered field generated by elements produces the far field under the impact of both skin and elements(Fig.2).

Amplitude and phase distribution of the antenna's aperture field is distorted in transmitting through the skin. Computing the transmitting coefficient of the skin, the far field after transmittance is obtained as[2]:

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$$F'(\theta,\phi)=\iint_S T_m E(x,y)e^{jk_0\sin\theta(x\cos\phi+y\sin\phi)}dxdy \quad (1)$$

Where $F'(\theta,\varphi)$ is field value in some point of far field; $E(x,y)$ is the aperture field of antenna; T_m is the transmitting coefficient of radome whose expression is given in Ref. [2].

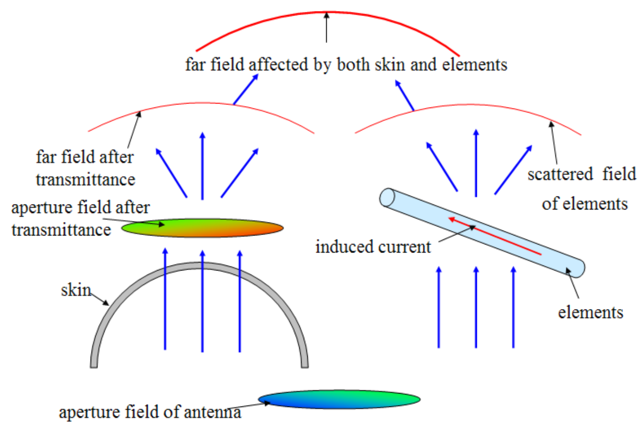

Fig.2 Analysis method of electrical performance of MSF radome

MSF radome usually has a large scale and the distance between elements is far greater than wave length so that the effect of multiple scattering between elements can be ignored reasonably. The overall scattered field of the elements is obtained by summing the scattered field of each element[2][5]:

$$F_{sca}(\theta,\phi)=\sum_{i=1}^{m}F_{sci}(\theta,\phi) \quad (2)$$

Where $F_{sci}(\theta,\phi)$ is the scattered field of the ith element; m is the number of elements; $F_{sca}(\theta,\phi)$ is the overall scattered field.

Adding the far field transmitted through skin to the scattered field generated by elements produces the far field under the impact of both skin and elements:

$$F_t(\theta,\phi)=F'(\theta,\phi)+F_{sca}(\theta,\phi) \quad (3)$$

While the radome is deformed, both T_m and $F_{sci}(\theta,\phi)$ vary, thus changing firstly $F'(\theta,\phi)$ and $F_{sca}(\theta,\phi)$ and then their summation, $F_t(\theta,\phi)$.

3. Simulation example

Some 20m MSF radome is used for numerical simulation. Elements are made of aluminum. Skin has three designs: single layer of fiberglass 1mm thick, Type-A with the inner and outer layer of fiberglass 1mm thick and the core layer of foam 26mm thick, Type-C with the inner and outer layer of fiberglass 1mm thick, median layer of fiberglass 2mm thick and two core layers of foam both 26mm thick. Dielectric constant of glass fiber and foam are 4.2 and 1.15 respectively. Loss tangent of glass fiber and foam are 0.026 and 0.0098 respectively.

The model is constructed in ANSYS using beam unit and the corresponding material properties are set. Wind loads on the nodes of every triangle unit are obtained by dividing the wind pressure on the triangle unit by 3. In addition, as the deformation caused by weight load is much less than that caused by wind load and the weight of the skin is much less than that of elements, only the weight of the elements is taken into consideration for convenience. The cross section of the elements are circular faces with a radius of 25mm. Wind velocity is 55m/s, blowing from right to left(Fig. 3).

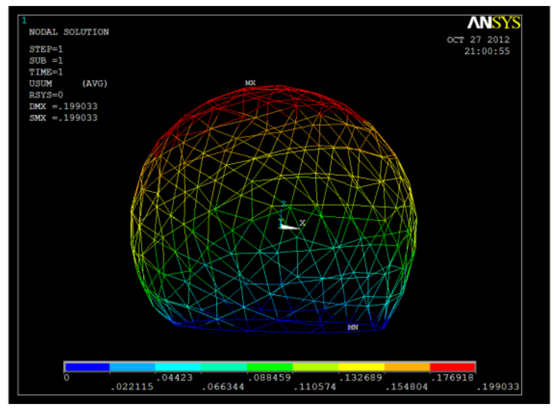

Fig. 3 The deformation of radome

It can be seen from Fig.3 that the deformation is asymmetrical. The deformation decreases from the top to the bottom where constraints are applied. The maximum deformation, occurring at the top, is 199mm, approximately 1% of the diameter of the radome. The maximum axial stress appears at the bottom and the maximum tensile stress and compressive stress are 214.9Mpa and 231.3Mpa respectively, both of them less than the allowable stress 300MPa.

A MATLAB program is written to analyze the electrical performance of the radome. A 13m reflector antenna with a focal length of 5.2m is used. The antenna's aperture field distribution is $E(r)=e^{-(0.59r)^2}$, where r is normalized radius of the aperture. The antenna can work at several frequency bands and the frequencies in this simulation are 4.5GHz and 9GHz.

With different skin types and at different frequencies, the electrical performance is simulated under different working conditions. It is found that the effect of deformation on electrical performance remains to be great under the working condition of (75°, 340°), where 75° is the elevation angle and 340° is the azimuth angle. This is because the gradient of the deformation is great at (75°, 340°). Corresponding results are shown in TABLE 1. The comparison of far field pattern with type-C skin at 4.5GHz are shown in Fig. 4.

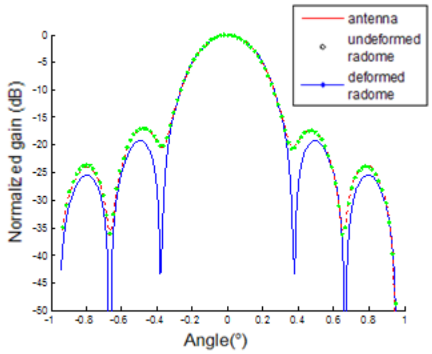

Fig. 4 Type-C skin

TABLE 1 Electrical performance under the impact of both elements and skin

Freqence /GHz	Radome conditions		Main beam location/°	L-sidelobe /dB	R-sidelobe /dB
9	Antenna		0	-19.25	-19.25
	Type-C	Undeformed	-0.0005	-12.04	-12.03
		Deformed	-0.0043	-11.61	-12.38
	Type-A	Undeformed	0	-16.41	-16.59
		Deformed	-0.0022	-16.18	-16.79
	Single layer	Undeformed	0	-19.19	-19.22
		Deformed	0	-19.21	-19.22
4.5	Antenna		0	-19.25	-19.25
	0 0	Undeformed	0	-17.04	-17.25
		Deformed	-0.0032	-16.88	-17.36
	0 0	Undeformed	0	-18.81	-19.11
		Deformed	-0.0022	-18.74	-19.22
	0	Undeformed	0	-19.29	-19.23
		Deformed	0	-19.27	-19.21

Compared with the undeformed radome, the main lobe location of the deformed radome is obviously shifted. For Type-C skin at 9GHZ, the shift is 0.0043°, as large as 3% of the beam width of antenna which is 0.1562° at the given frequency. The greatest effect of deformation are on the sidelobe which, generally lifted on the left and lowered on the right, becomes asymmetric because of the asymmetry of deformation.For Type-C at 9GHz, the difference between the left sidelobe and the right sidelobe varies from 0.01dB of the undeformed radome to 0.76dB of the deformed radome. For a same frequency, the effect of deformation increases from single layer skin, Type-A skin to Type-C skin as the skin becomes thicker. The effect of deformation also increases as frequency increases for both Type-A skin and Type-C skin while for single layer skin the increase is not penetrable because the effect of single-layered radome itself is very small. In addition, it is noticeable that the lift of sidelobe for Type-C skin at 9GHz is as high as 7.22dB for undeformed radome and 7.64dB for deformed radome. Such a dramatic variation of sidelobe is unacceptable in engineering application, i.e. Type-C skin is not a desirable choice at high frequencies.

By now it is illustrated that deformation of radome greatly affects electrical performance. To figure out the proportion of skin and elements in the effect of deformation, the electrical performance under the impact of skin only and elements only with undeformed radome and deformed radome is studied and corresponding results are shown in TABLE 2 and TABLE 3.

TABLE 2 Electrical performance under the impact of only elements

Freqence /GHz	Radome conditions		Main beam location/°	L-sidelobe /dB	R-sidelobe/ dB
9	Elements	Undeformed	0	-18.90	-18.88
		Deformed	0	-18.90	-18.89
4.5	Elements	Undeformed	0	-19.20	-19.12
		Deformed	0	-19.18	19.10

TABLE 3 Electrical performance under the impact of only skin

Frequency/GHz	Radome conditions		Main beam location/°	L-sidelobe /dB	R-sidelobe /dB
9	Type-C	Undeformed	-0.0005	-12.09	-12.12
		Deformed	-0.0043	-11.68	-12.46
	Type-A	Undeformed	0	-16.75	-16.99
		Deformed	-0.0022	-16.53	-17.19
	Single layer	Undeformed	0	-19.48	-19.49
		Deformed	0	-19.50	-19.49
4.5	Type-C	Undeformed	0	-17.34	-17.69
		Deformed	-0.0032	-17.21	-17.83
	Type-A	Undeformed	0	-18.69	-18.90
		Deformed	-0.0022	-18.62	-18.97
	Single layer	Undeformed	0	-19.32	-19.32
		Deformed	0	-19.33	-19.32

It can be seen that the deformation of elements has little effect on main beam location and has a small effect on sidelobe whose variation doesn't exceed 0.02dB. However, the deformation of skin shifts the main beam location apparently and affects the sidelobe greatly whose variation is as much as 0.41dB. The deformation of skin, as is shown, is the main factor in the degradation of electrical performance.

4. Conclusions

The electrical performance of a MSF radome is analyzed with and without deformation. It is found that deformation has a great effect on sidelobe, main beam location and null location, among which sidelobe is the most serious victim. The effect of deformation increases as the radome becomes thicker or the frequency increases. Further research on the effect of skin and elements separately indicates that the deformation of skin is the main factor in the degradation of electrical performance while elements are insensitive to deformation.

The blockage of elements is not taken into consideration in analyzing its effect on electrical performance. In addition, the maximum deformation reaches 1% the diameter of the radome in the simulation example. If elements are made of materials of better stiffness or the wind velocity becomes smaller, the deformation of radome would decrease. It remains to be studied that how large a deformation will greatly affect the electrical performance.

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6. References

[1] Wei Wang, Peng Li, Liwei Song. Mechanism of the influence of the panel positional error on the power pattern of large reflector antennas[J]. Journal of Xidian Universiy(Natural Science), 2009(04):708-713.[In Chinese]

[2] Yaowei Du. Telecommunications design method of the radome[M]. Beijing: National Defence Industry Press, 1993. [In Chinese]

[3] Qiao Jia, Zheng Wu, MingMin Guo, et al. Numerical Simulation on the Wind Load of Truncated Sphere Radome[J]. Chinese Journal of Hydrodynamics, 2012(05): 605-614. [In Chinese]

[4] Zi Wang, Len Weng, Zheng Wu, et al. Research on wind load distribution of truncated sphere radome[J]. Journal of Fudan University(Natural Science). 2009,48(06):807:814. [In Chinese]

[5] Alan F.Kay. Electrical Design of Metal Space Frame Radomes[J]. IEEE Trans. Antennas and Propagation, 1965(13):188-202.

[6] Changfeng Zhang, Xiaolong Mi, Wen Tang, et al. Application of Radar Absorbing Material in Design of Metal Space Frame Radomes[C]. Cross Strait Quad-Regional Radio Science and Wireless Technology Conference, Harbin, July 26-30, 2011.

[7] A.D.Monk, T.Wells, et al. Radomes for Large Millimeter and Sub-millimeter Wave Antenna Systems[C]. The 10th International Conference on Antennas and Propagation, Edinburgh, UK, April 14-17, 1997.

[8] Raveendranath U.Nair, Sandhya Shashidhara, and R.M.Jha. Novel Inhomogeneous Planar Layer Radome Design for Airborne Applications[J]. IEEE Antennas and Wireless Propagation Letters, 2012(11):854-856.