THERMO STRUCTURAL ANALYSIS OF METALLIC REFLECTOR

Dhaval G Rajyaguru [1], Ulkesh B Desai[2], Arup Hait[2], Kartik D.Kothari[1]

[1]*Department of mechanical Engineering, R.K. University*
[2]*Microwave-payload & Antenna system Mechanical Group, Space Application Centre, ISRO, Ahmedabad*

---***---

Abstract - *The design and construction of lightweight mirror used in satellite communication as antenna reflector operating on RF signals, is the vast subject of study in recent years. A consensus has been reached that the best design approach involves metallic plates made with an array of ribs consisting single material throughout. Stability of that light weight metallic reflecting surface is most important to get precise antenna working. This paper involves designing and modelling of the metallic reflector and its simulation at the different space environments constraints with the help of FEM simulation software ANSYS 18.0, also identifies surface RMS and wave-front aberration using Zernike Coefficients for the same.*

***Key Words*: *RMS*, *Wave-front aberration*, *Zernike* coefficient, ANSYS 18.0.**

1. INTRODUCTION

Antenna receives and transmits high frequency electromagnetic signals using reflecting surface known as reflector. These signals in the range of radio and micro wave frequency range in frequency spectrum. Reflector may be in many shapes but mostly they are in parabolic shape. Because of parabolic surface, it has one focal point. Therefore, it can concentrate input signals at one point. Reflectors are made from different types of materials like mesh, glass, polymers, ceramics, composite and metals [1]. In low frequency communication any material that could reflect microwaves would be acceptable. But in high frequency like GHz or THz the reflecting surface should be made from the highly polished surface that will be able to transmit the high frequency signals.

CFRP (Carbon Fiber Reinforced Plastic) is composite material with low weight and low coefficient of thermal expansion but it cannot be used as reflector because to transmit high frequency signals the reflecting surface should have very precise RMS which is difficult to achieve with CFRP. So, metallic reflector is used in this antenna design.

An optical reflecting surface is very sensitive signal collector. This type of reflecting surface directly depends on types of antenna used. The different types of antenna reflector are on-focus parabolic reflector, off-axis reflector, Casse grain reflector, Gregorian reflector, off-set parabolic antenna reflector and Duel antenna reflector [2]. Antenna reflector are mainly made of in the elliptical and circular shape with parabolic profile of reflecting surface attached in the antenna.

Space antenna reflector has to experience various boundary conditions. Reflector should be designed so that it can work precisely in all these different types of conditions. For that, while designing reflector various kinds of conditions are considered. Various parameters like space environments, earth environments, high amplitude vibration etc. [1] will be taken into consideration. In these conditions metallic reflectors can be deformed due to variation in temperature of Earth and space. The metallic antenna reflector may break due to high amplitude vibrations and deform under the influence of space thermal environments. To design such type of reflectors opto-mechanical theory is helpful.

Opto-mechanical theory is used in designing light weight mirror. This theory gives optimum weight, cost, size and best structure for light weight reflecting surface made from metal [3]. Dimensions of the reflector can be found on the basis of this theory.

The efficiency of optical reflector is directly related to its surface area, reflectivity and surface accuracy [3]. Structural stability of reflecting surface depends on reflector support systems, mirror manufacture and other influences. This study was deeply conducted on reflector support systems and other influences like induced error due to vibration and thermal variation.

Parabolic Reflector is supported with the help of axial support system like triangular, square and hexagonal rib pattern. The designed parameters for reflector's axial support systems are rib solidity ratio, face sheet thickness, rib support structure and holding positions to avoid deflection due to space environments. Flexural rigidity of light weight sandwich type symmetry and open back structural mirror depends on face sheet thickness, solidity ratio and axial support of the rib. The metallic light weight reflector offered minimum deflection in space environments when it designed with 20% solidity ratio with 2mm face sheet thickness and support with axial triangular ribs [4].

The purpose of this paper is to identify best design of reflecting surface which can offer minimum deformation and structural stability at various orbital parameters. Surface RMS and wave front errors of antenna reflecting surface are also calculated which can work on very high frequency.

1.1 Design parameters and modelling

As per above discussion, reflecting surface deformation mainly depends upon the design parameters like types of support, flexure rigidity, face sheet thickness and types of support rib. Main design parameters are Rib solidity ratio and shape of the rib. To offer minimum deformation, reflector should have 20 % rib solidity ratio [4] and support through triangular rib [3, 7]. Solidity ratio is defined as the effective area of all individual elements of reflector to the area enclosed by the boundary of the frame of the reflector. Rib is the back supporting structure of the reflector. Ribs are mainly in three type of shapes- triangular, square and hexagon. The rib parameters are shows in below figure-1. These parameters are related to the solidity ratio. Also, other parameters of reflector like height of the ribs, thickness of the ribs and face sheet thickness are as shown in figure-2 below.

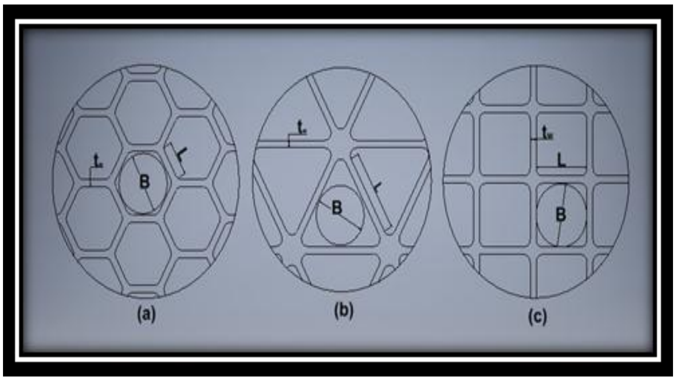

Fig-1 Types of ribs with parameters (a) Hexagonal, (b) Triangular and (c) Square

As per above parameters reflector has been modelled with two parameters. In this study first reflector has been modelled as per 20% solidity ratio with different types of rib pattern like triangular, square and hexagonal. These model are different as per different rib pattern and holding position.

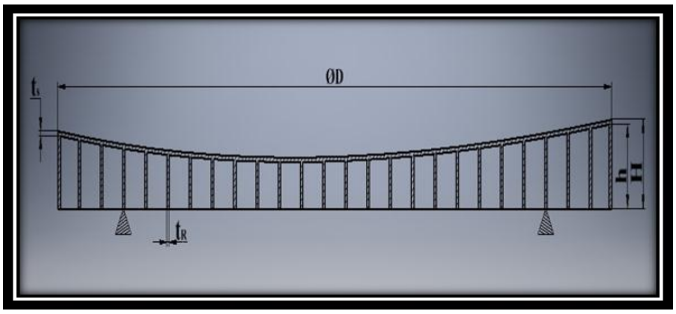

Fig. 2 Geometry of parabolic reflector

In second study reflector has been modelled with variable solidity ratio between 0.1 and 0.9 with the triangular supporting ribs. As per these parameters simulation carried out for approximately more than 18 models. These simulation results of the reflector as per various parameters are discussed in coming section.

The reflector models which are made as per above parameters, have been simulated using FEM software ANSYS 18.0. In simulation, Al-6061 has been used as reflector material, very fine mesh is created and on that FEM model vibration, Thermal and structural analysis has been carried out.

1.2 Simulation

As discussed above, antenna can be fail due to high vibration effect. For safe mode and resist failure due to vibration, natural frequency of space component should be more than 80 Hz [1]. Natural frequency of the reflecting surface indicates its failure mode. Modal simulation gives structural stability of reflecting surface; results are shown below. If reflecting surface has good stiffness it can resist failure due to vibration. In this study reflector model has been created with various types of rib pattern (mainly triangular, square and hexagonal) [1] and natural frequency at different holding position is calculated. Here reflecting surface is held by screw at particular PCD that is made at its back structure. The changing phenomena of natural frequency of the reflecting surface are shown in Chart-1 below.

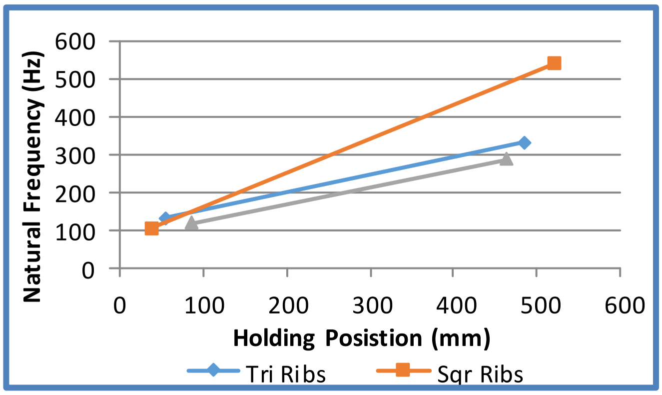

Chart-1 Structural Stability of reflector at various position

Thermo-Structural simulation of the reflecting surface has been done using FEM software ANSYS 18.0. The reflector is subjected to high solar flux and high temperature at support bracket of reflector, therefore it may get deformed due to these factors. In this simulation maximum solar flux was considered and reflector was held from different mounting positions from the back side of the reflector.

The simulation process with boundary condition mentioned above has been done for all different types of reflector which have been modelled as per different 20% solidity ratio with different type of rib patterns i.e. triangular square and hexagonal rib. The deformation of the reflector with different mountings position is shown in below Chart-2.

From the graph-2, it can be inferred that square rib and hexagonal rib pattern offer minimum deformation for 0.2 solidity ratio. Second study was done where the simulation process with the boundary condition mentioned above has been done for different types of reflector with different solidity ratio and constant rib pattern i.e. triangular rib. Deformation of reflector at various solidity shows in chart-3

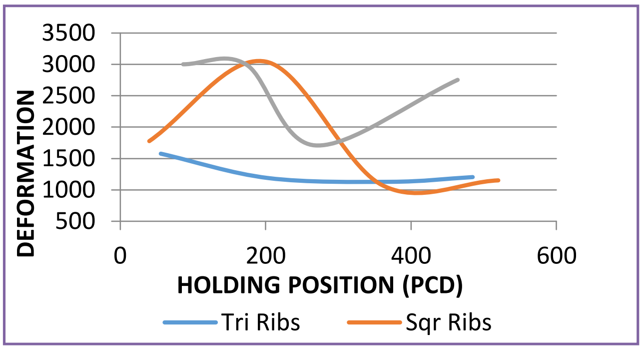

Chart-2 Deformation of reflector at 0.2solidity ratio

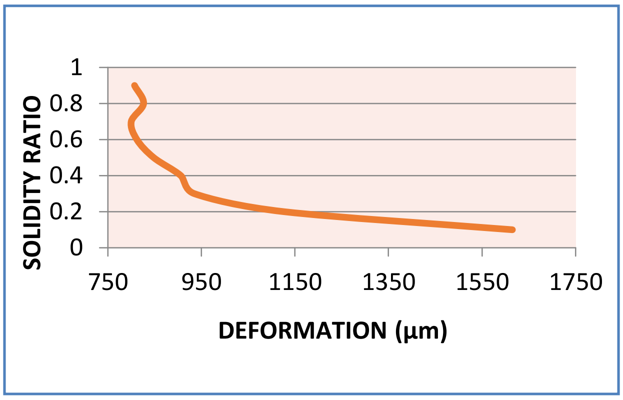

Chart-3 Deformation of reflector at various solidity ratio

It is observed that minimum deformation occurred at higher solidity ratio where weight of the reflector is more. Optimum deformation of the reflector with weight constraints is 0.6. As per the chart-3, deformation of reflector decreased with increase in solidity ratio. The minimum deformation of reflector occurred at 0.6 solidity ratio

A general trend is observed where minimum deformation occurs at high solidity ratio. However, the weight of reflector also increases with increase in solidity ratio. So, the optimum value is found considering the two constraints in mind. If weight of the reflector is the only constraints, then minimum deformation occurs in the range of 0.6 to 0.7. Reflector is modelled with designed parameters dependent on 0.6 solidity ratio and different types of rib patterns. Deformation with different rib pattern is shows in Chart-4.

As per the different simulation results presented in chart-4, it can be concluded that at maximum heat flux and maximum sink temperature minimum deformation of the parabolic reflector occurs at 0.6 rib solidity ratio with hexagonal ribs. The best designed parameters of reflector are with 60 % solidity ratio.

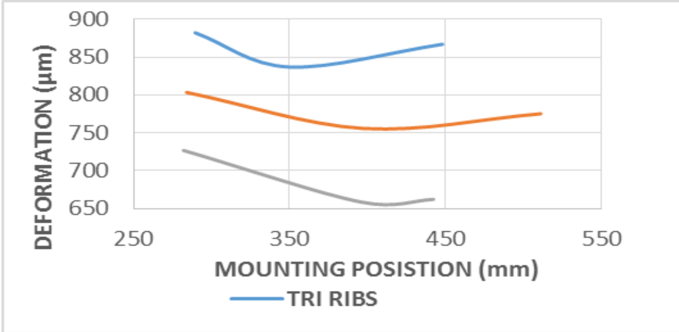

Chart-4 Deformation at 0.6 solidity ratio.

A different simulation is carried out to achieve the minimum deformation which can be done only by reducing the sink temperature. The deformation of the reflecting surface with sink temperature of 40˚C is shown in figure-3

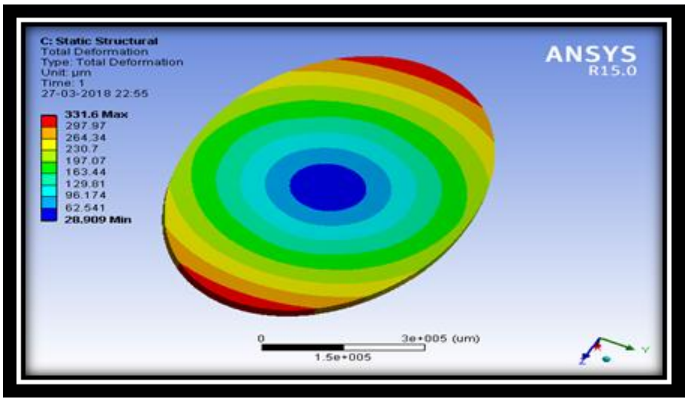

Fig-3 Deformation in reflector

The whole reflecting surface is attached to a support bracket which supports the reflector body. The stress is generated at holding points in the supporting ribs due to weight of the reflector. The maximum stress distribution in the reflector body is shown in figure-4.

Further wave front aberration of the reflecting surface made with 0.6 solidity ratio is calculated using Zernike polynomials. Zernike results are shown in the next part.

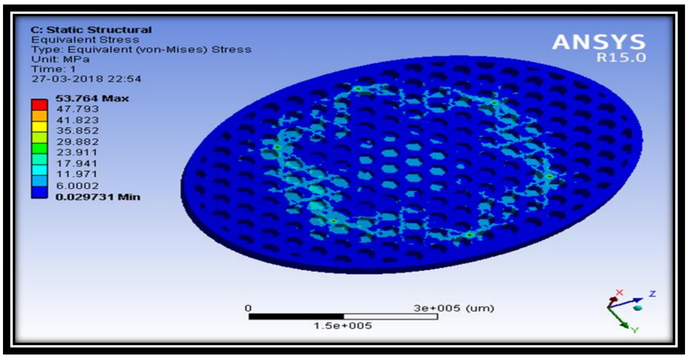

Fig- 4 Maximum stress in reflector

2. ZERNIKE COEFFICIENT FOR PARABOLLIC DEFORMED REFLECTING SURFACE

Zernike modes are an infinite series of polynomials that can be used to describe surface shapes on the unit disk. They are often used in optics to describe and quantify wave-front aberrations in mirrors and lenses with a circular aperture. Wave front aberration of parabolic reflecting surface are obtained using the Zernike coefficient. Calculation of Zernike coefficient for deformed parabolic surface is done using Zernike polynomials. The methodology to calculate Zernike coefficient for deformable surface is not exactly given but it can be obtained using comparing Zernike Coefficient for deformed and undeformed surface [6].

Wave front aberration for deformable parabolic reflector with the help of Zernike coefficient and surface RMS are calculated at maximum heat flux and minimum temperature. As per the boundary conditions, Zernike coefficient with wave front aberration is given in table-1.

Deformation of the reflecting surface because of expansion of the metallic reflector at various temperature. Boundary conditions are to be minimized so as to provide good reflectivity at higher frequency in the space environments. It means surface RMS of antenna reflector would be very small. In the study, value of sink temperature is taken at 40°C. Value of surface RMS of reflecting surface at various season is shown in the below graph. At various season like June, December solstice, March equinox and September equinox value of sun heat flux is different. The variation in surface RMS of reflecting surface is given in the Chart-5.

From the Chart-5 it can be inferred that maximum deformation occurs during December. The reflector is designed so as to resist the deformation during the month of December.

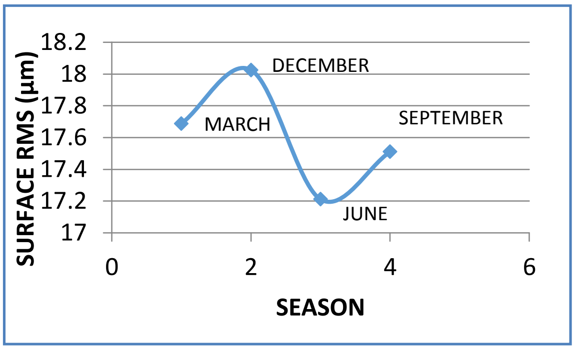

Chart-5 Surface RMS of reflector at various season

Table -1: Values of Zernike Coefficient for reflector

Sr. No	ZERNIKE COEFFICIENT	Error in REFLECTOR for Maximum Flux (mm)	ERROR
1	Z1	1	Piston
2	Z2	0.013174769	X-tilt
3	Z3	0.115930758	Y-tilt
4	Z4	-0.517503138	Focus
5	Z5	-0.116534505	Astigmatism 0
6	Z6	0.005493321	Astigmatism 45
7	Z7	-0.014667898	Coma
8	Z8	0.003934526	Coma
9	Z9	1	Spherical
10	Z10	0.013174769	Trefoil X
11	ZRMS	33.023 µm	

3. CONCLUSION

The analysis carried out in the present work shows that for a given reflector design, the deformation decreases with increase in the solidity ratio. The deformation is minimum at solidity ratio 0.6 when the weight constraints are taken into consideration with hexagonal ribs. Moreover, minimum surface RMS with minimum wave front error occurs at June solstice. It is also observed that the stress at holding position is large hence compliant mechanism can be used to reduce the stress.

ACKNOWLEDGEMENT

The authors are thankful to Space Application Centre, ISRO, Ahmedabad for financial support for completion of this work.

4 REFERENCES

1. W. Imbriale, S. Gao, L. Boccia. Space Antenna Handbook (2012).
2. D.K. Cheng, “Effects of arbitrary phase errors on the gain and beam width characteristics of radiation pattern,” IRE Trans. AP, vol. AP-3, No. 3, pp. 145-147, July 1955.
3. Daniel Vukobratovich, Light weight mirror design ,Opto-Mechanical Systems Design, Fourth Edition, Volume 2: Design and Analysis of Large Mirrors and Structures.
4. Pravin K Mehta, Flexural rigidity of characteristics of light weighted mirrors, Proc. of SPIE Vol. 0748, Structural Mechanics of Optical Systems II, ed. A.E. Hatheway (Jan 1987).
5. Dever, J., Banks, B., de Groh, K. and Miller, S. (2005) Degradation of spacecraft materials, in Handbook of “Environmental Degradation of Materials”, William Andrew, Norwich, NY. pp. 465–501.
6. Sanjay Gupta, Shiva Dev Rao Shindhe, A C Mathur, D Subrahmanyam, A new approach for mechanical design of antenna reflectors considering RF parameters & Zernike coefficients, 9th International Radar Symposium India - 2013 (IRSI - 13).
7. Cheng.j. Mirror Design for optical telescope, the principle of astronomical telescope design, 2009.