A NEW APPROACH FOR MECHANICAL DESIGN OF ANTENNA REFLECTORS CONSIDERING RF PARAMETERS & ZERNIKE COEFFICIENTS

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Abstract:

Communication Space-craft Antennas are using increasingly higher frequencies that require antenna reflectors having precise pointing accuracy and henceforth desired RF performance. Traditionally antenna reflectors designs are carried out independently in RF, Thermal and Structural domain. A new approach for design of antenna reflectors is used by the authors to interlink RF, Thermal and Structural domain using Zernike coefficients.

***Key Words:** Reflectors, Zernike coefficients, Thermo-structural analysis, RF performance*

I INTRODUCTION

The antennas used in spacecraft has high precision parabolic or shaped surfaces. Antenna structure can be categorized as solid or meshed. A solid reflector consist of a continuous surface with supporting structure on the rear of the shell. The structural design of these antenna must consider radiation and mechanical environments, both during launch and in-orbit phase. A design procedure is established to minimize RF performance degradations of a surface under mechanical loads. The following procedures are developed to accomplish this task.

- simulation of surface aberration of deformed surface using Zernike polynomials
- characterization of a surface using Zernike modes

II ZERNIKE COEFFICIENTS OF A DEFORMED PARABOLIC SURFACE

Zernike polynomials form a complete orthogonal basis on a circle of unit radius. Literature is available for its usefulness in the field of optics & optical instruments having circular shape. But literatures have not explained explicitly that 'how to obtain Zernike coefficients for Deformed parabolic surfaces', predominantly used as Antennae reflector surfaces since they reflect a collimated plane wave beam along the axis of the reflector.

The deformed plot of the parabolic surface under uniform thermal load of delta temperature of -100 degree Celsius is shown below along with un-deformed parabolic surface

Fig. 1: Free-free contraction of Parabolic surface

The zoomed view of deformed plot of the parabolic surface shows that deformation of all points on parabolic surface has taken place in all three translational directions

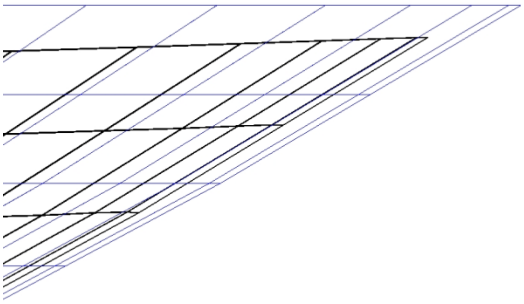

Fig. 2: Zoomed view of contracted Parabolic surface

The problem arises to represent Zernike polynomials of a parabolic surface due to

(a) Representation of Zernike co-efficient for out of plane deformation of parabolic surface instead of a flat circular surface
(b) In-plane deformation of surface with respect to un-deformed surface.

To obtain Zernike coefficient for out of plane deformation of parabolic surface, Zernike coefficients of both un-deformed and deformed parabolic surface in perpendicular direction to aperture plane are calculated Zernike coefficient of out of plane deformation w.r.t un-deformed parabolic surface is equal to the difference of Zernike coefficients of un-deformed and deformed parabolic surfaces. To get accurate Zernike coefficient from out of plane deformation w.r.t un-deformed parabolic surface , the in-plane co-ordinates of all points should be same for both un-deformed and deformed parabolic surfaces. This is achieved by mapping deformed and un-deformed surface.

Let us consider a metallic monocoque parabolic surface of diameter of 1m and f/d ratio of 0.4 and it is fully constraint at three equidistant points at the elevation of 25 mm. The Parabolic surface is subjected to soak temperature of -100 degree Celsius, deformation of surface is shown in Fig.3.

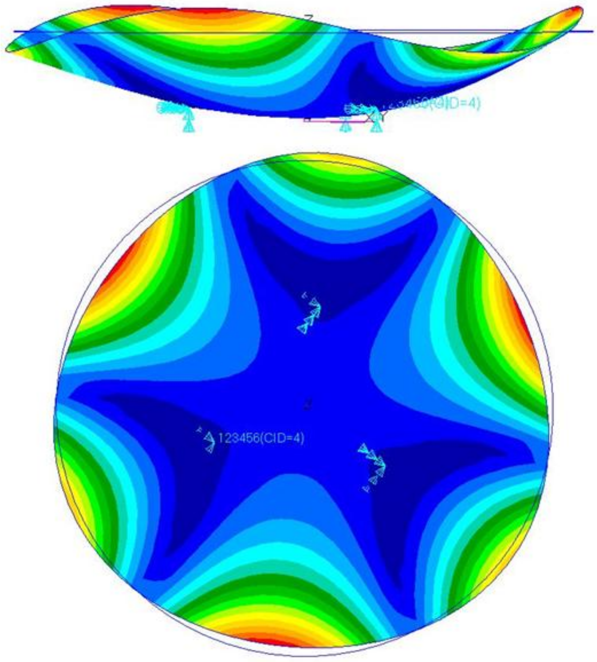

Fig. 3: Deformation of Parabolic surface under soak temperature

The Zernike coefficients of Parabolic surface are computed using programme made on Matlab and are furnished in Table 1.

Table 1: Zernike coefficients of deformed Parabolic surf.

S. NO	ZERNIKE COEFFICIENT (mm)			COMP. NAME
	Para-bolic surf.	Deform Para-bolic Surf.	Deform Surf. w.r.t Un-deform Surf.	
1	79.934	81.904	1.970	PISTON
2	0.0000	-0.0063	-0.0063	TILT-I
3	0.0000	-0.0055	-0.0055	TILT-II
4	46.1498	46.1587	0.0089	DEFOCUS
5	0.0000	0.0305	0.0305	ASTIG.-I
6	0.0000	-0.0409	-0.0409	ASTIG.-II
7	0.0000	-0.0009	-0.0009	COMA-I
8	0.0000	-0.0015	-0.0015	COMA-II
9	0.0000	0.0520	0.0520	PRI. SPH.
10	0.0000	-5.4006	-5.4006	TREFOIL-I
11	0.0000	-0.0200	-0.0200	TREFOIL-II
12	0.0000	-0.0003	-0.0003	SEC. ASTIG.

The accurate Zernike coefficients of deformed Parabolic surface w r t un-deformed parabolic surface are given in Column 3 of Table 1.

III RF PERFORMANCE OF DIFFERENT ZERNIKE MODES OF A PARABOLIC SURFACE

A study was carried out to characterises a surface based on affect of different deformation modes of Parabolic surface on RF performance. The different modes of surface are generated by increasing respective Zernike coefficients by delta amount. The RF parameters like Gain, Cross polarization, side lobe levels, Half power beam width (HPBW) etc. are compared for all modes of parabolic surfaces and given in Table 2. For each mode, RMS value of surface and amplitude & location of peak deflection is also computed.

Table 2: RF performance of different Zernike modes of a parabolic surface

Case ID:-	I	II	III	IV	V	VI
Para-meter	Para-bolic	De-focus	Pri. Astig.	Pri. Coma	Pri. Sph.	Trefoil
RMS (mm)	0.0	0.090	0.486	**0.556**	**0.506**	0.494
Peak def. In Z dir. (mm)	0.0	0.21	1.27	**1.45**	**1.12**	1.45
GAIN (db)	42.04	42.04	41.9	**41.8**	**41.80**	41.9
CROSS POLAR (db down)	55.94	55.74	55.3	54.2	55.60	53.7
SIDE LOBE LEVEL (db down)	31.88	31.64	22.8	**18.2**	**20.0**	22.8
HPBW (degree)	1.504	1.504	1.532	1.543	1.484	1.517

It shows that primary coma and primary spherical modes are degrading RF performance more as compare to other modes. Primary astigmatism is third critical mode to degrade the RF performance. The RF performance degrade as the surface RMS value increases The peak deflection of all the modes are also calculated. This study will assist the designer to know the permissible deformation at different location of parabolic surface with the consideration of RF performance .

IV DIFFERENT MECHANICAL LOADS ON REFLECTOR AFFECTING RF PERFORMANCE

The mechanical loads which affects RF performance can be broadly classified as

- **Loads which gives slowly varying distortions:** This generate most important RF degradation because they affects main and very first side lobes. Thermo mechanical , 1g and major adjustment assembly loads falls into this category
- **Loads which gives rapidly varying distortions:** these distortions occurs due to manufacturing

tolerances and limited adjustment accuracies. It generates modes of higher order which contributes only in far-out side lobe regions

Among these mechanical loads, thermo-mechanical loads are severely affecting the RF performance of reflector.

V THERMO-MECHANICAL ANALYSIS OF REFLECTOR

A metallic parabolic reflector of dia. 1m and f/d ratio of 0.4m is considered. The back side of reflector dish is mounted on housing of Rotating mechanism housing (SSM), enabling reflector to collect spatiotemporal parameters.

To find out temperature profile on reflector, thermal mathematical model is developed using UG NX 7.5, all the components are modeled as shell elements. SSM housing and Transition is modeled as cone incorporating SSM structural mass and coupling cross sectional area w.r.t transition & spacecraft interface. For on-orbit temperature estimations, this model has been integrated with the overall Thermal model of spacecraft to take care the IR loads and shadowing effects from the neighboring components. Optical properties of all surfaces are assumed to be temperature independent. IR emittance of surfaces is assumed to be constant with respect to time. Study has been carried out for both Dec. solstice and June solstice with consideration of SSM in rotating and non - rotating mode. SSM rotational speed taken as 20.5 R.P.M . The heat loads are calculated at 20 positions for each orbit with incremental positions before and end of eclipse. Results are obtained for the last analyzed orbit at different locations (i.e. reflector surface, Transition and SSM housing) of reflector assembly. The extreme temperature events at different locations of reflector assemblies were found out for all the cases. The Temperature profile on Reflector surface under June solstice is shown in Fig. 4.

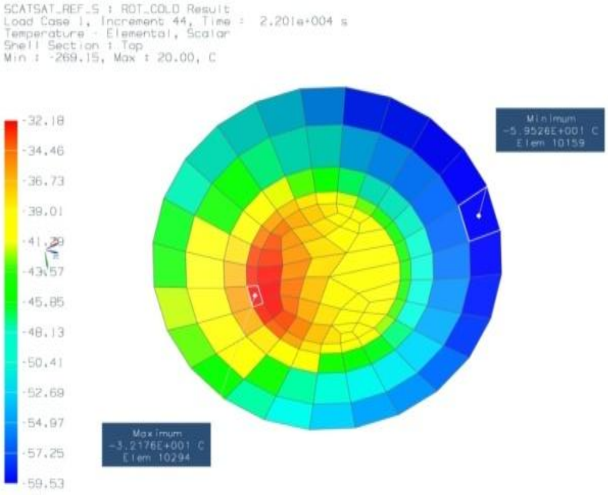

Fig. 4: Temperature distribution on reflector surface in June solstice

The mapping of temperature data on Structural model of reflector is carried out to find out deformation of parabolic surface. The Structural model is developed in MSC-PATRAN and analyzed using MSC- NASTRAN. The Zernike coefficients of deformed surface under Thermo-mechanical loads of December & June solstice are obtained and given in Table 3.

Table 3: Zernike coefficients of Reflector under Thermo-mech. loads

Case :-	**I**	**II**	**Coeff. name**
i	**Dec. solstice**	**June solstice**	
1	0.7546	1.3904	Piston
2	0.1767	0.0708	Tilt-I
3	0.0180	-0.0009	Tilt-II
4	-0.0020	0.0687	Defocus
5	-0.3915	-0.1956	Primary Astig.-I
6	0.0402	-0.0260	Primary Astig.-II
7	-0.0252	-0.0222	Primary coma-I
8	-0.0069	-0.0003	Primary coma-II
9	0.0011	-0.0099	Primary spherical
10	**-1.9473**	**-3.3929**	Trefoil-I
11	-0.0091	-0.0108	Trefoil-II
12	-0.0004	0.0049	Sec. Astig.-I
13	0.0029	0.0005	Sec. Astig.-II
14	-0.0032	0.0033	Sec. coma-I
15	0.0000	0.0008	Sec. coma-II
16	-0.0116	-0.0145	Sec. spherical
17	-0.0081	-0.0055	Quadrafoil
rms (mm)	1.898	3.216	

The table shows that reflector surface deformation due to thermal loads of June solstice is worst. The trefoil coefficient in June solstice case is 3.39, where as in Dec. Solstice case is 1.95 . All other coefficients are compare able in both case.

VI DESIGNING OF BACKUP STRUCTURE OF REFLECTOR

The following different design options under thermal loads of June solstice are studied. The design options are chosen to arrest major Zernike modes of deformation under June solstice.

Case I: Parabolic surface with no ribs, dia. 1 m, focus=0.4 m

Case II: Parabolic surface with main radial ribs+ inner-most circumferential rib

Case III: Case II + additional radial ribs

Case IV: Case III + middle & outer most circumferential ribs + additional radial ribs

The pictorial view of different design options are given in fig 5 to fig 7.

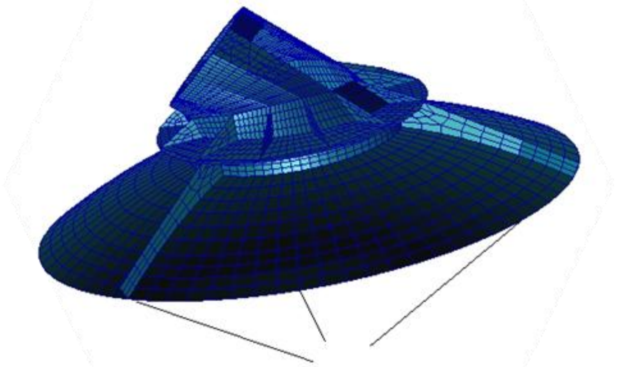

Fig. 5: Reflector with main ribs & inner most circumferential rib

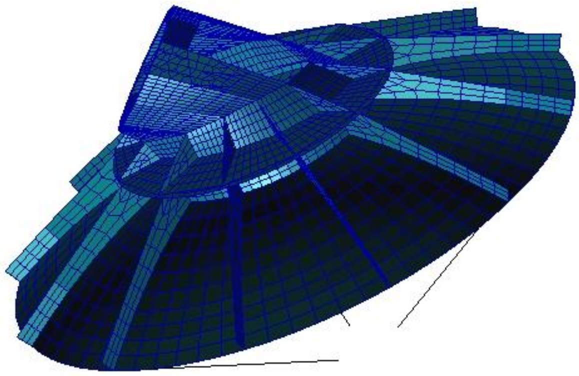

Fig. 6: Reflector with main ribs, inner most circumferential rib and additional Radial ribs

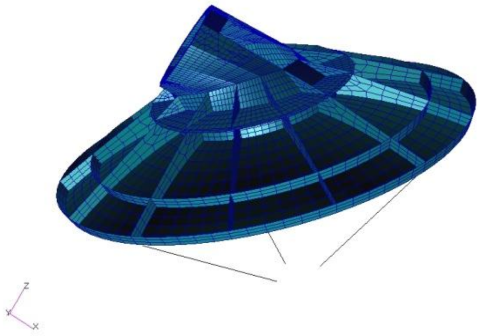

Fig. 7: Reflector with all radial & circumferential rib

The Zernike coefficients of different design options are furnished in Table 4.

Table 4: Zernike coefficients of Different design options of Reflector Backup structure

S. No	I	II	III	IV	Coeff. Name
1	1.3904	-0.1558	-0.2105	-0.2309	Piston
2	0.0708	-0.1124	-0.1034	-0.1006	Tilt-I
3	-0.0009	0.0042	0.0055	0.0066	Tilt-II
4	**0.0687**	**0.0271**	**0.0198**	**0.0196**	Defocus
5	**-0.1956**	0.0092	0.0064	**-0.0157**	Primary Astig.-I
6	**-0.0260**	0.0031	0.0045	0.0044	Pri. Astig.-II
7	**-0.0222**	**-0.0228**	**-0.0212**	**-0.0200**	Primary coma-I
8	-0.0003	0.0005	0.0007	0.0007	Primary coma-II
9	-0.0099	**-0.0316**	**-0.0236**	**-0.0285**	Pri. spherical
10	**-3.3929**	**-0.0570**	**0.0192**	**-0.0185**	Trefoil-I
11	-0.0108	-0.0003	0.0004	0.0006	Trefoil-II
12	0.0049	0.0068	0.0064	0.0043	Sec. Astig.-I
13	0.0005	0.0005	0.0005	0.0002	Sec. Astig.-II
14	0.0033	0.0013	0.0002	0.0015	Sec. coma-I
15	0.0008	0.0000	-0.0004	-0.0007	Sec. coma-II
16	**-0.0145**	**-0.0117**	-0.0060	-0.0039	Sec. spherical
17	-0.0055	**0.0642**	**0.0223**	**0.0088**	Quadrafoil

The RF performance of different design options are studied using software ' grasp 10.01'. The feed with Gaussian pattern having zero cross-polarization is considered. The radiation field of all design options are calculated by physical optics/physical theory of diffraction. The major RF performance parameters of all design options are compared against RF performance parameters of un-deformed parabolic surface and is given in Table 5.

Table 5: RF Performance of Different design options of Reflector Backup structure

S. No	**Case ID:-**	**I**		**II**	**III**	**IV**
	Parameter	Parabolic		js-mr-icr	js-mr-icr-fr	js-flconf
		No Load	With Load			
1	GAIN (db)	42.04	37.7	42	42.0	42.0
2	CROSS POLARI-ZATION (db down)	55.94	45.1	55.9	55.5	55.85
3	SIDE LOBE LEVEL (db down)	31.88	11.8	28.9	29.0	30.2
4	HPBW (degree)	1.504	2.48	1.510	1.507	1.517
5	RMS (mm)	0.0	3.216	0.149	0.099	0.081

VII RESULT AND DISCUSSION

Incorporation of three main ribs and inner most circumferential rib on parabolic surface(Case-II) has drastically improved RF performance & reduced trefoil mode as compare to parabolic surface without any ribs under thermal loads of June solstices. Among design cases ii to iv, the parabolic surface with only main ribs & innermost circumferential Ribs (Case-II) has worst RF performance and surface rms due to highest primary coma, trefoil & Quadafoil coefficients. Incorporation of radial ribs(Case-III) has helped in reducing all major Zernike coefficients and RF performance is slightly improved. Incorporation of both circumferential and radial ribs(Case-IV) has further helped in improving RF performance

CONCLUSION

The characterization of a surface by Zernike modes gives prior information to mechanical designer for worst RF performance mode-shapes. It also furnishes information of maximum permissible deformation at different locations on a surface. The designers can use this procedure to design Backup structure of Reflector which will improve RF performance under mechanical loads.

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