Surface Profile Estimation of Tracking Radar Antenna using Close Range Photogrammetry

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Abstract:- This paper highlights the Surface Profile Measurements carried out at 4m diameter Ground Station RADAR antenna installed at SHAR. Various unknown parameters like Surface Profiles (2D and 3D), Linear distances and vertex shift have been found out. Relation between Vertex Shift and Surface Profile Error (RMS Error) have been established. This paper also highlights the definition of various references needed for the antenna components, creation and application of coordinates and rotation matrices, use of coordinate systems & attainable accuracy of measurement. The presented concepts are based on experience at tracking antenna at SHAR and SAC-CATF facility.

I. INTRODUCTION

Large size steerable ground station antennae are used for establishing communication link with satellite or with launch vehicle during its launch operations. Spacecraft (S/C) antenna communicates through ground hubs installed at various locations. The ground station antenna size varies according to operating frequency band. These Ground station antennae are mostly of Cassegrain configuration where a Sub Reflector (generally part of Hyperboloid) and Feed are placed in Main Reflector (generally part of paraboloid) coordinate system meeting with optics given by RF designer. Since all three elements vis. Main Reflector (MR), Sub Reflector (SR) and Feed are to be bought in one defined geometry, carrying out Antenna Alignment Activity is must. **A good initial Design & later alignment of these antennas ensures a well defined geometrical parameters of antenna elements like Reflector, Sub Reflector & Feed. Requirements for the accuracy of the Antenna Integration & Alignment with respect to nominal parameters is as per RF specifications. Surface Profile Error estimation is one of the important aspects of Ground Station Antenna as well as Spacecraft Antenna.**

Antenna Alignment is carried out to achieve the required surface profile and Nominal Antenna Optics/Geometry. The goal of the alignment is to bring antenna elements (Reflectors and Feed) in required geometrical configuration to get best RF antenna performance. Various RF design parameters which are being measured are Antenna Gain, Side Lobes, Cross Polarization etc. The parameters like beam pointing, coverage area are also measured. These RF parameters are effected by the various errors like Reflector, Sub Reflector and feed misalignments, Reflector and Sub reflector Surface deviations, Sub reflectors positioning errors (in case of Cassegrain and Gregorian Antennas) etc Generally ground station antennae are in Cassegrain configuration having steerable capabilities. To align antenna elements in required geometry, various measurement methods are used worldwide. Close Range photogrammetry (CRP) is one of the high accuracy measurement method available for carrying out various type of measurements starting from simple linear distance calculation to complex surface error estimations. CRP is widely used (from high accuracy spacecraft level alignment to surveying applications) **to cater to high accuracy and faster measurement requirements which is in vogue now a days.** It uses retro reflective targets and a metric camera for generation of intended point coordinates. These coordinates are used for post processing of data for Alignment parameters which define geometrical configuration like reflector shape, focal length, feed orientations etc which are decided during RF design. Accuracy to which misalignment is permissible is operating frequncy dependent and is derived from the result of sensitivity analysis carried out based on RF parameters. The general requirements (for Ku-Band) are 0.5 mm and 0.05˚ in linear & in angular rotation for feed & sub reflector and 0.02˚ angular rotation for reflector. **Finally for evaluation of Antenna RF performance, the correlation between Antenna coordinate system, Sub Reflector Position and their surfaces is required.**

II. ANTENNA MEASUREMENT OBJECTIVES

Current measurements are being carried out at Tracking RADAR antenna at SHAR. These are 4m Ø steerable antennae operated in C & S band frequency. Various objectives of this measurement are to create surfaces of MR and SR (Reflectors), estimating surface errors of reflective surfaces w.r.t. available point cloud information, calculating relative distances of MR and SR and establishing correct optics, extracting various GD&T information's, and finding out effect of surface fitting errors on vertex position. The measurement is done by CRP system used for the first time by alignment team of Space Applications Centre (SAC). This system works on triangulation principle and calculate coordinates in Cartesian form. Since MR and SR are symmetric to their standing axes, single curve measurement approach is used here. Outdoor measurements of both C & S band antenna are carried out by sticking tape targets over one line curvature of reflectors. Combination of Tape and spherical targets is used for establishing standing axes of reflectors. Post processing of measured data is done by Polyworks (A software package from Polyworks India Pvt. Ltd. and an interface software for measurement and calculations).

III. COORDINATE SYSTEM (CS) DEFINITION

Following coordinate systems are established during Antenna Alignment of RADAR antenna.

- Antenna Coordinate System (ACS) is defined on vertex of Main Reflector (MR). It was established using 3-2-1 or Plane-Line-Point approach of metrology.
- Sub-Reflector (SR) Coordinate System (SRCS) is defined at physical centre of SR. Again 3-2-1 approach is used for defining CS.

Since the definition of ACS &SRCS is not available by reference spheres or Tooling Balls (TB's), general Best Fit Alignment (using probe) approach used in antenna alignment for establishing Coordinate Systems can't be used. Relationship of established CS like positions and orientations are calculated through Euler Angle Approach. MR and SR reflector Surfaces are also digitized and compared with available nominal point cloud data to get an error map and to establish one Best Fit Coordinate System.

IV. MEASUREMENT METHODS

Various high accuracy measurement methods are available now a days to carry out alignment. Some of the available methods are listed here:-

1. Electronic Coordinate Determination System (ECDS) using Theodolites
2. Laser Tracker system with Corner Cube Reflectors (CCR's), laser based scanner and a compact probing device.
3. Close Range Photogrammetry system (CRP) with Retro reflective Targets or a target projection system
4. Auto collimation Technique using stand alone Electronic Theodolite and Cube mounted on Subsystem.
5. Coordinate Measurement Machine (CMM)

CRP is chosen for this particular measurement given that antenna is installed in open environment & a large size data of about 4m is needed to be captured which required a compact & highly accurate system.

V. ANTENNA ALIGNMENT

A. Measurement Set up and Data Acquisition:

Prime objective of this measurement is to estimate unknown surface profile of MR & SR and to validate available point cloud data with measured results. As stated above MR and SR both are symmetric to their own standing axes but have shaped profile and doesn't follow regular parabola equation. A single curve segment is therefore measured instead of measuring full antenna. Idea is to revolve the data about its standing axis & then to get full surface of reflectors. To ensure proper measurement, Targets are glued along two curves of panel. 6mm Ø dot size targets are used in total measurement keeping the size of reflector into mind. To get a proper transformation of CS and to correlate MR and SR, proper targeting and sighting of both MR and SR in one measurement is necessary. To establish MR's Coordinate System (ACS) a 3-2-1 (Plane-Line-Point) approach is used. Hub plane is selected and measured for defining standing axis of MR. Similar approach is used in measurement of SR where it is ensured that periphery coordinates can be glued as accurately as possible.

Since its an outdoor measurement, AUTO mode of camera for setting Strobe power, Shutter speed is not appropriate. Therefore, a proper Strobe power and Shutter Speed is set manually based on some preliminary measurements done at site itself. Measurements are carried out by taking picture all around the antenna. A total of 172 pics were taken to ensure that all points are captured and processed. Scale size is kept comparable to size of antenna.

B. Post Processing of Data acquired:

Measurement data taken by CRP is imported into Polyworks as point coordinate information. Hub plane, Hub PCD centre and Line joining Hub centre to Inner periphery point is used as constraining Plane, Point and Line respectively for establishing ACS. All point coordinate information is transformed into ACS. Two different curve segments are measured over MR surface. A third order (cubical) curve is fitted over these point cloud data of segments. This curve is then revolved around standing axis (Z-axis) to get full MR surface. Two individual surfaces are generated and compared with each other as shown in Fig 3. This shows a close match in two surface measurements. These two measured surfaces are then used to do a detailed comparison with nominal point cloud data available. This nominal to measured comparison fits point data by minimizing deviations in all three directions (X,Y,&Z) i.e. Least Square Approach of calculations. Since points are free to fit in 3 Translations and 3 Rotations [i.e. Six Degree of Freedom (DOF's)], various cases are studied out by constraining various DOF's. Effect of Surface RMS Error in these different cases are studied. Also studies for vertex shift in all cases are done. Table1 shows the variation of RMS variations.

Figure 4 shows the error mapping of nominal to measured data of MR.

To estimate Surface Profile and error mapping of Sub Reflector (SR), points measured on SR is transformed in SRCS. This SRCS is set using 3-2-1 approach as done in ACS. Points measured on SR circumference is used to establishes a plane. SR centre is taken as required origin and a line joining centre to circumference point is taken as axis. A third order (cubical) curve is fitted over SR similar to MR. This curve is revolved around standing axis of SRCS to get SR surface. This surface is then compared with available nominal data of SR to get an error map with a similar approach used in MR. Figure 5 shows the surface profile error of SR.

Finally to validate optics, measured data of SR and MR is imported with reference to ACS. Similarly, Nominal data of MR and SR is also imported w.r.t ACS. Both Nominal and Measured point clouds of MR is then freed (unconstrained in all 6 DOF's) and fitted to get a Best Fit Alignment. A comparison of Nominal and Measured SR is done to get variation in Nominal and Measured optics of RADAR antenna. Different linear and angular calculations over various points on SR surface is done to validate the error.

Case No.	**Constraints**							
	Translation			**Rotation**			**Vertex**	**RMS**
	X	**Y**	**Z**	**X**	**Y**	**Z**		**mm**
1	F	F	F	F	F	F	F	0.878
2	F	F	F	L	L	F	F	0.871
3	L	L	F	F	F	F	F	0.872

4	F	F	F	F	F	F	L	0.877
5	F	F	F	L	L	F	L	0.875
6	F	F	F	L	L	L	L	0.875
F:- Free **L:- Locked**								

Table :-1 Effect of constraining DOF's on Surface RMS error

Figure:-1 Ground Station Antenna Measurements using CRP

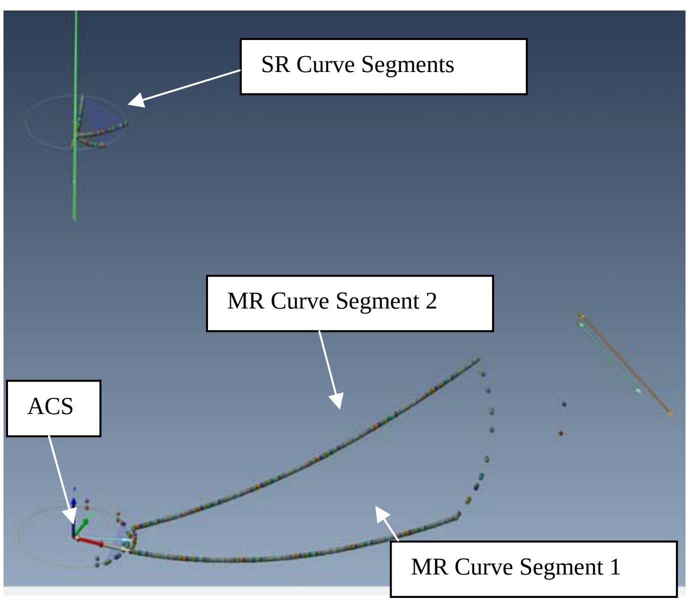

Figure:-2 MR and SR measured point cloud data w.r.t. ACS

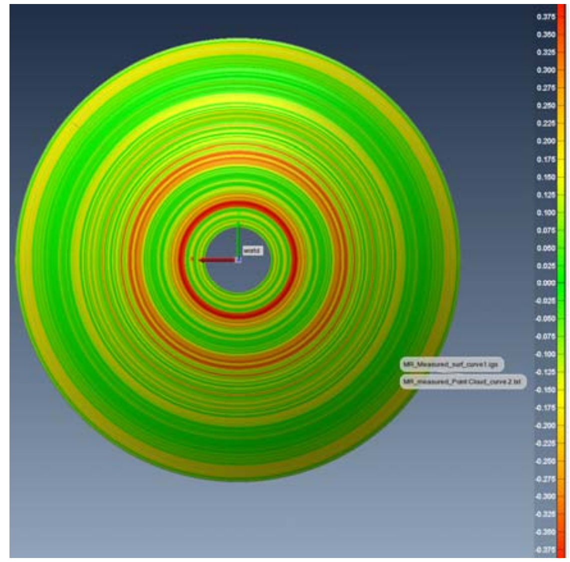

Figure:-3 Surface Error Comparison of surfaces generated using Curve Segment 1 and Curve Segment 2 (Data measured on MR)

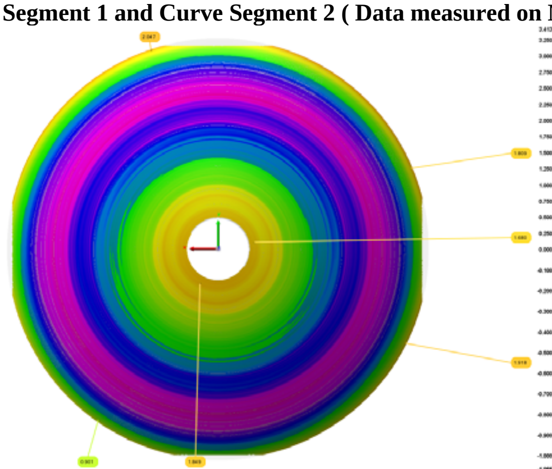

Figure:-4 Nominal to Measured Surface Error Comparison of MR

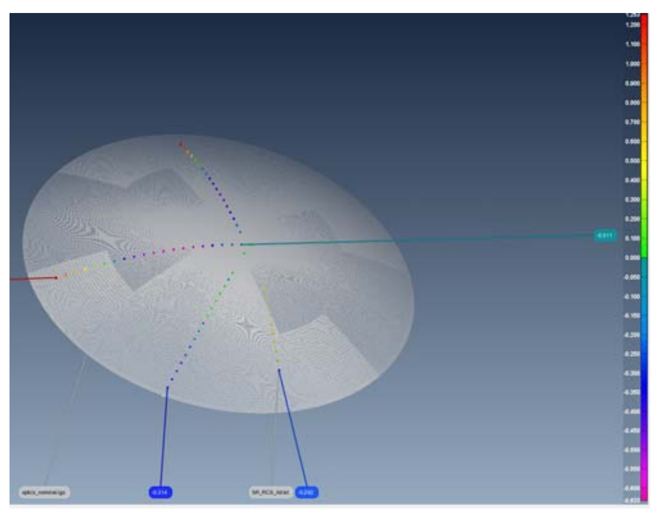

Figure:-5 Nominal to Measured Surface Error Comparison of SR

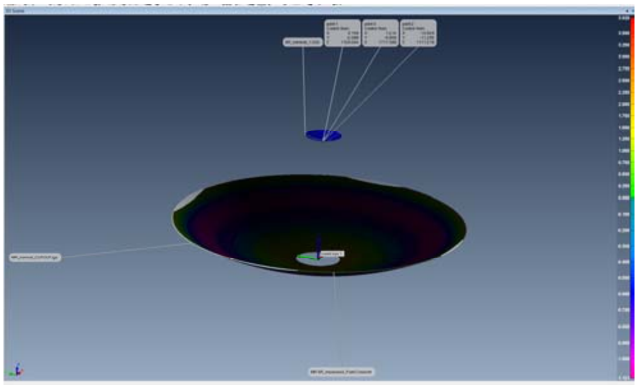

Figure:-6 Nominal to Measured Optics validation

VI. CONCLUSION

CRP is used for the first time by SAC alignment team to carry out outdoor measurements of ground station antenna. The measured point cloud information is used to extract MR and SR reflector surfaces and measured optics to carryout RF analysis. Misalignment information of SR w.r.t. ACS has been calculated and a comparison of theoretical and measured optics is done. Measured Paremeters of optics is mentioned in Table no. 2. RF analysis based on these observations and measurements are going on.

Parameters	**Measured values**
SR Position w.r.t MR	1717.41 mm
SR Tilts (Axis definition as per Fig.2)	About X axis:- 0.44° About Y Axis:- -0.37°

Table :-2 Measured parameters of Antenna Optics

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