Mechanical Design of Single Channel Rotary Joint at Ka-Band for Gimble Antenna System

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Abstract: - For certain applications now-a-days, Antennae are being operated in high frequency band like 30 GHz, 60 GHz or 180GHz. These high frequency bands imposes a challenge on Mechanical design of Antenna elements like Reflectors, Feed horns, Waveguide components etc. An additional requirement of continuous scanning type reflector enhances the complexities in design. This raises a requirement of Rotary Joint which allows Antenna to acquire real time data with minimum losses while it is mounted on S/c.

This paper highlights the mechanical design aspects including 3D modelling and integration of single channel rotary joint developed for Ka-Band antenna. This rotary joint is compatible with three different configurations of antenna vis. Cassegrain, Prime Focal & ADE. Paper highlights about the various options designed and realized keeping in mind fabrication approach when RF parameters puts a tight dimensional constraint. Surface finish, GD&T aspects of design is also described in the paper. Requirements for the accuracy of the Integration & Alignment with respect to nominal parameters are also specified. The presented concepts are based on the experience in SAC/ISRO.

I. INTRODUCTION

Spacecraft (S/C) antenna operates in various frequency bands varying from UHF to Ka band and extending in Millimeter Wave band (60GHz and 180GHz Frequency bands). RF parameters of antennae operating in high frequency bands are highly affected by Mechanical design and Integration/Alignment of antenna elements viz. Reflector, Sub Reflector, Feed and feed chain components. If Antenna has to acquire data by continous physical scanning, a rotary joint becomes mandatory. **For** various configurations of antenna like Cassegrain, Prime Focal or Axially Displaced Ellipsoid (ADE), a reflector or reflector & sub reflector assembly may have to be in continuous scanning mode while feed or waveguide routing may have to remain fixed. Scanning Antenna requires relative motion between the Antenna-Feed system and the remaining RF sub systems (waveguide routing and downstream chain). A rotary joint (RJ) facilitates such a relative motion between the subsystems. A rotary joint connects Reflector and Waveguide routing of antenna and allows continous rotation of reflector while waveguide remains fixed. It consists of two parts i.e. stator and rotor. Various configuration of Antenna from simple Prime Focal to complex cassegrain or ADE have impact on design of rotary joint. Since various RF parameters like Antenna Gain, Beam pointing, Cross Polarization, Insertion loss, Return loss etc depends on the accuracy of dimensions achieved, a proper estimation of tolerance is mandatory. More no. of joints in assembly increases RF leakage and thereby degrading RF performance of Antenna. Mechanical design of RJ is driven RF dimensions based on these RF parameters. It has to take care of tight tolerance requirments of fabrication and integration. RJ design should also take care of RF testing requirements.

II. DESIGN ASPECTS

Mechanical design of Rotary Joint is done over specific RF path designed for its operaion in Ka-Band. Figure1 shows the basic RF cavity path of Rotary Joint (RJ). It is divided into two parts i.e. ROTOR and STATOR. Following requirements are to be taken care for designing RJ:-

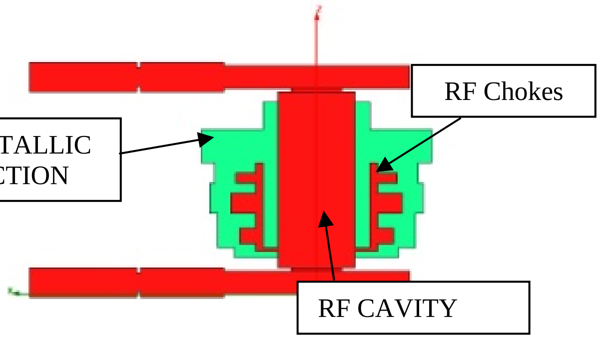
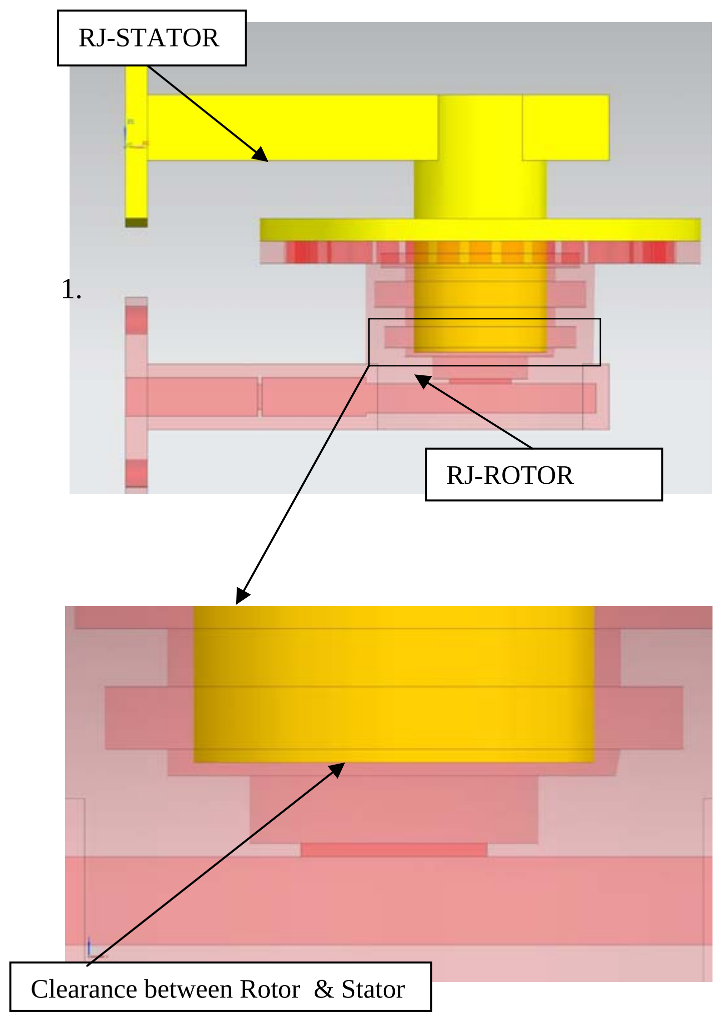


Figure:-1 RF design of Single Channel Rotary Joint

1. Rotor and Stator has to be aligned in one line along standing axis to provide coaxial path for RF energy. Also misalignment of axis will also restrict the 360 ^{o} movement of RJ. Initially design and later integration has to ensure alignment within $\pm$ 0.1^{o} accuracy. Selection of proper location of joining interface, planarity of inteface surface & Integration of Rotor and Stator effects the overall misalignment.
2. RJ have Physical (Mechanical) discontinuity. In order to maintain electrical (RF) continuity at the disjoint location, a RF choke is provided. This element of RJ permits mechanical discontinuity at junction but at the same time maintains electrical continuity. The varition in dimensions and location of these chokes after assembly is critical to ensure achieving required Insertion losses, impedance matching etc. Selection of appropriate GD&T's and doing proper integration will ensure proper electrical continuity.
3. The rotary joint uses circularly symmetric modes for transmissions. Such modes have no azimuth variation and hence do not suffer by transmission losses due to rotation. Two RF coupling slots are designed to facilitate required mode excitation.The variation in dimensions of these slots and misalignment w.r.t. axis of rotation shall lead to variation in Return Loss, Mode Excitation , Insertion loss, Impedance Matching etc. Selecting Proper GD&T, misalignment of rotation axis ,selection of the option where accessbiltiy for fabrication of these slots are provided are some of the affecting factors.
4. Leakage of RF energy due to intoduction of joints is equally critical. Pressure joints are designed and used to minimize RF leakage losses.

A varying size RF cavity (basic size of cavity is WR75) over a length of 65 mm poses a fabrication challenge (in Single piece concept) with a tolerance requirement of $\pm$20microns. Further realization of two small rectangular coupling slots (of size 7 X 2.4 mm and shown here in figure2) in RJ, requires an out of box thinking to make fabrication easy with the help of mechanical design. RF design also asks for a clearance of 3mm after assembly of Stator and Rotor with a selective tolerance of 20 microns in positive side. Figure2 depicts the requirement of clearance.



Front View

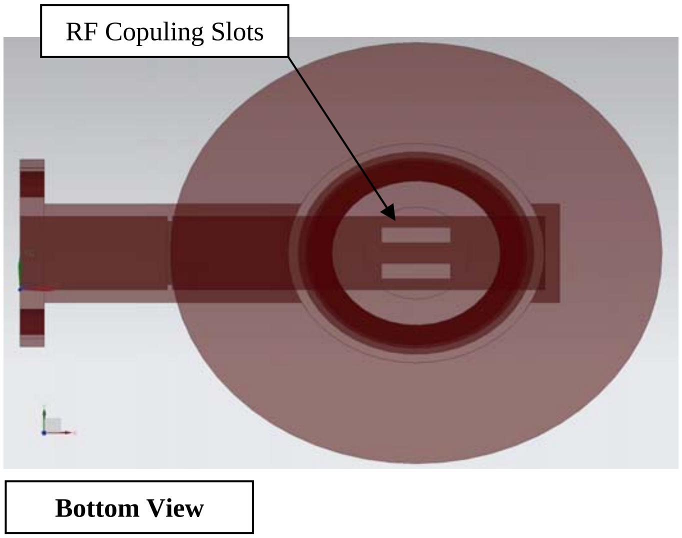
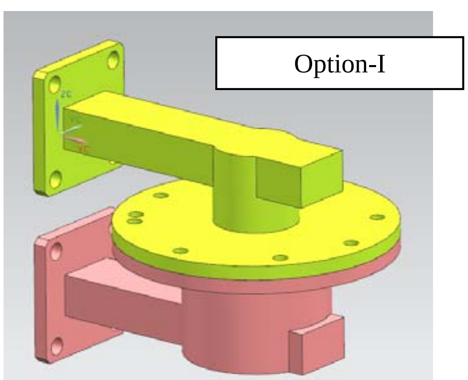
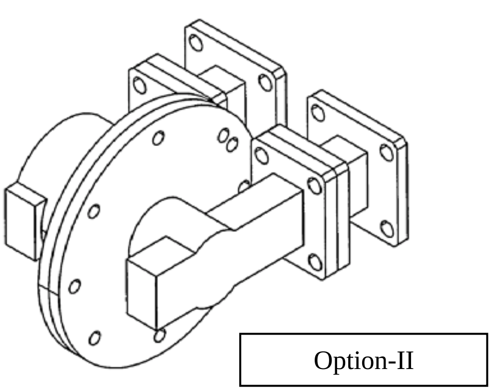


Figure:-2 Conceptual Mechanical design of Single Channel Rotary Joint

III. CONFIGURATION DESIGNED

To facilitate easy fabrication & integration and to achieve required RF path with proper clearance, various mechanical design options have been thought of. Single Piece design is always preferred over split design as introducing joint increases the risk of RF leakage. Three options designed for Rotary joint are mentioned here in figure 3.





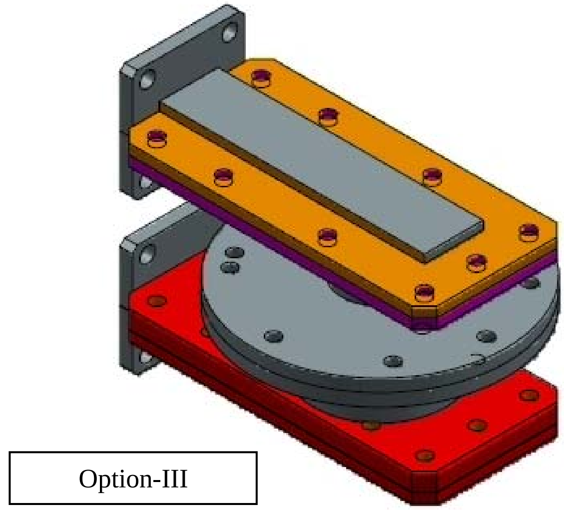


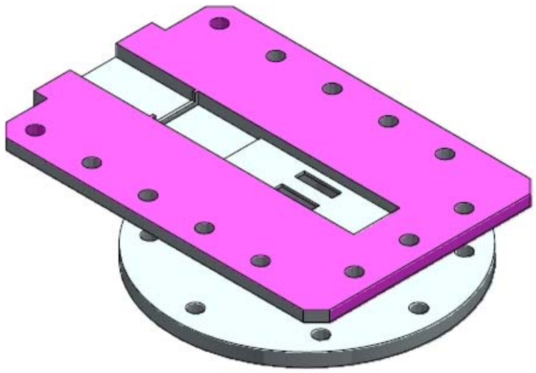
Figure:-3 3D Models of various options designed for Single Channel Rotary Joint

All options are designed based on various aspects mentioned in section II. Fabrication aspects of all three options are depicted below.

IV. FABRICATION ASPECTS

Option-I is a single piece design where stator and rotor is designed to fabricate in single piece. Since RF design requires a changing cavity cross section, achieving required dimension within specified tolerance zone with specified surface finish is a complex and tedious process. To facilitate proper access of cutting tool, Rotary joint is split as per Option -II and Option-III. In Option-II where splitting is done perpendicular to straight waveguide axis (along its length), Splitting doesn't fully solve the problem of difficulty in machining of the Chokes. To **solve this problem, Option-III is thought of where RJ is** split along the axis of straight waveguide portion. Option-III provides a clear access of machining but at the same time also increases the risk of RF leakage. To take care of leakage, pressure joints are introduced. Geometric dimensions and tolerances of pressure joints are being selected as per ISRO standards and heritages. All three options have a facility to rotate the Rotor w.r.t. Stator at every 5 degree for testing purpose. Clearance as shown in Figure1 should be maintained after assembly of RJ within specified tolerance zone.

Figure4 shows the detailed view of Stator and Rotor designed in option-III.



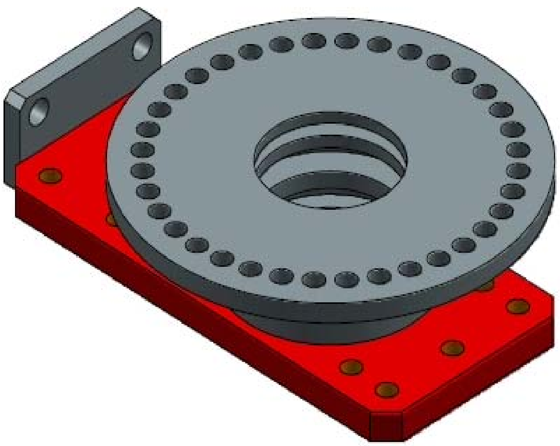


Figure:-4 3D Models of Stator & Rotor of option-III Rotary Joint

V. RESULTS

Option-II and Option-III are realized and RF testing is being carried out. Against the requirement of 20 dB return loss and 0.5 dB insertion loss, Option-II & achieves better then 17 dB and 0.7dB for all angles of rotation.

VI. CONCLUSION

Measured results shows a good match of Return loss and Insertion loss for developmental models. Option II is prefered due to its simple construction. Future work is focused on development of a single channel rotary joint with bearing and giving full physical scan freedom to antenna.

VII. REFERENCES

1. Mechanical & RF design documents of Single channel Rotary Joint available at ISRO

VIII. ACKNOWLEDGEMENT

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