PRELIMINARY DESIGN, ANALYSIS AND MANUFACTURING ASPECTS OF LOW BETA 350 MHZ REENTRANT SUPERCONDUCTING RF CAVITY

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Abstract

A superconducting reentrant cavity for low beta, high intensity beam has been designed using SUPERFISH and MAFIA. The study has been done for cavity shape optimization. Further its structural design has been done and feasibility study of different manufacturing aspects has also been done. A full-scale mild steel model with copper coating has been fabricated. A twin arm mechanical tuner has been designed for slow tuning by elastic deformation. This was tested with low power RF to validate the design parameters and to check the tuning sensitivity. In this paper the design and development activity of the reentrant superconducting are discussed.

INTRODUCTION

It is proposed to build 100 MeV, high current H^+/H^- linac at RRCAT. The main components of linac are H^+/H^- ion source at 50 keV, low energy beam transport line, 4.5 MeV RFQ, MEBT, 100MeV injector linac. It is planed to use SFDTL structure after the RFQ from 4.5MeV to 100MeV. H^- linac will be used as an injector for 1Gev, 25Hz rapid cycling synchrotron, for the proposed Indian spallation neutron source (ISNS). Proton linac can be used as the low energy part of 1GeV linac, which will be used for accelerator driven subcritical systems (ADS).

As a technology development of superconducting cavity, we have started the work on reentrant low beta cavity. If we succeed in making the cavity to desired satisfaction, we will replace SFDTL structures with these re-entrant cavities.

CAVITY DESIGN CRITERIA

In designing the cavity, the criterion followed was to minimize the surface fields and maximize the R/Q. The cavity was optimized for beta equal to 0.20. All these issues are directly linked to shape of the cavity and the effects of the shape are different. The effects of shape on electric and magnetic fields compete and the optimization of the shape must be done wisely. Generally superconducting cavities are used to provide the high accelerating gradients (E_{acc}). But the linac beam dynamics design required relatively low energy gain per cavity in our case. The purpose of our design was not to achieve the maximum gradient but to operate it reliably and it must be capable of using the RF energy efficiently.

CAVITY SHAPE OPTIMIZATION

Fig.1 shows the quarter geometry and the cavity shape variables. The cavity optimization was done for frequency of 350MHz. The optimization was done step by step. The first variable was the gap length g. The frequency was adjusted with the help of R_{eq}. The gap length was optimized for the maximum R/Q. Fig.2a, 2b shows the variation of R/Q and E_{max}/E_0 Vs. gap length respectively. The value for R/Q shows a maximum for gap value of 1.7408cm. At this value the curve of Emax/E0 changes its direction. The second variable was the radius r1.This parameter was optimized for the minimum surface electric and magnetic field. During the whole optimization process the frequency was adjusted with the help of R_{eq}. The details of the cavity optimization can be found in refrence [1] [2] [3].

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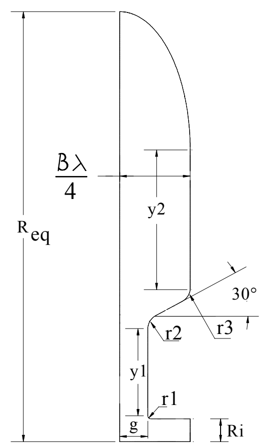

Fig.1 Cavity shape variables

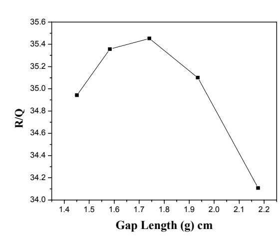

Fig2a R/Q Vs. Gap length

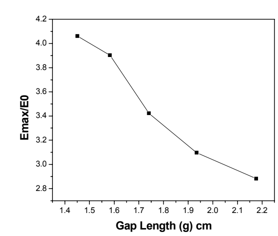

Fig.2b E_{max}/E_0 Vs. Gap length

Table-1 lists the basic parameter of the optimized cavity.

Table 1: Basic Shape Parameters of Reentrant cavity

Parameter	Value	Unit
g	1.7408	cm
Ri	1.5	cm
r1	5	mm
Y1	5.7564	cm
r2	2	mm
angle	30^0	degrees
r3	6	mm
Y2	10	Cm
R_{eq}	28.45	cm

As a comparison of the above calculation the same geometry was simulated with the help of MAFIA. During this simulation manual meshing was chosen in such a way as to produce the actual geometry. Geometry near the equator was not given due consideration. Fig.3 below shows the electric field of the TM_{010} mode. Table-2 shows the comparison of SUPERFISH and MAFIA, considering the cavity as normal conducting. The last column of the table lists the same parameters considering the superconducting cavity. The residual resistance used in this calculation was 100 nano-ohms. The results obtained in these calculations were encouraging. So we decided to make a full flagged model to validate the design.

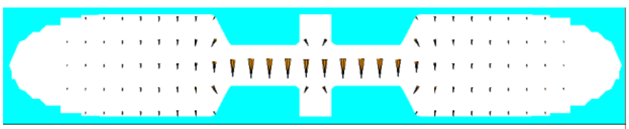

Fig.3 Electric field plot of TM_{010} mode

Table 2: Comparison of SUPERFISH and MAFIA

Parameter	SUPERFISH Normal conducting	MAFIA Normal conducting	SUPERFISH Super conducting
Freq (MHz)	350.02	349.85	350.02
Q	18384.4	18783.81	6.3656E+08
Z_{sh} MOhm/m	20.263	20.266	7.0160E+05
Emax/E0	3.6497	-	3.6497
Bmax/Emax mT/(MV/m)	0.7878	-	0.7878

ENGINEERING DESIGN

The basic design requirement of the accelerating structure is to provide the desired geometrical dimensions and surface characteristics at operating temperature. It is also required to maintain the same within allowable tuning bandwidth, typically within few KHz. Different factors considered during design are sensitivity of the structure due to various loads like LHe pressure fluctuation, Lorenz force detuning, microphonics, cool down distortions, RF power coupling etc [4].

The Mechanical design of reentrant cavity requires designing inner vessel, stiffeners and outer vessel along with ports and support operating at cryogenic condition. The design is considered for displacement and stresses evaluation for different loading condition during testing, cool-down to 4.5 K and certain fault conditions. The design is also considered for deforming the cavity elastically for tuning purpose. Two types of options, circumferential and radial stiffeners, are considered for stiffening purpose. FE model of both are shown in fig 4. Thickness of cavity is varied from 2 mm to 5 mm for Bulk Niobium structure by taking various combinations. All possible combinations of thickness for different components are tried for all load cases. Fig. 5 illustrates effect of thickness variation on stress and deformation using circumferential stiffeners at evacuation condition (here all the components are considered with uniform thickness). Further the results of thickness variation within the inner vessel, stiffeners and outer vessel evolves two safe designs for all loading situations. First design is 4-3-3 (Inner vessel 4mm, Stiffeners 3mm and Outer vessel 3 mm) having circumferential stiffeners and the other design is 3-3-3-45 (Inner vessel 3mm, Stiffeners 3mm welded at 45^{o} and Outer vessel 3 mm) having total 8 radial stiffeners.

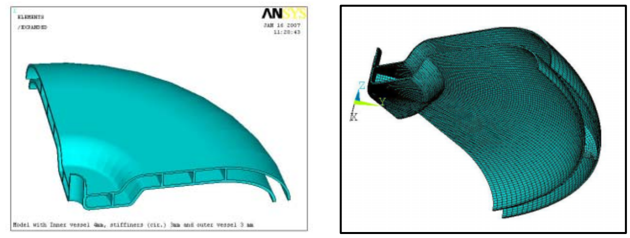

Fig.4 Re-entrant cavity model with circumferential stiffeners (Left) and with Radial stiffeners (Right).

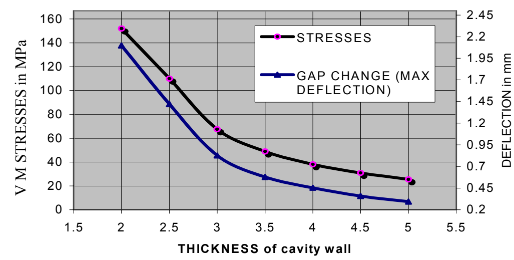

Fig.5 Effect of thickness change on maximum Von Misses stress and gap change due to evacuation of the Cavity with circumferential stiffeners

Since the cavities are fabricated and inspected at room temperature (300K) and operated at 4.5 K (LHe temperature), it is necessary to estimate and design dimensions of the cavity at room temperature. Fig.6a shows actual dimensions of the inner profile of the cavity, which is the basis for evolving manufacturing dimension of other parts.

Tuning force required to elastically deform the cavity for adjusting the fundamental frequency is estimated using a coupled approach between structural analysis and HF Emag analysis. Fig.6b shows the deformation pattern (profile) of the cavity of 4-3-3 model. HF Emag analysis using ANSYS is performed with HF119 element (taking second order accurate option) as shown in fig 7. Structural deformation sensitivity analysis yields 2.28 MHz /mm of gap change in 4-3-3 model.

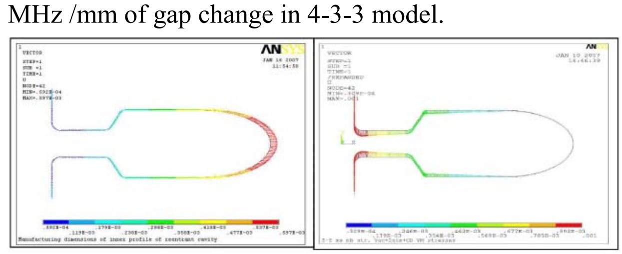

Fig.6a and 6b. Actual manufacturing dimensions (at room temperature) of inner profile (left) and Dimensions of inner profile for 1mm deformation (right).

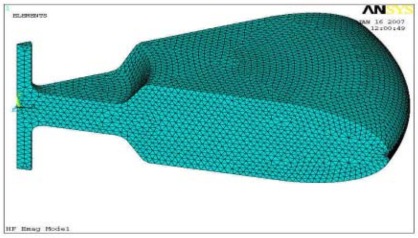

Fig. 7 HF Emag Model of deformed RF zone in ANSYS

DESIGN FOR MANUFACTURING

Input from FEM Analysis served as a basis for the design for manufacturing. In order to satisfy the design requirements careful study of the geometry, various possible options of forming & joining and different special process involved is necessary for designing for manufacturing, Apart from these the vacuum sealing techniques at low temperature, integration of tuners, RF power couplers in cryogenic enclosure along with cavity with proper alignment needs to be considered carefully. A detail feasibility study has been made for the manufacturing & processing of the RE cavity. Cavity fabrication requires variety of special infrastructure mainly Nb forming & EB welding, chemical cleaning & high pressure rinsing, heat treatment & finally assembly in to clean room. Necessary infrastructure as well as technology for the manufacturing of the SC Cavities is not readily available with domestic Industries.

Prototype activity

During the feasibility study a mild steel model was made & given 50 μm the copper coating. The two halves of the cavity were assembled by pressing the one half over the other. There was no welding done at the rim of the cavity. This model was used for the low power RF measurement. The quantities measured were frequency, quality factor and tuning range. Further as it is impracticable to use Niobium for initial development, it is planned to make the full scale copper/ ss prototype for the development of the manufacturing. Simultaneously different parameters for EB welding joining and cleaning will be first established over Nb samples.

Development of tuner

The slow tuner assembly under development consists of two levers and an actuating mechanism. There are two long parallel levers having ring at the center and pressing the cavity form both the ends at the center with the help of two buttons, on each levers in the plane perpendicular to that of the levers. These levers are connected with the help of two pins and a turn-buckle (for distance adjustment) at the bottom end and a motorized actuator at the top end. Fig. 8 shows the copper plated model under testing along with tuners (left) and tuner assembly (right). The design of the levers is optimized for the low weight and high rigidity. The tuning force required for the 1mm deflection of the cavity is calculated (~7500N).

The tuner was assembled along with stepper motor-based actuator. Two dial-indicators were installed to find the deflection of the cavity at the central portion. The cavity was made to resonate with low power RF then the tuner was made to press the cavity and the resonant frequency was measured both while pressing and retracting. The tuning frequency variation of 350.64 to 350.42 MHz was observed with total deflection of 84μm. Very high symmetry, linearity of deflection and the repeatability of tuning was observed. A tuning sensitivity of 2.619 MHz/mm was measured against a calculated value of 2.339 MHz/mm with SUPERFISH. Fig.9 shows the Tuning sensitivity test result. The measured Q of the cavity was 4700.

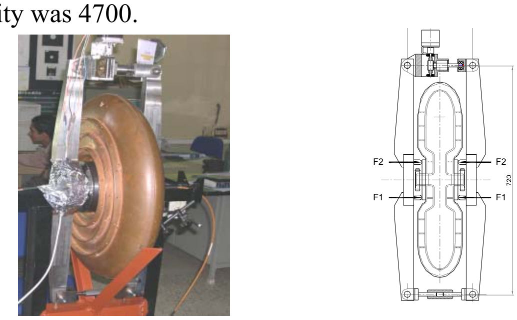

Fig.8 cavity with tuners on measurement bench (left) Tuner Assembly (right).

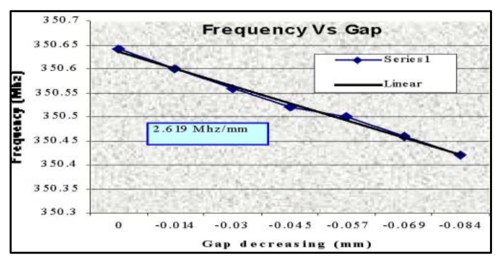

Fig.9 Frequency Vs. change in gap

CONCLUSION

We have build and tested the 350MHz copper coated mild steel Reentrant cavity. The RF tests and mechanical properties are consistent with calculation. The higher order mode analysis and multipacting study is in progress. The studies concerning the powering of the cavity is also in progress.

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