SINGLE CELL SCRF CAVITY DEVELOPMENT IN INDIA

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Abstract

Under Indian Institutions and Fermilab Collaboration (IIFC), Raja Ramanna Centre for Advanced Technology (RRCAT) Indore, India has initiated the development of SCRF cavity technology. The R&D efforts are focused on the proposed Project-X accelerator complex at FNAL and High Intensity Proton Accelerator activities in India. As an initial effort, two prototype 1.3 GHz single cell bulk niobium cavities have been developed in collaboration with the Inter University Accelerator Centre (IUAC), New Delhi. Learning from the experience gained and the initial results of these prototypes (achieving E_{acc} ~23 MV/m), two more improved 1.3 GHz single cell cavities are being developed. These two improved single cell cavities will also be processed and tested at FNAL. Development of a single cell 650 MHz (β=0.9) prototype cavity is being undertaken as the next stage in these efforts. This paper will present the development activities and test results on the 1.3 GHz single cell cavities and status of the ongoing work.

INTRODUCTION

Superconducting radio frequency (SCRF) technology is playing a major role in many ongoing and upcoming accelerator projects all over the world. RRCAT has also initiated research program to develop the necessary infrastructure & technology for design, manufacturing and testing of SCRF cavities. Under IIFC, RRCAT together with IUAC have initially developed two 1.3 GHz (β=1) bulk niobium single cell SCRF cavities during 2009. They were processed & tested jointly by FNAL & ANL during early 2010. Based on the feedback from the test results, two more single cell cavities have been fabricated during late 2010-early 2011. Further, to align with Project-X, activities have been initiated for the development of 650 MHz (β=0.9) SCRF cavities also.

CAVITY DEVELOPMENT

Design, fabrication & testing of 'Single Cell Cavity' is a standard practice for development of various crucial elements of the cavity development cycle. Work on the 1.3 GHz single cell cavity started with the development of aluminum [1] and copper [2] cavities. This was followed by development of two bulk niobium cavities.

Forming Tool Development & Cell Forming

The first step was design and development of the half cell forming tools made of aluminum alloy (AA7075-T6). RRCAT has developed two sets of forming tools suitable for 1.3GHz structure. One set was delivered to FNAL. The second set was used for all forming work performed at RRCAT. The experience gained during aluminium and copper half cell forming were used to improve the die shape, strategy for handling, control in thickness variation & orthogonal error, before forming niobium half cells. Four precisely shaped parts viz. male forming die, female forming die, hold down plate and coining ring (Fig. 1a) constitute the forming die. A 200 ton hydraulic press with a die pillar set was used to form the half cells. Fig. 1b shows half cell forming.

Figure 1: a) Forming tool and 1b) Forming of the half cell.

CAVITY DESIGN & FABRICATION

Under the framework of Tesla Technology Collaboration (TTC), the basic DESY design was adopted for development of initial prototype of 1.3 GHz single cell cavity. As part of design validation effort, HF Emag eigen mode analysis was done using ANSYS to estimate the RF frequency for change in frequency with temperature and extra lengths at equator (Table-1). The equator frequency sensitivity coefficient K_{eq} is estimated to be -5.1 MHz/mm. This was verified during equator trimming of prototype cavity fabrication. Standard DESY recipe [3] with added FNAL experience of 3.9 GHz cavity fabrication became the basis of cavity fabrication activities. Design for manufacturing was done that included square butt joint type weld edge design, welding lip at the backside of flange joint and no recess in the flange bore.

Table 1: Estimated frequency at different temperatures

Temperature	300 K	77K	2K
Frequency MHz	1297.2872	1299.8814	1300.00

The beam tubes were rolled using dedicated precision rolling machine and were seam welded. Design and fabrication of the machining fixture, parts machining as well as inspection of various tooling and components were done at RRCAT. Detailed manufacturing plan was

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developed consisting of stage wise machining and inspection [4].

Initial welding of prototype single cell cavities in copper and aluminium were done using industry facilities. This helped to test & prove various tooling & fixtures and to develop the cavity manufacturing cycle using inexpensive material. Electron beam welding of niobium prototype cavity was performed at IUAC using their facility. The bulk BCP etching (20µm) was skipped due to limitation in the available infrastructure. The parts were ultrasonically degreased and subjected to pre-weld etch (3µm) just before welding. The welding was performed at $<5\times10^{-5}$ mbar pressure (Fig 2a).

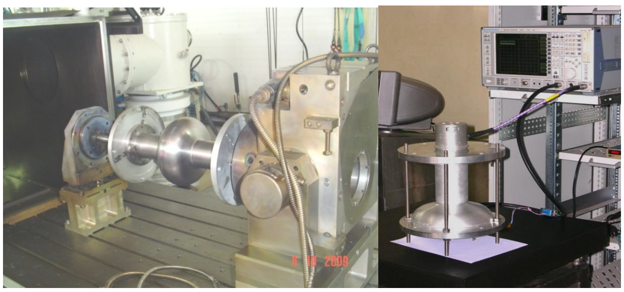

Figure 2: a) Electron beam welding setup and b) RF measurement of welded half cell assembly.

Special RF measurement test setups were also designed and developed at RRCAT. These were used for RF measurement during fabrication stages and after complete cavity fabrication. Efforts were made to control the length and final frequency of the single cell with intermediate frequency measurement and cell length trimming accounting for weld shrinkages (Fig 2b).The completed cavities were subjected to mechanical, RF (Fig. 3a & 3b and table 2) and vacuum leak test, both at 300 K & 77K, before dispatch to FNAL.

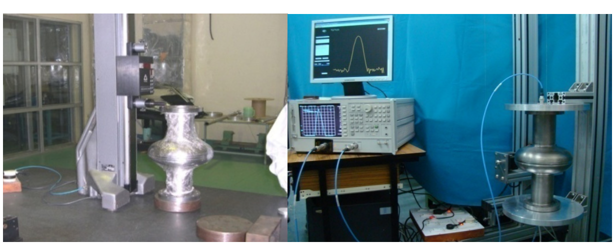

Figure 3: a) Mechanical measurement and b) RF measurement

Table 2: Mechanical, weld shrinkage, frequency data

Cavity ID	Length (mm)	welding shrinkage (mm)	Frequency (MHz) 300K	Q-factor at 300K
TE1CAT001	393.58	0.46	1296.926	9076
TE1CAT002	392.96	0.42	1296.675	9328

PROCESSING AND TESTING

RRCAT has also embarked upon setting up the cavity processing & testing infrastructure. These include Electropolishing (EP), Centrifugal Barrel Polishing (CBP), High Pressure Rinsing (HPR), Heat Treatment (HT) furnace, clean room assembly and vertical test stand (VTS) [5]. Till RRCAT infrastructure is in place; the cavities made in India will be processed & tested at FNAL under IIFC. Both the prototype cavities were dispatched to FNAL for further processing & testing after their pre-dispatch qualification test done at RRCAT.

The processing stages followed on each cavity are given below:

TE1CAT001

- CBP ~ 120 µm Equator, 40 µm Iris
- HT ~ 800 °C for 6 Hrs
- Light EP ~ 30 µm, HPR 85 bar for 6 hrs
- Clean room assembly, Low temperature baking 120 °C - 48 hrs, 2 K testing

TE1CAT002, RUN-1

- Bulk EP ~ 120 µm, HPR 85 bar for 6 hrs
- Clean room assembly, Low temperature baking 120 °C - 48 hrs, 2 K testing

TE1CAT002, RUN-2

- CBP ~ 120 µm Equator, 40 µm Iris
- HT ~ 800 °C for 6 Hrs, Light EP 30 µm

During internal optical inspection of the cavities at FNAL, certain features at the inner equator weld bead were seen. To polish the inner-equator weld features, these cavities were subjected to CBP in addition to standard processing stages (EP+HT+HPR). Figure 4a shows the plot of measured material removed at different cavity locations during the CBP run and Fig. 4b & 4c shows the comparison of inner equator weld before & after CBP.

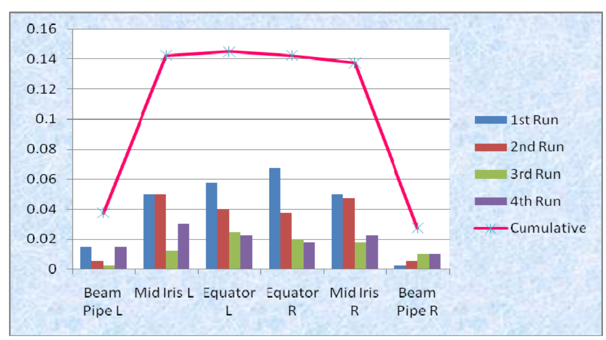

Figure 4a: Plot of material removed during CBP.

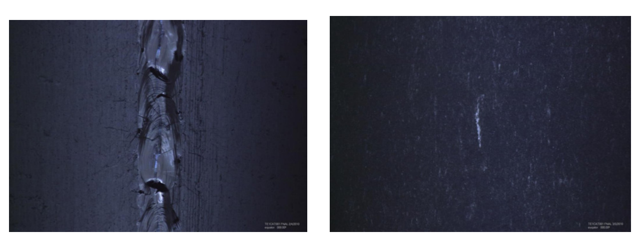

Figure 4: b & c shows the inner equator bead before & after the CBP.

The cavity TE1CAT1 was tested at 2 K and achieved E_{acc}=19.3 MV/m with Q>1.5E+10. On analysis it was concluded that the tumble polishing did not remove weld imperfections completely. Yet the T-map suggested those imperfect areas did not cause quench. The quench area has no noticeable features.

TE1CAT002 when tested during first run achieved E_{acc} of 21 MV/m with Q>1.5E+10. In order to investigate the cause of quench and to analyse the weld bead undulation, silicone moulding and profilometry was done at T-map identified spot at inner equator as shown in Fig. 5a & 5b.

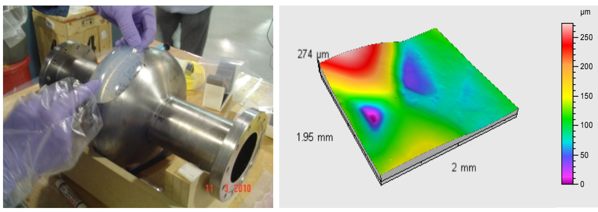

Figure 5: a) Cavity moulding and b) Profilometry plot of weld bead.

The cavity TE1CAT002 after 2nd run of processing stage, when tested at 2 K in the VTS test showed a further improvement of E_{acc} to 23 MV/m. Fig-6 shows the result and also compares the test result of run #1.

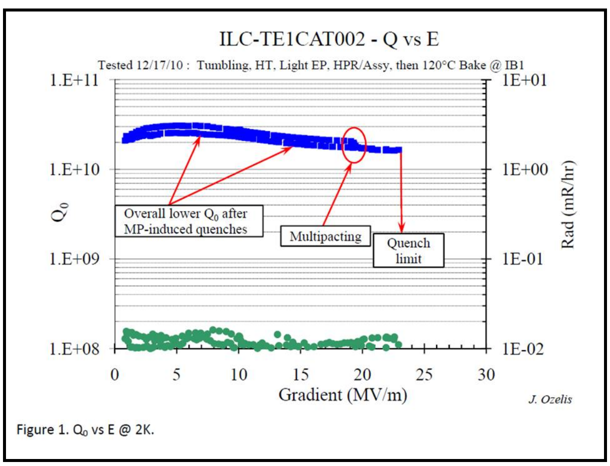

Figure 6: Q vs E plot of TE1CAT002.

There was no FE observed at any time, but some minor radiation levels were briefly observed accompanying the multipacting. Both low field and high field Q_0's were reasonably good; 2.5 x 10^{10} and 1.7 x 10^{10}, respectively.

FURTHER IMPROVEMENT

The test results of the initial two 1.3 GHz single cell SCRF cavities were discussed and analysed. Based on this it was decided to make two additional (second generation) single cell cavities incorporating several improvements including careful handling of niobium components during all manufacturing processes, 20 µm bulk BCP etching (in addition to 3 µm pre-weld etch). Special BCP etching handling fixtures were also designed and developed. In order to improve the critical equator electron beam weld bead, trial welding was performed on niobium half cells to optimize the parameters.

Figure 7: a) Half cell assembly with equator welded from both sides and b) Inner equator weld bead.

As an alternate method for better control on the critical equator joint, the equator welding was performed from both outside and inside (in that order) on cavity TE1CAT004 (Fig-7a & b). The full penetration iris welding was subsequently done from outside.

Two more single cell cavities have been completed. They have been checked for mechanical specification, RF & vacuum leak tested before shipping to FNAL. The cavity TE1CAT3 upon arrival at FNAL has also undergone optical & RF inspection. The inner equator weld bead has improved considerably since the first prototype. This cavity will now be processed & tested in the coming months jointly by ANL & FNAL facility.

650 MHZ SINGLE CELL CAVITIES

To align the activities with Project-X at FNAL, the efforts are now focused on development of 650 MHz (β=0.9) single cell cavities. The experience gained during the prototype design & fabrication of 1.3 GHz single cell cavities will be useful. Initial work has been done in design & development of forming tools, forming of half cell in aluminum & copper. Design and development of various machining, welding and RF measurement fixtures have been initiated. It is planned to fabricate the first prototype cavity by end of 2011.

SUMMARY

Under IIFC, two prototype 1.3 GHz bulk niobium single cell cavities had been fabricated & tested as a technology demonstration phase. Based on the 2 K test results, two more (second generation) 1.3 GHz single cell cavities have been developed which are under processing & testing. Work on 650 MHz (β=0.9) single cell cavities has been initiated.

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