Superconducting Cavities Developments efforts at RRCAT

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Abstract. Superconducting RF cavities are the work-horse for many existing and proposed linear accelerators. Raja Ramanna Centre for Advanced Technology (RRCAT) has initiated a comprehensive R&D program for development of Superconducting RF cavities suitable for high energy accelerator application like SNS and ADS. For the initial phase of technology demonstration, several prototype 1.3 GHz single cell-cavities have been developed in Aluminum, Copper & Niobium. The critical technology of forming and machining of niobium as well as various mechanical and RF qualification were developed at RRCAT. The EB welding of Aluminum and Copper cavities were carried out at Indian Industry and that for bulk niobium (Nb) cavities was carried out in collaboration with IUAC, New Delhi at their facility. The prototype dumbbells and end group made of aluminium, comprising of RF and HOM couplers ports have also been developed, with their EB welding done at Indian industry. In this paper we shall present the development efforts towards manufacturing of 1.3 GHz single cell cavities and their initial processing and qualification.

Keywords: **Superconducting RF cavities. Electron beam welding, ADS, SNS, Niobium**
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INTRODUCTION

SCRF technology is proving its role in many of the ongoing and upcoming particle accelerator projects. RRCAT has taken up development of SCRF cavities and associated technology under XI plan project with application in proposed SNS and ADS projects. Efforts are made on development of bulk fine grain niobium SCRF cavity manufacturing technology with present focus on 1.3 GHz (TESLA shape) cavity. For the initial phase of technology demonstration, several prototype 1.3 GHz single cell-cavities have been developed in Aluminum, Copper & Niobium as shown in Figure-1a, b & c. [1], [2]

FIGURE 1. a, b & c, shows the prototype 1.3 GHz Single cell Aluminum, Copper and Niobium cavities.

Prototype Single Cell Cavity Development

Fabrication & testing of single cell cavity is a standard practice for development of various crucial elements of the cavity development cycle. Niobium being expensive material, initial efforts has been made to go through the complete manufacturing cycle using alternate & inexpensive (aluminum and copper) material.

Forming Tool Development & Cell Forming

Design and development of the half cell forming tools using standard hard Aluminum (AA7075-T6) die was the first step. Experience gained during aluminum and copper half cells forming were used to improve the die shape, strategy for handling, control in thickness variation &orthogonal error before forming niobium half cells. [3] Four precisely shaped parts viz. male forming die, female forming die, hold down plate and coining ring constitute the forming die.

FIGURE 2. a, b & c, shows the forming tool, process & 1.3 GHz formed half cells .

Engineering Design & Fabrication

Cavity manufacturing plan was developed consisting of stage wise machining, intermediate RF measurement, and final RF and mechanical inspection based on the standard DESY report [4]. Design for manufacturing included certain design modification like welding lip at the backside of flange joint, no recess in the flange bore and square butt joint type weld edge design. Frequency shift between operating temp (2K) and manufacturing temp (300K) was estimated for different material (Nb, Cu, Al). This data is helpful to predict cavity frequency during measurement at cold. RF frequency estimation was also done for various extra lengths at equator. The equator frequency sensitivity coefficient K_{eq} is estimated to be - 5.1 MHz/mm. The measured K_{eq} matched well with estimated values. Manufacturing of SC cavities is an iterative process between press shop, machine shop, metrology, RF measurement, chemical cleaning, electron beam (EB) welding and finally leak testing and RF measurement. Half cell forming, machining and testing (mechanical, vacuum & RF) were done at RRCAT. [5]

Electron beam welding

Electron beam welding of aluminum and copper cavities was done at Indian industry. These gave very valuable experience and helped to qualify various tooling and develop the cavity manufacturing & testing cycle. Welding fixtures were designed, developed and qualified during aluminum and copper cavity welding. They were suitably modified for Nb welding. EB welding of Niobium cavities was performed in collaboration with and at the facility of IUAC. Weld shrinkages were accounted for during machining of parts to control the final frequency with additional length needed to maintain correct frequency at operating temperature. Intermediate frequency measurements were made and cell length tuned at the equator. The parts were ultrasonically degreased and whole body buffer chemical polishing (BCP) of ~ 20μm was done after all fabrication steps are over. The parts were also subjected to additional pre-weld etch (3μm) just before welding. Pre-loading was used during welding to compensate the weld shrinkage. The welding was performed at $<5\times10^{-5}$ mbar pressure. Figure 3 a, b & c shows the various stages of aluminum, copper & niobium cavity fabrication.

FIGURE 3. a, b & c, shows the fabrication stages of prototype Single cell Aluminum, Copper and Niobium cavities.

Various Testing and Qualifications

The completed cavities were subjected to various inspection and testing that included mechanical dimensional check followed by RF & vacuum leak testing both at 300 K & 77K as shown in figure 4 a, b and c.

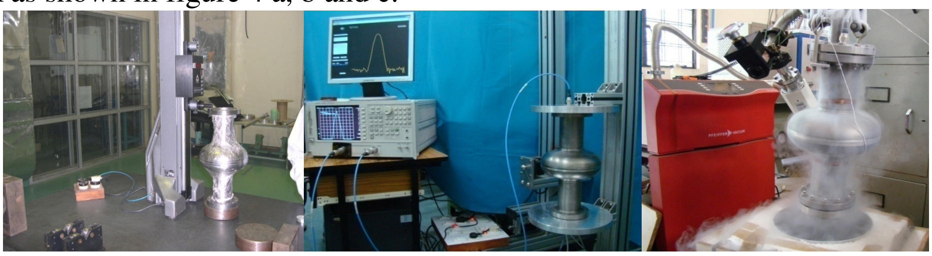

FIGURE 4. a, b & c, shows the prototype 1.3 GHz Single cell Al, Cu and Nb .

The shift in frequency from 300 K to 77 K was measured to be about 2 MHz which corresponded well with the estimated values. The results are given in Table-1.

TABLE 1.

Cavity ID	Vacuum leak rate (mbar l/s)		Frequency (MHz)		Total length (392 ±1)
	300 K	77 K	300 K	77 K	mm
TE1CAT001	$< 1 \times 10^{-11}$	$< 1 \times 10^{-11}$	1297.2666	1299.3333	393.52
TE1CAT002	$< 1 \times 10^{-11}$	$< 1 \times 10^{-11}$	1296.7333	1298.8666	392.97
TE1CAT003	$< 1 \times 10^{-11}$	$< 1 \times 10^{-11}$	1299.8752	1302.0385	391.62
TE1CAT004	$< 1 \times 10^{-11}$	$< 1 \times 10^{-11}$	1299.7107	1301.8528	390.08

After all the pre-dispatch inspection and testing the cavities were shipped to Fermi National Accelerator Lab (FNAL) USA for processing and performance evaluation at 2 K. Initial two prototype cavities were quench limited at ~ 19 to 23 MV/m. Based on the experience gained the additional two prototype cavities were made. These have been tested to successfully achieve Eacc > 35 MV/m with very good Q value. Table-2 shows the 2 K test results of the four prototype 1.3 GHz bulk niobium single cell cavities.

TABLE 2.

Cavity ID	2 K test Results	
	E acc (MV/m)	Q
TE1CAT001	19 (MV/m)	1.5 E +10
TE1CAT002	23 (MV/m)	1.7 E +10
TE1CAT003	35 (MV/m)	2.1 E +10
TE1CAT004	37.5(MV/m)	8.7 E +09

FUTURE WORK

Based on the experience gained during single cell cavity work, we now plan to move for the development of 1.3 GHz multicell cavity. Our plans are to develop dumbbells and end group. Prototype 1.3 GHz dumbbells and end group in aluminum have been developed with industry. We are going through the phase of their various RF & mechanical qualification process before moving on for Nb multicell cavity.

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