FABRICATION AND INSTALLATION OF RADIO FREQUENCY CAVITY FOR K500 SUPERCONDUCTING CYCLOTRON AT KOLKATA

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Abstract

K500 Superconducting Cyclotron (SCC) is already commissioned successfully at VECC, Kolkata by accelerating Ne 3+ internal beam with 70 nA beam current at 670 mm extraction radius. The Radio Frequency cavity of SCC is successfully operational since last two years. All these years were very challenging and worthy period from the point of view of gaining experience and knowledge by solving fabrication and assembly problems faced during construction of 10 M tall copper made coaxial RF cavities and tackling RF related commissioning problems. RF system operates within frequency range of 9 to 27 MHz for generating maximum 100 kV DEE voltage. The construction of the RF system demands making of numerous critical soldering and brazing joints including joints between ceramic and copper along with maintaining close dimensional accuracies, assembly tolerances, mirror symmetricity, surface finish and utmost cleanliness. This paper presents the details of fabrication and installation procedures and their effects on the final performance of the cavities. It also highlights the problems faced during the commissioning process of the RF cavities.

INTRODUCTION

Being the only cyclotron institute in India, after a long period of eventful operation of the K130 room temperature cyclotron for fulfilling the national and international demand of the medium energy ion beams during past eighties and nineties, VECC has taken up a project to scale up its experimentation facility inline with MSU and TAMU by building K500 Superconducting Cyclotron (SCC) to mitigate the demand of higher and higher energy ion beam, as national cultivation of science especially experimentations with varieties of ion beam grew up.

DESCRIPTION

The room temperature radio frequency (RF) system of the K500 Superconducting Cyclotron (SCC) is designed to provide 100 kV (max) RF voltage for accelerating the charged particle rotating in the 5T average magnetic field produced in the median plane of the SCC by Nb-Ti made superconducting magnet coils immersed in liquid helium bath at 4K temp.

The RF system for Superconducting Cyclotron consists of three transverse electromagnetic half-wave coaxial resonating cavities placed vertically 120^o apart. It is mostly made of OFHC copper and 10 M tall. Each half-wave resonating cavities has two quarter wave cavities tied together at the centre and symmetrically placed about the median plane. Each resonating cavity is made off with a short-circuited transmission line terminated by a crescent shape electrode called DEE placed within each of the valley region of the magnet iron pole. The coarse tuning of frequency from 9 MHz to 27 MHz is done by precise sliding short movement within annular region of the inner and outer conductor located in the atmosphere & fine tuning (±3%) is achieved by a hydraulically driven trimmer capacitor situated in the cyclotron vacuum itself. The drive RF power from the RF amplifier is fed to the DEE of the resonator through transmission line by coupling capacitor which is also driven hydraulically.

Its major sub-assemblies are DEE stem, sliding shorts, DEE, coupling and trimmer capacitor, liners, center region components and RF power amplifier (see figure 1)

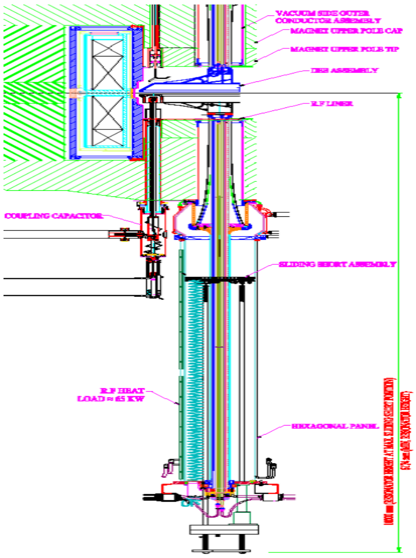

Figure 1: 2D assembly drawing of lower section of RF. cavity.

FABRICATION & ASSEMBLY

The fabrication and assembly of mostly thin copper sheet and tube made RF system demands development of successful joining process, specially soldering and brazing for non-ferrous metal, the process unlike welding is not systematically and exhaustively parameterized in any of the world wide available standard code. Presence of electrically insulating material in the interface between cyclotron vacuum (1x10^{-7}mbar) and atmosphere enhances the criticality and vulnerability in many folds of developing unconventional ceramic to copper metal joints for some of the sub-system. Presence of some of these joints in close proximity makes the filler selection, grove design, optimizing heating and cooling rate very critical as failure of some of these joints during operation would led to the total dismantling of the system because of its inaccessibility which in turn might results into low utilization time to shutdown time ratio.

Requirement of maintaining dimensional and positional accuracy like parallelity, concentricity, coaxiality, flatness, perpendicularity and in most demanding need of azimuthal and mirror symmetricity of the RF structure makes the sub-system fabrication and assembly and installation of the whole system at the site utmost challenging. Failure in meeting of any these accuracies would cause perturbation to the resonance of the resonating RF structure and hence results into a uneven heating. All the above anomalies converge to the cascading effect of creation of the diverging hot spots over a period of time.

Fabrication of Subassemblies

Inner & outer conductor spinning of the DEE stem is fabricated by cold spinning process . DEEs (figure 2) were fabricated from 2.34 mm think thin copper sheet after placing it over its fixture and causing stepwise cold flow of the material by applying controlled pressure on it with the help of specially contour mandrels of different shape and size.

Figure 2: DEE.

For some of the brazing and soldering joints (e.g. tri-joints, a joint which has three joints within proximity of centimeter distance, see figure 3) several no of trials were performed and several parameter were optimized like filler road selection, grove design, heating and cooling rate, cleaning process, brazing position and sequential acceptance test before carrying out the final brazing and soldering joints. In total the system would have around 700 M soldering and brazing joints. Finally each of the three joint of the tri-joint were brazed and soldered one after another according to their decreasing melting point temperature of BAg-5 (Ag-45%, Cu-30%, Zn-25%, liquidus temp-743^{o}C) and 1801 (Ag-85%, Cu-15%, liquidus temp-600^{o}C) brazing filler rod and 95 Sn-5 Ag (Liquidus temp-183^{o}C) soldering filler rod. In most of the other cases BAg-5 was chosen as brazing filler rod and 95Sn-5Ag as soldering filler rod. 90Sn-10Ag soldering filler rod was preferred if electrical connectivity is required to established. While trials were carried out, it was found that high rate of heating and cooling (preferred to reduce trial time) of the brazing joint was detrimental to both of its dimensional accuracies and stiffness of the thin copper sheet which is required to sustained the cooling water operating pressure (12 kgf/cm^2). Exhaustive thermo-mechanical structural analysis for some of the critical components reveals that preferring heating rate less than 10^{o}C/min and normal room temperature cooling was not detrimental to the assembly and these results were well verified by above mentioned trials before it was implemented on the actual assembly. Optimization of the three specific filler rods for tri-joint was corroborated by this analysis too.

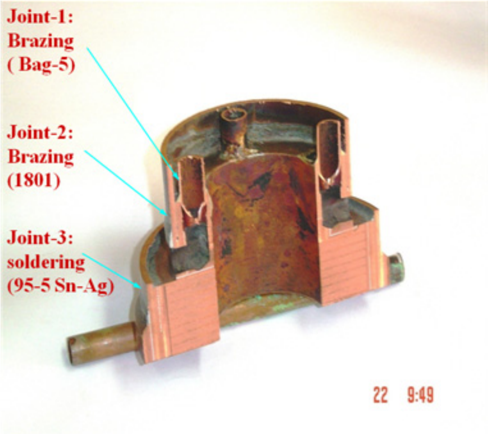

Figure 3: Tri-joint section.

Several fixtures including the giant tri-joint brazing fixture (figure 4) and post brazing machining fixture were suitably designed, fabricated and ingeniously employed to control the brazing and soldering distortion to maintain the dimension and positional within tolerable limit. After each of the soldering and brazing joint is performed, each individual components as well as sub-assemblies were tested for hydrostatic pressure test (16 kgf/cm^2) and helium leak tightness (<1x10^{-9}mbar.lit/s) following ASME code.

Figure 4: DEE stem brazing fixture.

Assembly at Site

Assembly of RF system at VECC project site with other systems was started at the end of august, 2007. Each of the subassemblies of the RF system was transported with the help of over head crane and installed maintaining positional accuracies and assembly tolerances. After installing each of the subassemblies, helium leak tightness was found to be better than $1x10^{-9}$mbar.lit/s. All the above processes were carried out in controlled manner and maintaining clean environment so that copper surface remain clean and scratch free. A miniature camera was installed inside the 26 mm median plane during first time lowering of the upper pole cap to assess the changes in relative assembly positions between RF system components that are located within the beam chamber. Fig-5 & 6 show integrated lower cavity with cryostat and final view after installation of entire RF cavity.

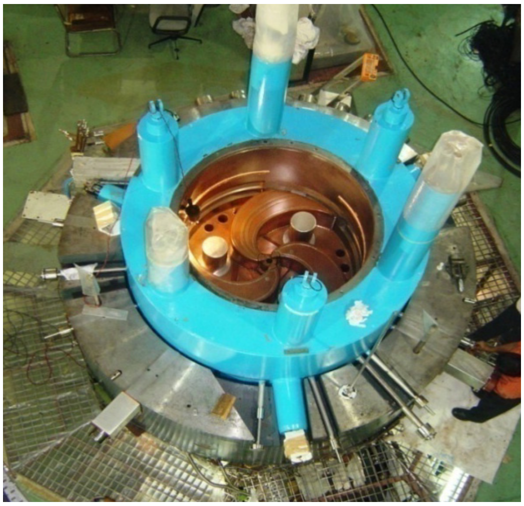

Figure 5: Lower RF cavity with Cryostat.

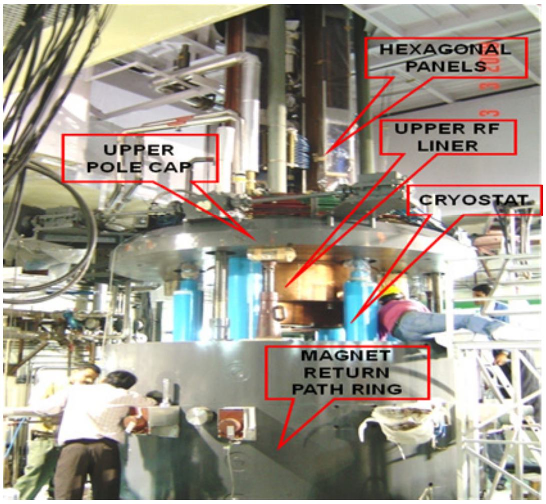

Figure 6: Final view after installation of entire RF cavity.

After completion of the installation of the RF system with the other system of SCC at the site, frequency calibration of the cavity with the position of sliding short was carried out (see Figure 7).

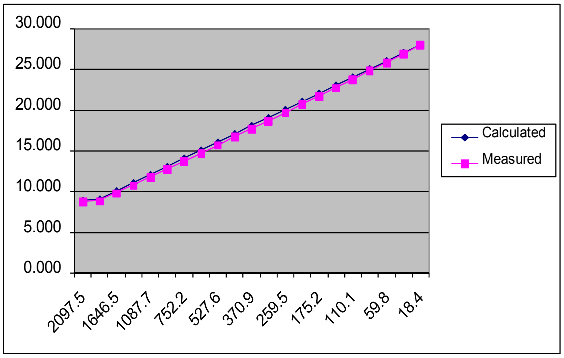

Figure 7: Plot of Frequency (MHz)along y axis Vs sliding short position(mm) along x axis.

COMMISSIONING AND OPERATION

The commissioning of the RF system was started by pumping down the beam space with the help of three scroll pump for rough vacuum followed by three turbo-molecular pump for high vacuum. After running these pump for a period of two weeks 10^{-6} mbar pressure was achieved and subsequently cool-down of cryo-pump was started by flowing liquid N_2 to the cold baffles attached to the cryo-panels located in the cyclotron vacuum.

Finally, after achieving beam chamber pressure of the order of $1x10^{-6}$ mbar, RF commissioning has been started by feeding power to the DEEs of the resonating structure from RF amplifier through transmission lines and coupling capacitors. With DEE voltage about 50 kV and magnetic field 3 T, Ne^{3+} internal beam was accelerated up to extraction radius (667 mm) with 70 nA beam current.

Several modifications of the center region of the RF system are incorporated to maximize the beam current by improving the beam centering. Provision of cooling of the ceramic insulators was made available to avoid excessive heating that was obvious for achieving higher DEE voltage. Pole cap lifting system was upgraded with variable frequency drive system to make lifting of pole cap jerk free and hence safe.

At present, works are going on for extracting the beam up to the first experimental cave.

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REFERENCES

[1] Cavity Construction technique by I. Wilson, Cern, Geneva, Switzerlan.

[2] H. Matsumoto "High power Coupler issues in normal conducting and superconducting accelerator application" PAC1999, New York.

[3] First Operational Experience with the RF System of the LNS Superconducting Cyclotron.

[4] Development of A 50 KW CW L-band rectangular window for Jefferson Lab Fel Cryomodule by V.