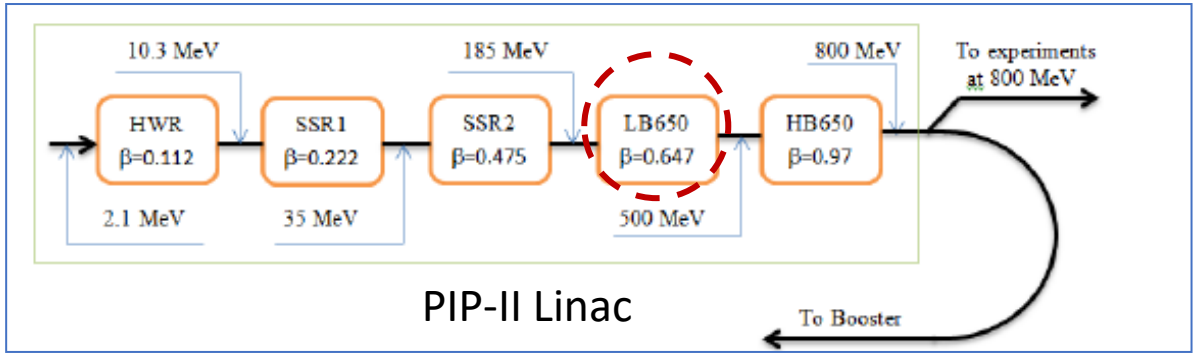
"LB650 Cavity Fabrication Experience and Status Update -VECC"

Sudeshna Seth
(on behalf of the team working on LB650 cavity at VECC)

For

PIP-II Technical Meetings, July 12th – 14th,2022

INTRODUCTION



PIP-II Linac

In India, DAE laboratories and other institutes are now actively involved in research and development activities on SRF cavities and associated technologies for the proposed high current, high energy proton linear accelerators like ISNS/IADS and also for the FERMILAB PIP-II program under Indian institutions- Fermilab collaboration (IIFC).

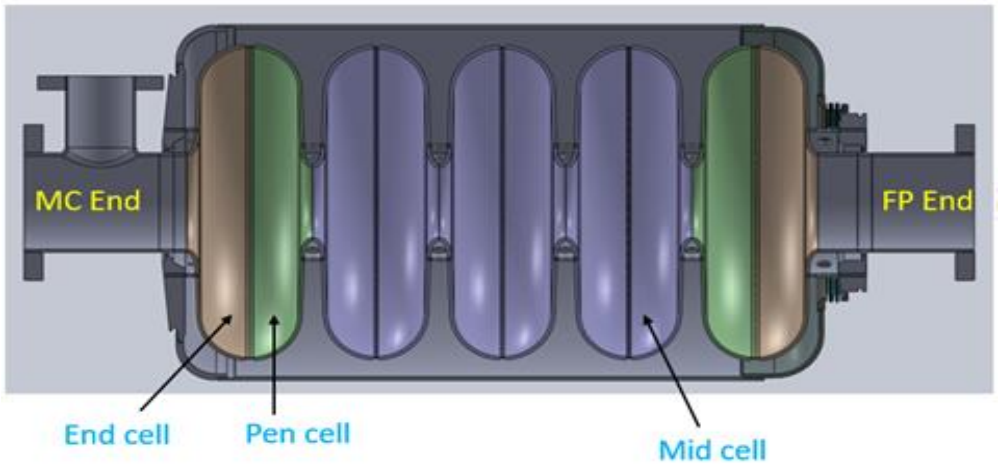
As part of the above activities, VECC, Kolkata, has been involved in the design and development of a 650 MHz, β=0.61, 5-cell (LB650) elliptical shape Superconducting RF linac cavity

OUTLINE

- **Overview of Low beta ,5-cell ,650 MHz cavity (LB650 cavity) for PIP-II Linac**
- **Fabrication experience and test result of first single cell ,low beta 650 MHz Niobium cavity**
- **Fabrication experience and test result of second single cell ,low beta 650 MHz Niobium cavity**
- **Fabrication status of two LB650 cavities for R&D Phase.**
- **Fabrication experience, so far, of 650 MHz low beta, 5-cell niobium cavities**

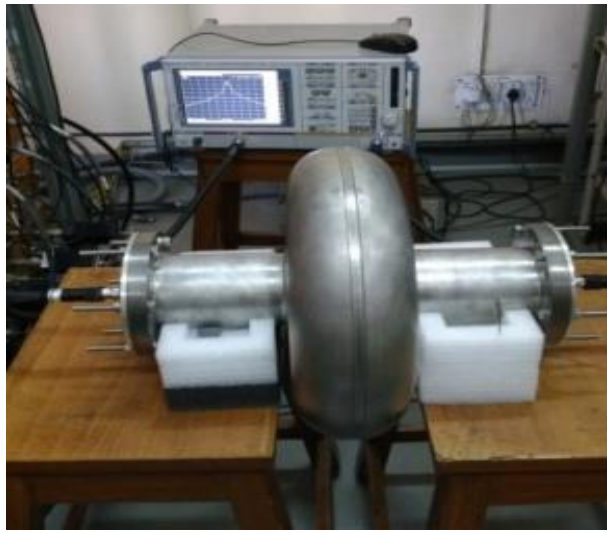
Overview of Low beta ,5-cell ,650 MHz cavity (LB650 cavity) for PIP-II Linac

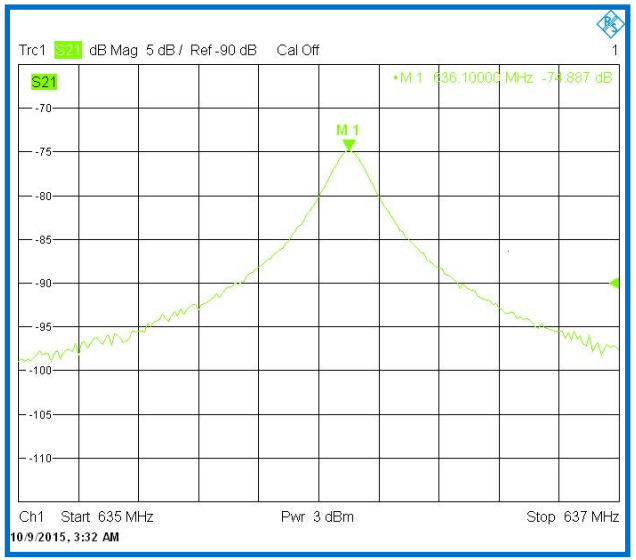
- LB650 cavity consists of three types of halfcells(midcell, endcell and a pen halfcell which is a connecting halfcell between mid and end half cell,)
- The design of this cavity is required to satisfy a Functional/Technical requirement specification(FRS/TRS) consisting of specified values of Electro magnetic parameters and operational parameters .
- The geometry of this cavity needs to comply the constraints of cavity wall angle(>2 º)

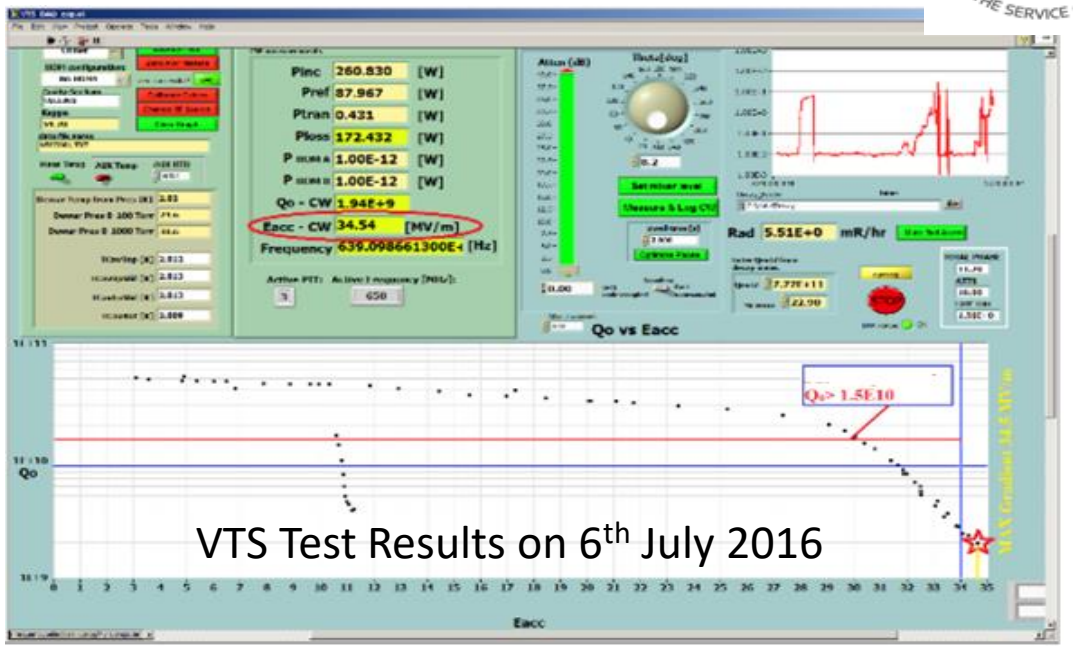


Design Parameter	Units	LB650
Frequency	MHz	650
Iris aperture	mm	88
Effective length $L_{eff} = 5\cdot(\beta_g \lambda/2)$	mm	703
Geometrical/Optimal beta β_{gt}	-	0.61/0.65
Optimal shunt impedance $(R/Q)_{opt}$	Ω	341
Energy gain at optimal beta V_{opt}	MeV	11.9
Surface RF electric field E_{peak}	MV/m	< 40
Surface RF magnetic field B_{peak}	mT	< 80
Sensitivity to LHe pressure fluctuations of dressed cavity	Hz/mbar	< 25
Lorentz Force Detuning coefficient	$Hz/(MV/m)^2$	< 2.2
Longitudinal stiffness	kN/mm	< 5
Operating frequency tuning sensitivity	kHz/mm	> 150
MAWP RT/2 K	bar	2.05 / 4.10
Operating Field Flatness in dressed cavity	%	> 90
Operating cavity gradient $G_{acc} = V_{opt}/L_{eff}$	MV/m	16.9
Unloaded quality factor Q_0	-	$> 2.3\cdot10^{10}$
Dynamic RF power dissipation	W	< 20
Operating cavity Q-loaded/bandwidth	Hz	$1.04\cdot10^7$ / 62.5

First Single Cell Niobium Cavity - Fabrication and Test Result







VTS Test Results on 6th July 2016

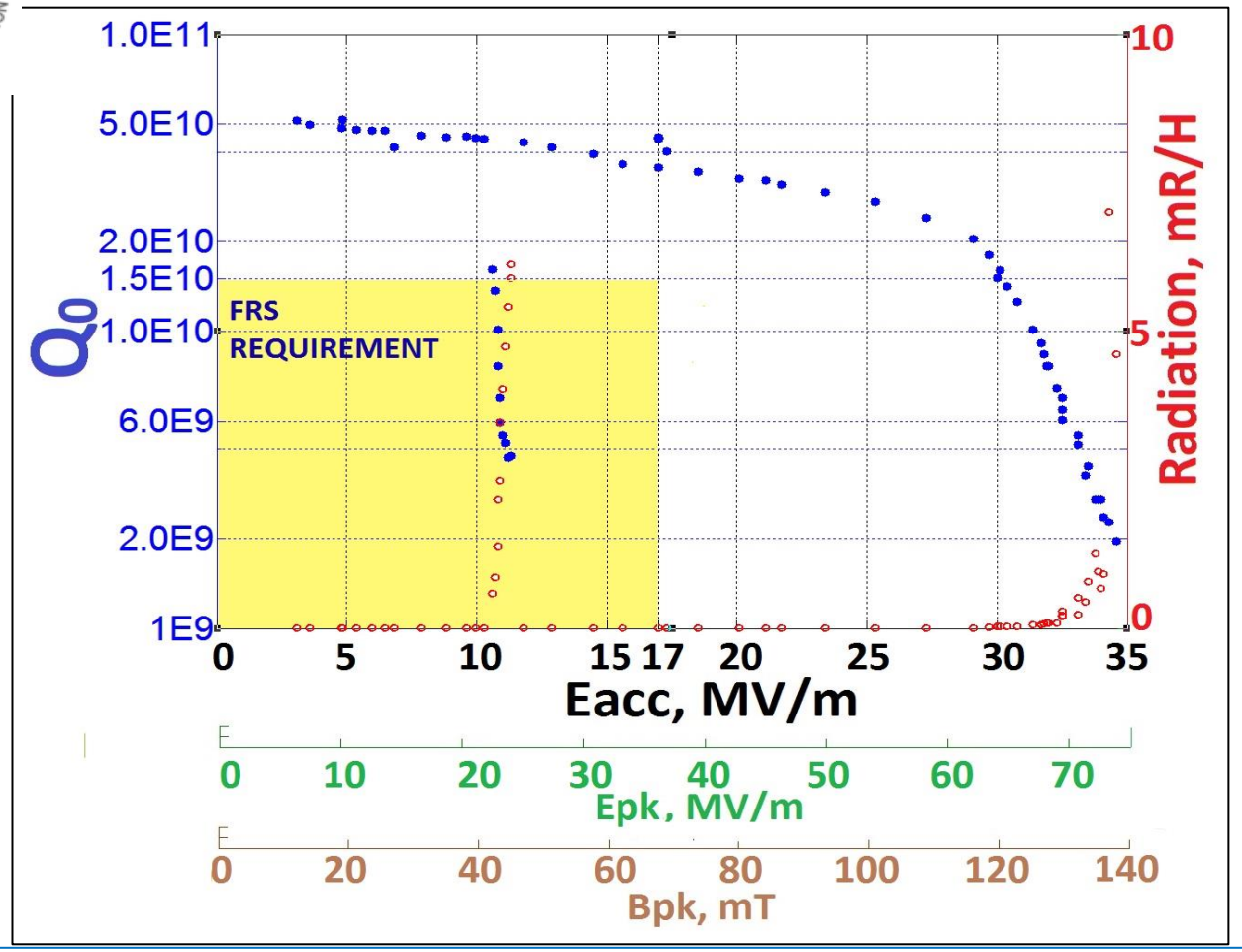
After Electron Beam welding of the beampipes and iris region, the frequency and the quality factor of the final single cell niobium cavity are measured to be 636 MHz and 9880 respectively.

The decrease in frequency after iris welding is due to unanticipated shrinkage and deformation at iris region caused by some difficulties we faced during iris welding process to get full penetration at welded region. Several number of welding passes were required .

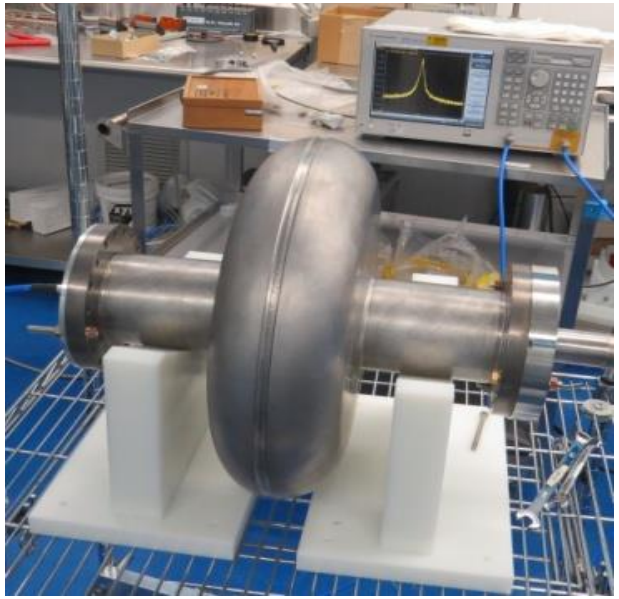
The process encountered a problem of blow through at iris joint. This is successfully taken care of by machining the blow-through to a regular shape and fixing a niobium button at the blow through.

Although above incidents caused a decrease in frequency of cavity ,compared to simulated value of 645.2 MHz, cavity reached a very high gradient of 34.5 MV/m ,without quenching, in VTS Test at Fermilab. Quality factor >$3X10^{10}$ upto 22 MV/m and >$1.5X10^{10}$upto 30MV/m

VTS Results : VECC First Single Cell LB650 SRF Cavity



Cavity could sustain 74MV/m Peak Electric Field (E_{pk}) and 137 mT Peak Magnetic Field (B_{pk}), with accelerating gradient of 34.5 MV/m @ 2K (-271^0 Celcius).



Single-cell LB650 niobium cavity (EBW done at IUAC,Delhi)

Maximum accelerating Gradient: 34.5 MV/m @2K and No quench with full power

Accelerating Gradient of 30 MV/m @2K achieved with unloaded cavity quality factor Q_0 =1.5E+10.

Fabrication of second single cell niobium cavity

- ✓ The first single cell Niobium cavity was fabricated in a welding sequence in which the equator welding was done first and then the iris welding was carried out.

- ✓ However, the 5 cell cavity will have the welding sequence in the exact reverse manner. In order to validate the actual welding methodology, a second single cell cavity was fabricated with changes in welding sequence as shown below

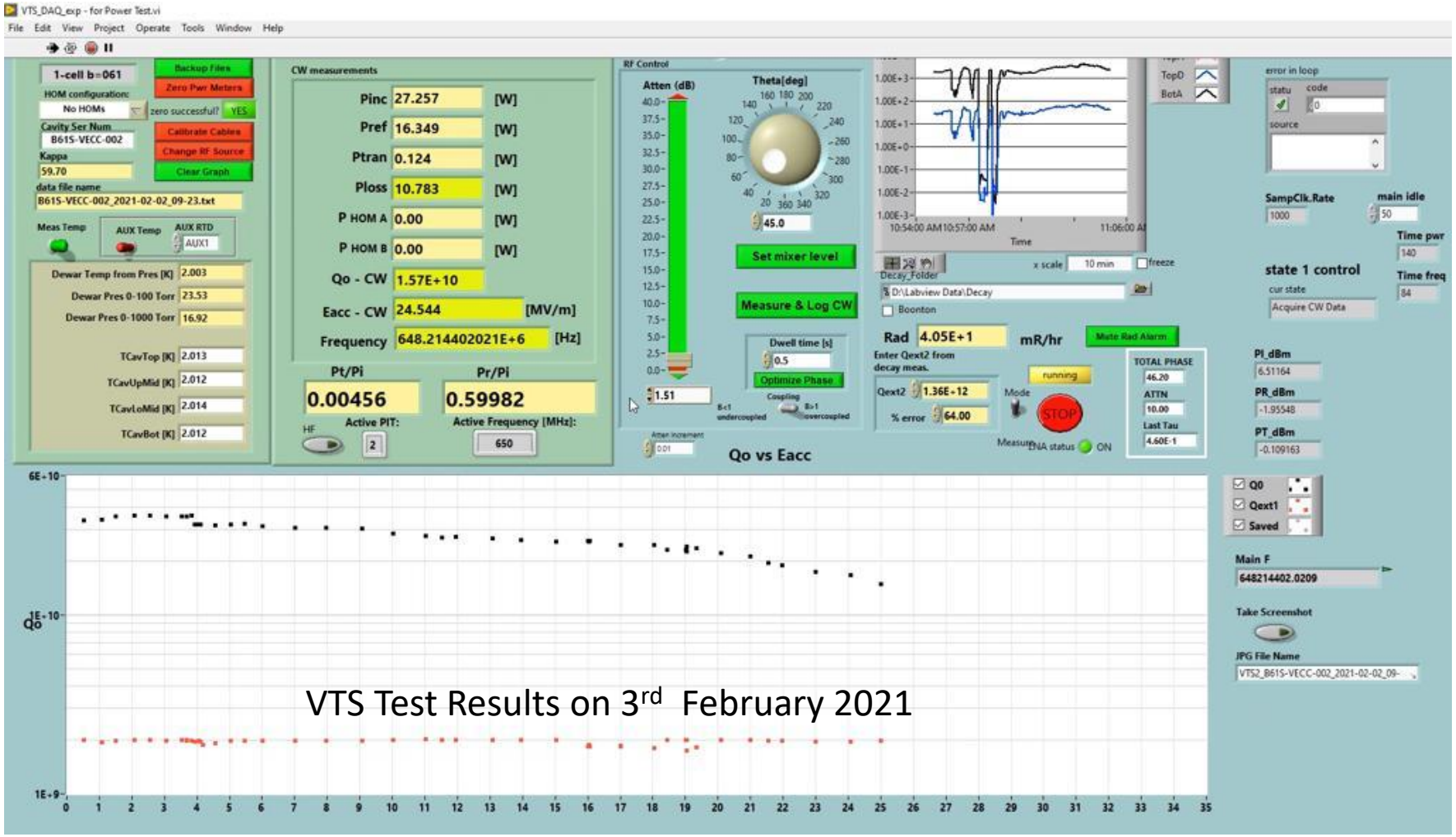
  i. beam pipe welding
  ii. Half-cell cavity iris to beam pipe and Nb-Ti flange to beam pipe
  iii. welding of equator (welding parameter is developed using spare niobium half-cells, then equator welding done successfully on actual cavity)

- ✓ Electron Beam Welding of the cavity has been carried out at IUAC, Delhi.

- ✓ Frequency measurements of the cavity was done at VECC and the value is found to be 645.9 MHz.

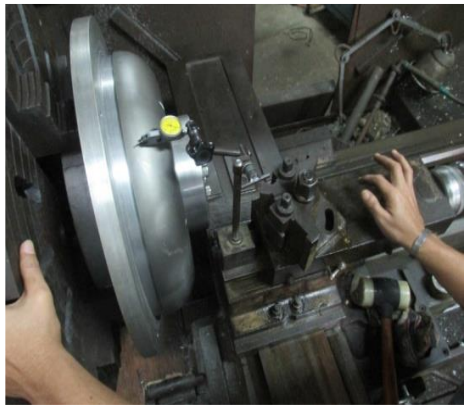
Second VECC-make single-cell LB650 Niobium Cavity test result

Accelerating Gradient of 25 MV/m @2K achieved before field emission started.



Superconducting RF Niobium Single cell Cavity Development at VECC

Forming set up



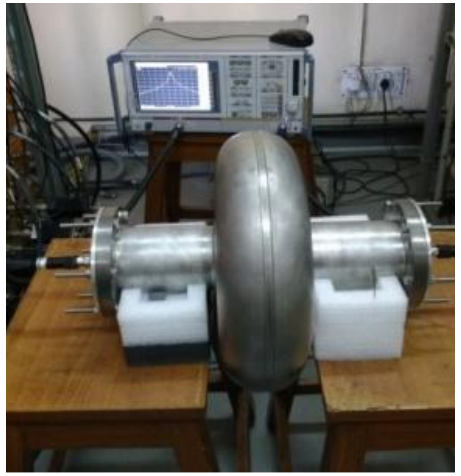
Half Cell machining

EBW,IUAC

EBW at IUAC

Cryo-shocking

MSLD



RF measurement

Present Status of Fabrication of two LB650 Cavities for R&D Phase

- For fabrication of two prototype LB650 cavities, 12 niobium mid halfcells , 4 niobium pen halfcells and 4 niobium end halfcells, 12 set of of stiffener rings are developed.

- Online meeting was held in first week of April,2022 with IUAC,New Delhi, regarding electron beam welding of two 5-cell Low Beta 650 MHz (LB650) cavities.

- IUAC personnel visited VECC during end of April, to inspect niobium components and welding fixtures to check the preparedness for the electron beam welding of 8 dumbbells (4 dumbbells for each of the LB650 cavity), 4 beam pipes (2 for each LB650 cavity) and 2 pipes for coupler ports (1 for each LB650 cavity).

- With the suggestion from IUAC, the niobium components and the fixtures for EB welding were modified /rectified by VECC .

- Boxes with proper protection for vibration/shock ,were also fabricated for transportation of niobium components and fixtures without damage.

- At present , all the niobium components and fixtures , properly packed in three boxes ,have been handed over to our Central Regional Store Unit(CRSU) for despatch to IUAC and they will send the materials to IUAC ,once the time slot for welding at IUAC is confirmed.

LB650 Cavity Fabrication Experience …so far

- 3 types of die punch assemblies using aluminium 7075-T6 have been developed to form the elliptical halfcells.

- To validate the process of fabrication of 5- cell LB650 niobium cavity , a prototype 5- cell copper LB650 cavity has been developed first before we started the development of 5- cell LB650 niobium cavity

- The fabrication stages of a 5 -cell cavity consists of fabrication of halfcells and stiffener rings , welding of these halfcells into a 4 sets of dumbells and 2sets of End groups, including the welding of stiffener rings, subsequent welding of the dumbells and endgroups, to fabricate sub-assemblies(half of the whole cavity) and then final welding to fabricate the 5-cell cavity.

- To take care of the frequency deviation introduced during forming of halfcells and welding of halfcells, dumbells and subassemblies frequency measurements have been carried out for halfcells, dumbells, end group and subassemblies

- Depending on the measured values , dumbbells are trimmed in the equator region. Deviation of Frequency of final 5- cell copper prototype is found to be 450 KHz with respect to designed frequency.

LB650 Cavity Fabrication Experience …so far

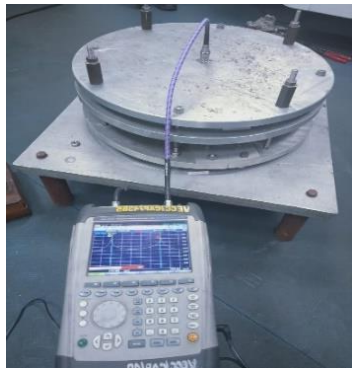
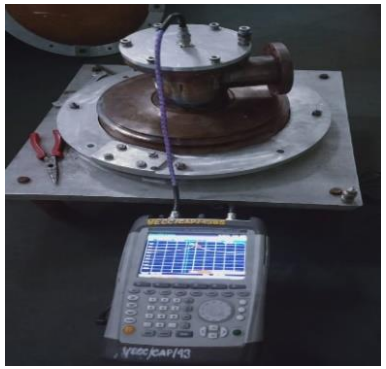
- Tooling ,fixtures and frequency measurement set up for 5- cell copper prototype

- Measurement of copper mid halfcells showed frequency deviation,on higher side, in the range 0.4 MHz to 2.7 MHz, for copper pen halfcell , frequency deviation is around 1 MHz on higher side.

- After formation of copper Dumbbell with stiffener ring (by TIG welding), frequency deviation goes to lower side, in range of 2.5 MHz to 3 MHz, due to weld shrinkage and deformation during welding.



Copper prototype half-cells, sub-assemblies with welding fixture & welding of coupler port


Frequency measurement of dumbells, endgroups and dumbbell trimming



Frequency measurement of sub-assemblies and 5-cell LB650 copper prototype cavity

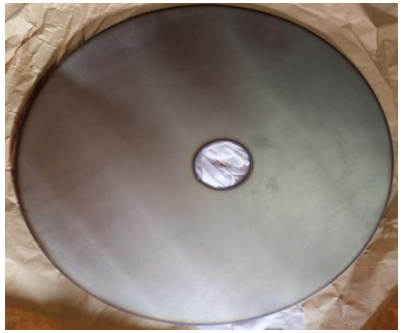
LB650 Cavity Fabrication Experience …so far

- Die Punch Assemblies, Tooling ,fixtures and frequency measurement set up, which were used for 5- cell copper prototype, are and will be used for fabrication of 5-cell LB650 niobium cavity.

- Forming and machining of niobium Mid halfcells, niobium End halfcells and niobium Pen halfcells for two LB650 cavities have been completed.

- Frequency measurement of niobium mid halfcells shows frequency deviation,on higher side, in the range 0.2 MHz to 1.3 MHz, which is better than copper halfcells and for niobium pen halfcell , frequency deviation is around 1 MHz on higher side. Frequency measurement has been done for two niobium halfcell connected in form of dumbbell,before EBW ,so that we can get data about frequency deviation due to weld shrinkage after EBW.

- CMM measurement of niobium halfcells has been carried out .For mid halfcell, maximum deviation is ~ 0.35 mm in equator ellipse region and iris ellipse region,~ 0.6 mm in the straight portion . For pen halfcell, maximum deviation is ~ 0.45 mm in equator ellipse region,~0.3mm in iris ellipse region,~ 0.5 mm in the straight portion .

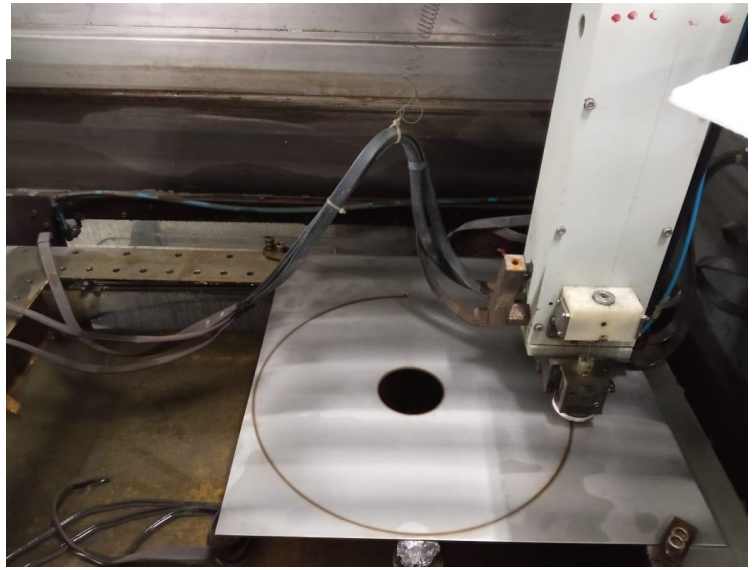


Niobium Blank

Niobium halfcells with template

Frequency measurement and CMM measurement of Niobium halfcells

Photographs for LB650 Cavity Fabrication



THANK YOU