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INJECTOR CAVITIES FABRICATION, VERTICAL TEST PERFORMANCE AND PRIMARY CRYOMODULE DESIGN

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Abstract

After the electromagnetic design [1] and the mechanical design [2] of a beta=0.6, 2-cell elliptical SRF cavity, the cavity has been fabricated. Then both 2-cell and 7-cell cavities have been bench tuned to the target values of frequency, coupling external Q and field flatness. After buffer chemistry polishing (BCP) and high pressure rinses (HPR), Vertical 2K cavity test results have been satisfied the specifications and ready for the string assembly. We will report the cavity performance including Lorentz Force Detuning (LFD) and Higher Order Modes (HOM) damping data. Its integration with cavity tuners to the cryomodule design will be reported.

SPECIFICATION AND STRING LAYOUT

The new SRF cryomodule construction for the CEBFA injector has been restarted and built until the string assembly. This cryomodule used to be two 5-cell cavities built within a quarter CEBAF cryomodule. Now it is going to be placed after the chopper, buncher and capture sections and before R100 (C100 prototype) cryomodule. In order to overcome the difficulties during the beam tuning up operation for the CEBAF injection particularly for the new 12 GeV machine, this new cryomodule contains a low beta cavity which can handle the low injection energy beam (~200 keV) well both in bunching and acceleration processes without blowing emittance up. After electrons reaching nearly relativistic (β≈0.99), acceleration can be taken by the R100, β=1 cryomodule up to 130MeV. Table 1 lists the cryomodule design specification derived from the beam dynamic analysis and beam user requirement. This derivation has been documented in a project note [3]. The minimization of transverse RF kick induced by the FPCs without a skew quadruple effect (x-y coupling) on the beam trajectory is critical for the cavity design. This achievement has been described in publication [1] and its references.

After the electromagnetic design [1] and the mechanical design [2] of the 2-cell cavity, the cavity has been fabricated in 2013. After delay holds due to funding, the project was restarted in April 2014. First step is to qualify both cavities in vertical tests. The second step is to advance the cryomodule design for primary components including cavity tuners, magnetic shields, and beam pipe components by taking the advantage of C100 type design for the 12GeV Upgrade. The third step will be hardware preparation for the clean room string assembly like the design layout in Figure 1.

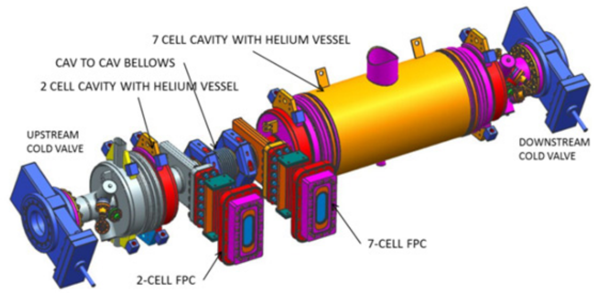

Figure 1: String assembly design of injector cryomodule electrons beam runs from 2-cell to 7cell cavity.

Table 1: Injector Cryomodule Design Specification

Cavity type	**2-cell**	**7-cell**
End beam energy (MeV)	0.533	5
Peak on axis E field (MV/m) nominal / (range)	4.6 (2-8)	13.2 (8-26)
E_{acc} including TTF (MV/m) nominal / (range)	2.6 (1.1-4.5)	7.1 (4.3-14.1)
Beam voltage V_a (MV) nominal / (range)	0.33 (0.13-0.54)	4.9 (3-10)
Beam current I (mA) nominal/max	0.38/1.0	
Geometry β_g	0.6	0.97
Q_0 at nominal gradient	>4E9	>8E9
Off-crest phase setup Φ_b (deg)	-17	-15
FPC Qext for max. beam current	6E6	9E6
FPC Qext for nominal beam current by using stub tuner	1.3E7	2.0E7
Klystron power for max E_{acc} 1mA beam current (kW)	0.547	14.6
HOMs dipole Imp.[1] $R_\perp$, Ω/m	<2.4E10	<2.4E10
FPC RF kick dP_y/P_z (mrad)	<1	<2
Tuning Sensitivity, (MHz/mm) ANSYS	2.63 cold	0.592 cold 0.431 warm m.
Helium Pressure Sensitivity (Ref. only, Hz/Torr)	382	320

CAVITIES' FABRICATION

The specification for two cavities for the vertical cold test acceptance criteria has been developed in Table 2.

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Table 2: Cavity Design Specification and Vertical Test Acceptance

Parameters	b2-cell	7-cell
Operation Freq., MHz	1497	1497
Freq. w/o tuner, MHz	1496.400-1496.700	1496.400-1496.700
Particle input β_b	0.7	0.9
Geometry β_g	0.6	0.97
R/Q including TTF, Ω	98.4	871.5
κ=sqrt(R/Q)/L	82.64	42.17
E_s/E_{acc}	1.638	2.233
B_s/E_{acc}, mT/(MV/m)	3.341	3.887
Geometry Factor, Ω	172.4	281.0
W Active Acceleration Length, mm	12.0	700.0
E_{acc}, nominal, MV/m	2.6	7.1
E_{acc}, range, MV/m	1.1-4.5	4.3-14.1
E_{acc}, max+10%, MV/m	5.0	15.5
Q_0 at E_{acc}, max. ±0.3MV/m	>4E9	>8E9
Q_{ext}, input	0.8-1.2E10	0.8-1.2E10
Q_{ext}, field probe	0.8-1.8E12	0.8-1.8E12
Q_{ext}, TM010-pi mode	≥ 3E12	≥ 3E12
LFD coefficient, $Hz/(MV/m)^2$	<20	<20
Q_{ext}, all HOMs[1]	<1E8	<1E8

Note 1 (also in Table 1): Subject to a TDBBU single-pass BBU simulation study.

After the dumbbell trimming and electron beam welding (EBW) of the 2-cell cavity, the beadpull measurements were carried out before and after the bench tunings, buffered chemistry polishing (BCP) for the field flatness (FF) and warm target frequency. Figure 2 shows the waveguide coupling Q_{ext} changes due to the FF and the beampipe length between end cell and FPC trimming finally lead to the target Q_{ext}=6E6. The 7-cell cavity was rebuilt from a prototype of Low Loss (LL) cavity from Renaissance cryomodule with siffening rings. A "T" shape beam pipe adaptor transition to the fundamental power coupler (FPC) side of cavity end cell iris and new stainless steel Helium vessel end dish had been made. Later a vacuum to Helium leak on this iris was found, then a cut on this iris' stiffening ring on the weld of NbTi/Nb transition was made in order to use the EBW to repair this leak. Several bench tunings were made during these process.. The beadpulls on the first and last this process were made as shown in Figure 3. The final Q_{ext}=9E6 was made after trimming a longer length of beam pipe than original LL cavity's.

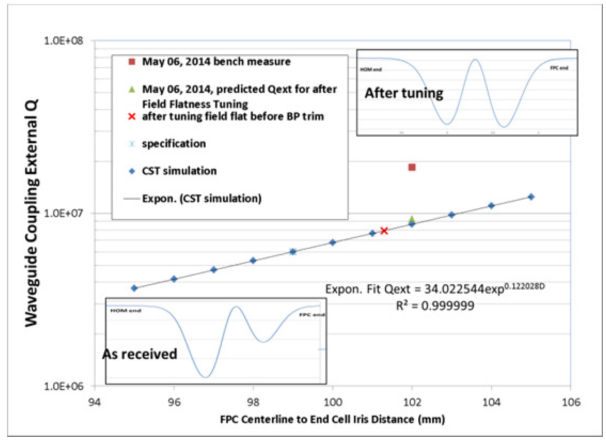

Figure 2: 2-cell cavity bench tuning for Q_{ext} and FF.

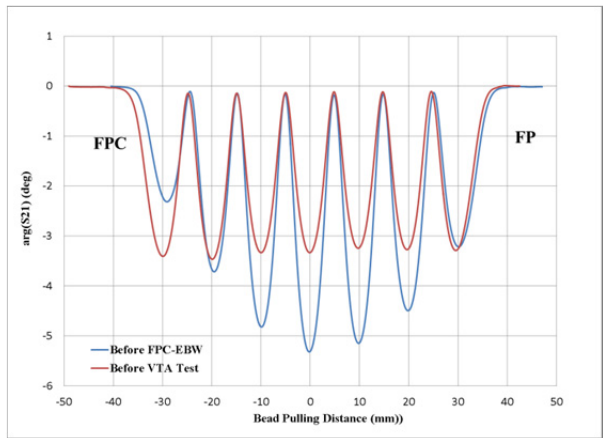

Figure 3: 7-cell cavity bead-pulls before and after tunes.

VERTICAL TEST PERFORMANCE

The 2-cell cavity has a relative lower specification on Q_0 than 7-cell since its lower geometry factor due to its low beta shape. The operation gradients of 2-cell and 7-cell are also lower than C100 cavity. The design specification of Q_0 versus E_{acc} has been achieved on the 2nd test after a better HPR to overcome the field emission (FE) problem in its 1st test. The LFD coefficient was measured as -9.48 $Hz/(MV/m)^2$.

The 7-cell cavity had an early FE onset (10MV/m) problem in its 1st test, but has reached nearly the specification as shown in Figure 5. The LFD coefficient was measured as -3.72 $Hz/(MV/m)^2$, lower than the unstiffened C100 cavities'. The Helium leak problem was found and repaired after this 1st test. The 2nd test is going to be done at about the time of this conference.

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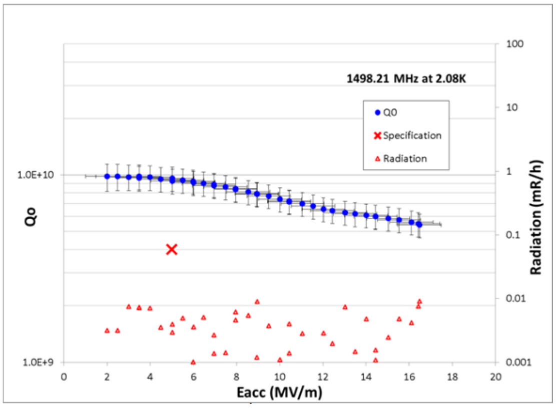

Figure 4: 2-cell cavity 2nd vertical test Q_o vs E_{acc} curve.

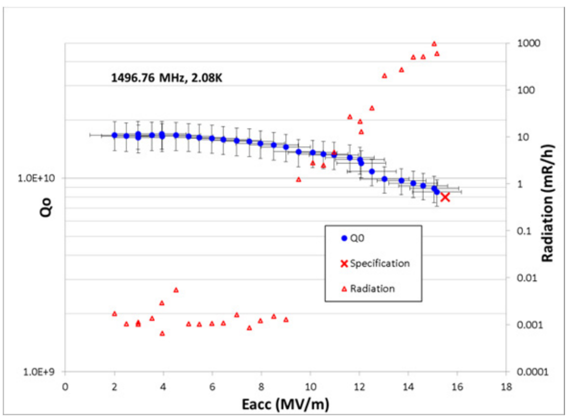

Figure 5: 7-cell cavity 1st vertical test Q_o vs E_{acc} curve.

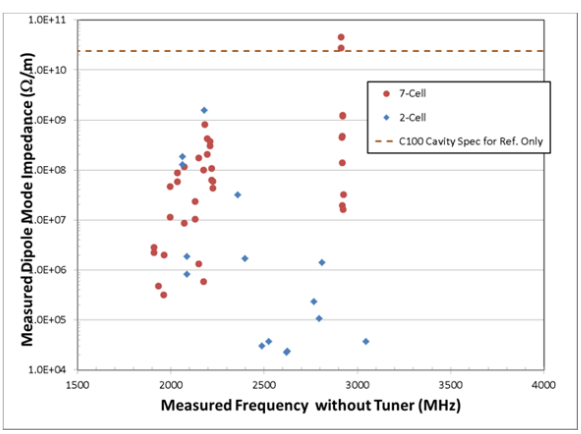

Figure 6: HOM dipole impedances measured with HOM couplers terminated with 50Ω loads in cavity vertical tests.

The HOM surveys have been done during the vertical tests.

The HOM couplers are connected by cables and terminated at room temperature 50Ω loads. The loaded Q measurements use either Polfit automation program to post-process the Vector Network Analyser (VNA) data or manually taken -3dB bandwidth on each HOM. The $R_t/Q*k$ values of dipole modes for each cavity are calculated by CST MWS with coupler detail so the mode ID and field feature with the FPC waveguide and HOM couplers can be identified. The dipole impedance data shown in Figure 6 are this $R_t/Q*k$ value times measured loaded Q on each mode. The impedance budget limit is for reference only which was for the C100 cavities being within the multi-turn CEBAF recirculation path (12GeV, 175μA injection beam). The real impedance budget is subject to the single-pass BBU simulation which we believe being higher than this since this cryomodule is designed for the CEBAF injector.

PRIMARY CRYOMODULE DESIGN

The design of cryomodule components is still on-going at this time. Long lead time items such as beam line bellows and cold gate valves are either purchased or on the shelf. The primary components of cavity tuners, magnetic shields, suspension structure have been designed. The tuner sensitivity measurement data, Helium riser designs of both cavities and the pressure safety analysis for Helium vessel and vacuum tank have been reviewed by the project team. Figure 7 has shown the cavity tuner designs for 2-cell and 7-cell cavities.

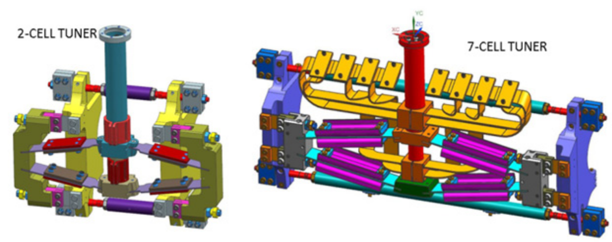

Figure 7: Scissor jack style tuner designs for 2-cell and 7-cell.

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