NINE-CELL ELLIPTICAL CAVITY DEVELOPMENT AT TRIUMF

V. Zvyagintsev, C. D. Beard, A. Grassellino, D. Kaltchev, P. Kolb, R. E. Laxdal, D. Longuevergne, B. Waraich (TRIUMF, Vancouver), M. Ahammed (DAE/VECC, Calcutta), R. Bolgov, N. Sobenin (MEPhI, Moscow), R. Edinger (PAVAC, Richmond, B.C.)

Abstract

The superconducting e-Linac project at TRIUMF requires a new nine cell elliptical cavity at 1.3GHz of TESLA influenced design capable of providing a CW accelerating voltage of 10MV at 10mA of beam intensity. This corresponds to a challenging 100kW of beam loaded rf power and a Beam Break-up (BBU) threshold in multi-pass mode of $R_d/Q*Q_L$=10MOhm. For this purpose we use two opposed CPI 60kW CW rated couplers. Another challenge is to provide HOM damping for the possibility of multi-pass ERL operation by means of end cell optimization and higher order mode (HOM) dampers. Results of the cavity design work including developments toward a passive HOM damper will be discussed.

INTRODUCTION

TRIUMF eLinac project requires 50MV acceleration effective voltage [1]. It was decided to build this voltage with 5 nine cell 1.3GHz elliptical Tesla/ILC cavities operating at 2K. Each cavity will operate for 10MV or E_a=10MV/m acceleration gradient. It's quite realistic goal for production. This class of cavities, achieved operation gradients of 25-30MV/m.

The challenges for these cavities are related with 10mA beam current at 10MV which require:

- 100kW CW rf power in the cavity
- suppress HOM to below BBU threshold

ERL operation mode for last 4 cavities are under consideration and it will require additional attention for HOM damping.

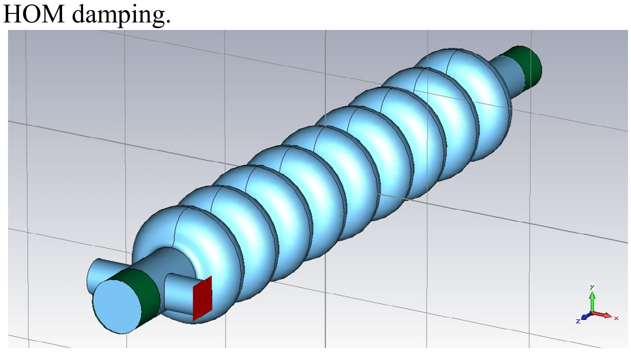


Figure 1: 9 cell TRIUMF cavity CST MWS model with input couplers and HOM damping rings

Two single cell elliptical test cavities have been built by PAVAC Industries of Richmond, BC [2] and are processed and tested at TRIUMF [3, 4]. Current TRIUMF results for these cavities didn't reach design goal of $Q_o=10^{10}$ at 10MV/m. Meantime PAVAC made the same 6 cavities. Processing and testing of these cavities in Fermilab show good results [5].

RF DESIGN

The cavity rf design is a combination of borrowed solutions for the project requirements:

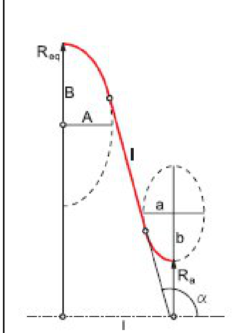
- 9 cell TESLA superconducting cavity [6] operating at 2K was chosen to get 10MV acceleration voltage at 10W power dissipation
- coupler section of 2 cell Cornell ERL cavity consisting of 2 CPI couplers [7] delivering 100kW rf power in CW
- HOM damper rings similar to Cornell ERL HOM load [8] to be simple solution

The cavity rf 3D CST MWS [9] model was used for design (Fig.1). It consists of 9 elliptical cells, 2 symmetrically opposed couplers and beam pipes with rings of rf absorber material for HOM damping.

Cavity

The cavity shape is mainly the same as 9 cell TESLA cavity with the difference in end cell iris radius adjacent to coupler beam pipe to put 2 CPI coupler ports. Such a way coupler beam line has radius 48mm (like Cornell did) and tuner beam line (opposed to coupler) - 39mm (the same as TESLA). Cavity cell geometric parameters were tuned to get flat distribution of accelerating component in CST model and presented on Table 1.

Table 1: TRIUMF 9 cell cavity geometry (in mm)



Dimension	Inner cell	Coupler end cell	Tuner end cell
Length L	57.692	56	57
Iris Radius R_a	35	48	39
Equator Radius R_{eq}	103.3	103.3	103.3
Iris half axis a	12	10	9
Iris half axis b	19	13.5	12.8
Equator half axis A	42	45	42
Equator half axis B	42	40.5	42.275

RF parameters of the cavity in comparison with 9 cell Tesla (DESY) cavity [6] are presented in Table 2. We can see that rf parameters of TRIUMF cavity are very close to TESLA (DESY). R_{sh}, E_p/E_a and B_p/E_a are ~3-5% worse because of coupler end cell iris increase. Geometric factor is 7% higher from coupler end cell volume increase. Coupling between cells is a little bit more.

	TRIUMF	DESY	TRIUMF/DESY
Frequency [MHz]	1300	1300	-
R_{sh}/Q [Ohm]	1000	1030	3% less
Geometric factor G [Ohm]	290	270	7% more
E_p/E_a	2.1	2.0	5% more
B_p/E_a [mT/(MV/m)]	4.4	4.2	5% more
Cell coupling [%]	2.0	1.9	

Table 2: RF parameters of TRIUMF cavity in comparison with TESLA (DESY)

Using the data on Table 2, we can see that for nominal acceleration gradient of 10MV/m peak values for magnetic and electric fields will be very moderate: 44mT and 21MV/m.

To get 10MV acceleration voltage at R_{sh}/Q=1kOhm and Q_o=1e10 quality factor the cavity will dissipate 10W in 2K liquid He. Such a way the requirement for cavity is quality factor of $Q_o \geq$1e10 at E_a=10MV/m.

Wake fields cavity 2D simulations with code ABCI [10] at for one bunch of 16pC and sigma 3mm gave 1W (injector cavity) of losses and for sigma 0.3mm (accelerator module cavity) 3.5W and 22W for high brightness beam.

Coupler Section

The coupler section configuration is shown on Fig. 2 and consists of 2 symmetrically opposed couplers. This borrowed from Cornell ERL cavity [7] solution

- provide nominal 100kW CW drive into cavity by dividing power on two CPI (60kW CW capability) couplers
- twin setup is compensating a kick for beam coming from field perturbation from each coupler [11]

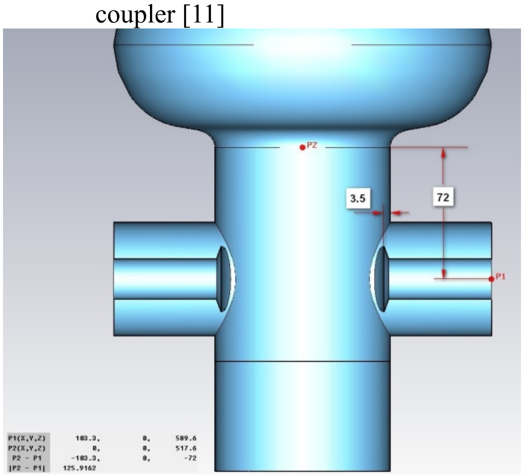


Figure 2: Coupler section with 2 opposed CPI couplers in nominal position for $Q_{ext}=10^6$: ±5mm antenna penetration range gives the Q_{ext} of $5*10^5$ - $2*10^6$.

CPI coupler consists of antenna plate attached to inner conductor of coaxial 62/22 (OD/ID in mm) with 62 Ohm impedance.

The distance from coupler port to cavity iris is 72mm from fabrication considerations: cavity helium vessel flange should be installed between the cavity end cell and coupler port. Nominal coupling for 10mA beam 10MV acceleration is corresponding to $Q_{ext}=10^6$. According to CST simulations nominal antenna coupler penetration in the beam pipe is 3.5mm. The coupler antenna travel ±5mm gives the Q_{ext} range of $5*10^5$ - $2*10^6$.

HOM Damping

Beam passing through the cavity create wide HOM spectrum which induces beam instabilities. The main danger comes from dipole modes. Beam dynamics study shows that BBU threshold in multi-pass mode of $R_d/Q*Q_L$=10MOhm.

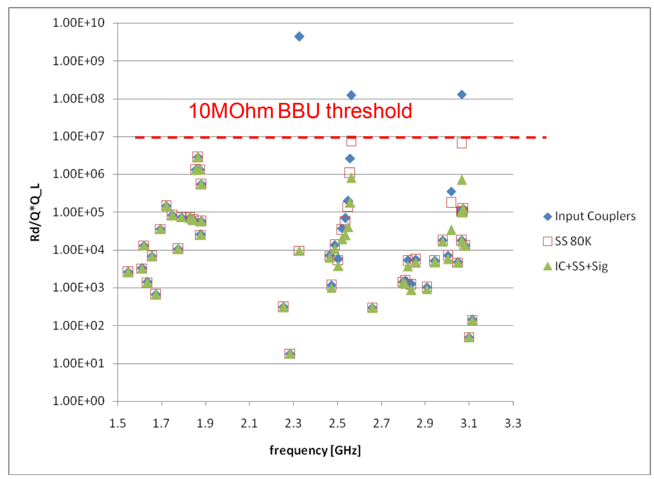


Figure 3: Dipole modes shunt impedances: diamond - loaded just with input couplers, square - loaded in addition with stainless steel damping rings, triangle - stainless steel damping ring on coupler side and Sigradur damping ring on tuner side.

CST cavity model presented on Fig. 1 was used for HOM study [12]. HOM dipole modes spectrum 1.5-3.25GHz is presented on Fig. 3. The plot shows calculated values of dipole shunt impedances $R_d/Q*Q_L$ of the cavity loaded with input couplers and damping rings with rf absorber materials. In the model we used 60mm long rings on a distance of 117mm from end cells to load HOM and avoid load for operating mode ($Q_{rings}>10^{11}$). Calculating loading effect from the rings we can find loaded dipole shunt impedance for HOM spectrum and justify about HOM propagation from the cavity. Blue diamonds on the plot correspond to the loading just from input couplers; there are 3 modes with $R_d/Q*Q_L$>10MOhm. Empty squares correspond to stainless steel rings (electrical conductivity of $1.5*10^7$) and all impedances are below the threshold except for modes TE11 2.56GHz and 3.1GHz. Green triangles show significant decrease of impedance for these 2 modes down to 1MOhm in case of using Sigradur [13] or Cesic

[15] materials (electrical conductivity of $2*10^4$Sim/m) for damping ring on tuner side of the cavity. Low frequency part of HOM spectrum are not damped with rings because of for this part the beam pipes are cut off waveguides.

We studied another variants of the cavity shape. Impact of fabrication error of ±0.5mm for dangerous TE11 2.56GHz mode statistical analysis was done with Slans code [16]. The cavity study results are presented in paper [12].

MECHANICAL DESIGN AND PRODUCTION

TRIUMF 9 cell cavity (Fig.4) is a bulk Nb (with thickness of 2.8mm) structure similar to TESLA cavity except for coupler section and absence of HOM hooks.

The cavity will be welded in LHe jacket and equipped with tuner adopted from 7 cell Jlab cavity [17] without piezzo for microphonics compensation.

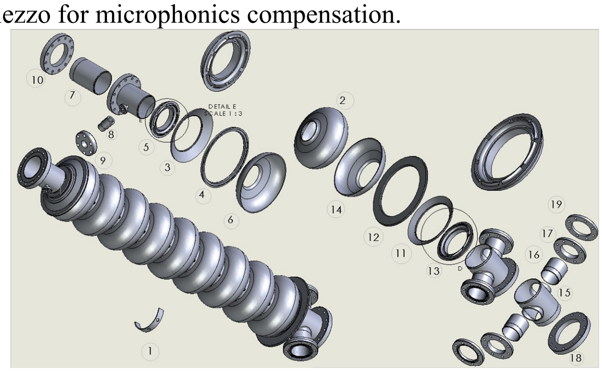


Figure 4: Mechanical design of TRIUMF 9 cell cavity.

We are considering to place HOM damping rings in transition sections similar to Cornell ERL solution [8] of beam lines inside of cryomodule (Fig. 5). The ring in this section will screen bellows from beam. We suppose to have stainless steel damping ring on coupler side. For tuner side we are considering to use ring from Cesic material which have enough good thermal conductivity and vacuum properties [14].

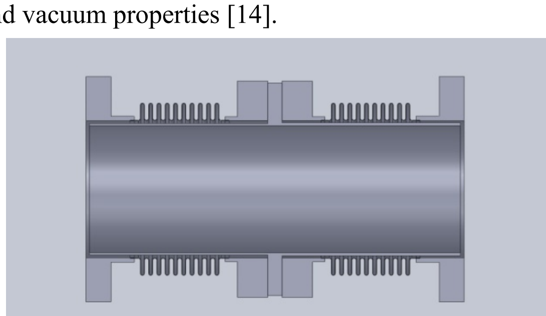


Figure 5: Design of transition section with passive HOM damper.

Preparation for the cavity fabrication of the cavity has been started in collaboration with PAVAC Industry. Copper model of 7 cell cavity is in production.

CONCLUSION

The 9 cell cavity design for TRIUMF eLinac project is completed and cavity fabrication has been started. We've done HOM cavity study in the range 1.5-3.25GHz and found that we can provide damping of dipole modes with rf absorber materials up to value of loaded shunt impedance at least 2 times below of BBU threshold.

RF design of HOM dampers has been started and much work to be done in this direction.

Copper 7 cell model cavity to be completed in August 2011. TRIUMF 9 cell Nb cavity fabrication will commence in September 2011.

REFERENCES

[1] S. Koscielniak, "An electron linac photo-fission driver for the rare isotope program at Triumf", SRF09, Berlin, Germany, September 2009.

[2] http://www.pavac.com/.

[3] R. E. Laxdal, "Recent Developments in SRF at TRIUMF", SRF2011.

[4] D. Longuevergne et al. TRIUMF, Vancouver, Canada. "Performance Limitation Studies on ISAC-II QWR's and e-Linac Elliptical Cavities at TRIUMF". SRF2011. MOPO017.

[5] Joe Ozelis, private communication.

[6] B. Aune et al., "Superconducting TESLA cavities", Phys. Rev. ST Accel. Beams 3, 092001 (2000).

[7] V. Veshcherevich et al: "A High Power CW Input Coupler for CORNELL ERL Injector Cavities", SRF 2009, p 722-725, 2009.

[8] V. Shemelin et al., " Status of HOM Load for the CORNELL ERL Injector", Proceedings of EPAC 2006, Edinburgh, Scotland, MOPCH177.

[9] http://www.cst.com/.

[10] http://abci.kek.jp/abci.htm.

[11] V. Shemelin et al. "Low-Kick Twin-Coaxial and Waveguide-Coaxial Couplers for ERL" In: Proc. of the Workshop on High Power Couplers for Superconducting Accelerators, 2002.

[12] P. Kolb et al. TRIUMF, Vancouver, Canada. "HOM Cavity Design for the TRIUMF eLINAC". SRF2011. Student poster session.

[13] www.htw-germany.com.

[14] V. Shemelin et al., " Using a Resistive Material for HOM Damping", Proceedings of IPAC'10, Kyoto, Japan, 2010, WEPEC063.

[15] http://www.cesic.de/.

[16] D.G. Myakishev, V.P. Yakovlev, "The New Possibilities of SUPERLANS Code for Evaluation of Axisymmetric Cavities". Proc. of 1995 Particle Accelerator Conference and International Conference on High-Energy Accelerators, May 1-5, 1995, Dallas, Texas. p 2348-2350.

[17] R.A. Rimmer et al., " JLAB CW CRYOMODULES FOR 4TH GENERATION LIGHT SOURCES", Proceedings of SRF 2007, Peking Univ., Beijing, China, TUP65.