HOM CAVITY DESIGN FOR THE TRIUMF eLINAC

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Abstract

The TRIUMF eLINAC, currently in its design phase, is a 50 MeV electron linear accelerator and will be used for photo-fission to produce rare isotopes for experiments. Future upgrade plans include an option to go to a recirculating LINAC to provide higher energies. This brings up the need to calculate the shunt impedances of higher order modes (HOM) to avoid beam instabilities and beam break up (BBU). The cavity design for a 9 cell cavity has to account for the limitations given by the desired beam current of 10mA and the layout of the recirculating path to create a high enough BBU limit.

Work on the cavity design to accommodate for those requirements will be presented as well as a way to reduce the shunt impedance by the use of ring dampers will be discussed.

INTRODUCTION

The TRIUMF e-Linac consists of five nine-cell cavities. Each cavity is supposed to provide 10MV of accelerating voltage at 1.3 GHz and a $Q_0 \geq 10^{10}$. The linac is divided into one injector cryomodule (ICM) with one cavity and two accelerating cyromodules (ACM) with each two cavities. The ACM section of the linac is under consideration to be extended to an energy recovery Linac (ERL) or recirculating linac. This future upgrade requires attention to the HOMs of the cavity. Modes with a high shunt impedance will cause beam breakup and too much dissipated power in the cavity, especially if one of the modes is on a beam repetition rate harmonic. One of the goals is to come up with a cavity design that does not rely on active HOM couplers to work within the given limit.

The baseline for the cavity design is the TESLA 9 cell cavity as described in [1]. TESLA cavity HOMs have been measured in [2] and [3].

To accelerate 10 mA electrons by 10 MV per cavity two power couplers provide each 50 kW rf power to combine to the needed 100kW. Modifications to the cavity shape have to be made due to those high power couplers and the BBU considerations. Simulations are done with the codes CST MWS for the coupler positioning and damping calcuations and SLANS for the fabrication error study. For SLANS a custom input file generator script was written as well as a post processing application that allows for calculations of damping with resistive materials.

DEFINITIONS

The dipole shunt impedance of mode *n* is defined [4] as:

$$(\frac{R_d}{Q})_n = \frac{V_z^2(\rho)}{\rho^2(\frac{\omega_n}{c})^2\omega_n U} \tag{1}$$

with ρ being the distance off axis.
For the proposed recirculating beam dynamics a $R_d/Q \cdot Q_L \leq 10M\Omega$ for each mode should give a threshold current for BBU of 20 mA. A value of 1 MΩ should give enough safety margin on the threshold current compared to the design current of 10 mA. The beam pipe with the power couplers attached to it will be called the 'coupler side' of the cavity, the opposing side is the 'tuner side'.

COUPLERS

To provide the beam with 100 kW cw power two 50 kW couplers are specified and are placed at the coupler of the cavity symmetrically opposed. Two coaxial couplers, opposing each other, are each delivering 50 kW cw. Because of the attached helium vessel the 62 mm inner diameter coupler ports have to be at a distance of 72 mm away from the last iris. Since a Q_{ext} of 10^6 is required to provide the required bandwidth for the 10mA beam, the couplers have to penetrate the beam pipe by 3.5 mm. The couplers are orientated in the horizontal plane.

DAMPING RINGS

To decrease the Q_L of a mode damping rings of normal conducting material are introduced at the beam pipes on both ends of the cavity. Those dampers introduce an additional loading to the mode and dissipate rf power. They will be located outside the helium reservoir and are temperature wise staged at 77K, so there is no additional heat load on the 2K helium. The generated heat will be transported out of the cryogenic system over the LN2 circuit. The distance of 117mm between damper rings and iris of the closest halfcell also guarantees no additional damping of the accelerating mode as the Q_{ext} of those rings for the accelerating mode is designed to be greater than 10^{11}. We are exploring different materials but for the purpose of this paper to be used as dampers: stainless steel and Sigradur [5] are considered, a glassy carbon with a electric conductivity of around $2 \cdot 10^4 S/m$. For more details on the design of the damper rings and Sigradur, see [6].

CAVITY SHAPE

Three different variants for a nine cell cavity have been studied. The main difference in each model is the size of the tuner side beam pipe: 48mm, 39mm and 55mm. Smaller changes to the shape of both endcells are done do optimize each variant for maximum *R/Q* of the accelerating mode before dipole modes are considered. The goal is to push the dangerous modes to one of the absorbers at both ends of the cavity. A 48 mm radius was chosen for the beam pipe on the coupler side to accommodate two 62mm inner diameter power coupler ports as in the Cornell two-cell cavity [7]. For practical reasons the shape of the inner half cells is not altered from the TESLA cavity.

The first model, a symmetric cavity with both beam pipes at 48 mm radius, was first analyzed with respect to the polarization of the dipole modes (fig. 1). The polarizations are forced in CST by implying different field symmetry conditions in the horizontal and vertical symmetry planes in the cavity with either the transverse component of either the electric or magnetic field equal to zero. It appears that the vertical polarization of the dipole modes is the more dangerous polarization. All following plots are in this polarization.

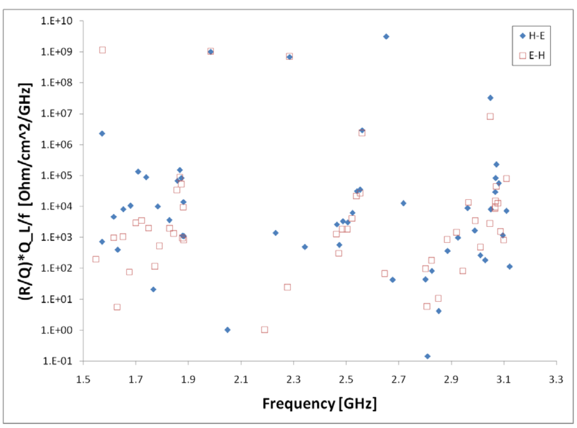

Figure 1: H-E: vertical electric field polarization, E-H: horizontal electric field polarization.

The dipole spectrum of this 48/48 model with and without (only with the power couplers) stainless steel dampers (fig. 2) shows several modes that are above the threshold limit of $R_d = 10^7\Omega$. While some of them are well damped, two modes at 1.57 GHz and 2.56 GHz are remarkable. The 1.57 GHz mode is affected by the stainless steel dampers, but not strong enough to get below the safety threshold of $R_d = 10^6\Omega$. The 2.56 GHz mode is not affected by this damping strategy. The Q of the damping rings is too high to have any effect on the Q_L for this mode. It is safe to say that this mode is trapped and that there is not enough stored energy in the region of the dampers to increase the loading of this particular mode. A different cavity shape or damping strategy is required.

Asymmetric cavity shapes with 39 mm and 55 mm radius on the tuner side beam pipe are compared without (fig. 3) and with (fig. 4) dampers. In fig. 4 stainless

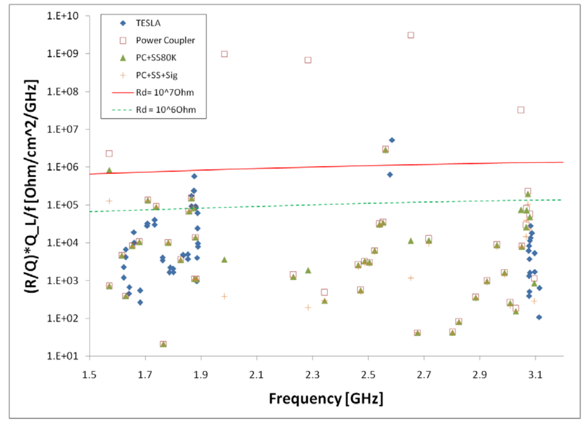

Figure 2: Dipole Spectrum for 48/48 with and without stainless steel dampers.

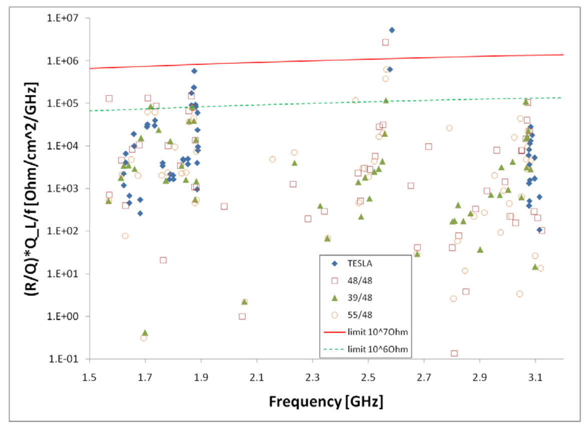

Figure 3: Undamped shunt impedances for various models.

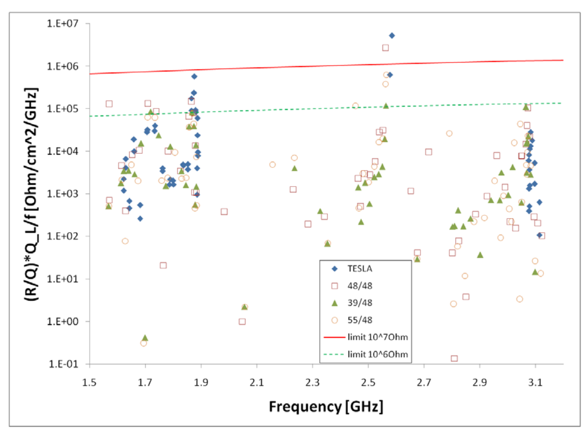

Figure 4: Damped shunt impedances for various models.

Table 1: RF parameters of the accelerating mode for the 39/48 variant

Frequency	1300 MHz
R/Q	1000Ω
G	290Ω
E_p/E_a	2.1
B_p/E_a	4.4 mT/(MV/m)
cell to cell coupling	2%

steel is used on the coupler side and Sigradur on the tuner side of the cavity. Significant damping occurs in the fundamental power couplers themself. Sigradur on the coupler side would be too much for the accelerating mode since the damper in close proximity to the power couplers. In the 39 (mm tuner side radius)/48 (mm coupler side radius) variant the 2.56 GHz mode actually increases in shunt impedance without any damping. Going from 48/48 to 39/48 the *R/Q* of this mode does not change significantly (20 to 19 Ω/cm^2). But the stored energy in the tuner side damper region increases. In the 39/48 variant the mode propagates towards the tuner side of the cavity and can be damped close to the lower threshold of $10^6\Omega$.

Increasing the radius of the tuner side beam pipe to 55mm (cut-off frequency for TE11 modes 1.59 GHz) not only makes the dampers ineffective for the high shunt impedance mode. The shunt impedance is not affected by the introduction of the dampers for the 2.56 GHz mode much like in the symmetric model. The increase of diameter also introduces a strong mode at 1.47 GHz.

Table 1 shows the RF results for the preferred 39/48 variant.

FABRICATION ERROR ANALYSIS

For the 39/48 variant a fabrication error analysis has been done with SLANS. Each geometric parameter of each half cell received a random perturbation in a Gaussian distribution with a range of $\pm 5\sigma$ with $\sigma = 0.1mm$. In total 60 randomized 'seeds' with completely independent randomizations of each halfcell have been simulated.

The focus of this analysis is in the changes in frequency, quality factor and Rd of the first 60 dipole modes. Of interest is the variation of those values with the fabrication errors. As can be seen in figure 5, the frequency is very stable for all modes with a standard deviation of less than 1% of the average value.

R_d is much more sensitive to those small changes with up to $\pm 100\%$ of the average value. A factor of two in uncertainties is acceptable if the BBU threshold limit is lowered to $5 \cdot 10^6\Omega$ or less. This is the reasoning for the lower limit of $R_d < 10^6\Omega$. The dangerous 2.56 GHz mode is very stable with only $R_d = \pm 8\%$ variation around its average.

Looking at the accelerating mode those samples result in an average *R/Q* of 700 Ω with a standard deviation of 180 Ω. Since tuning a cavity would increase the *R/Q* closer to the optimal value of around 1 kΩ, a more realistic choice of samples are those with a high *R/Q* of the accelerating mode. Six seeds have an *R/Q* of 900 Ω or higher. Reducing the sample size to those six seeds does not change the

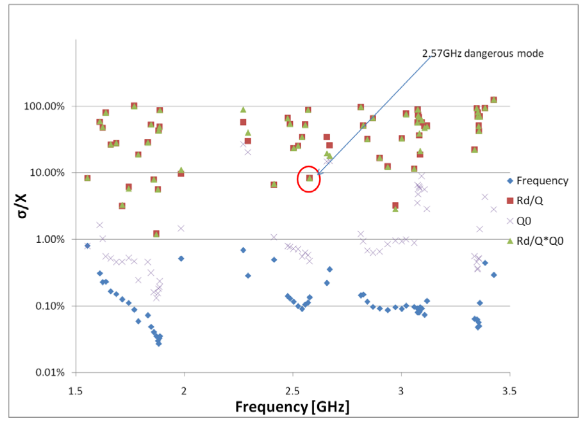

Figure 5: Results of the fabrication error analysis, y axis: standard deviation divided by average value.

deviations in frequency or shunt impedance significantly compared to the complete sample size evaluation.

CONCLUSIONS

An asymmetric cavity design has been developed that fulfills the requirements for the BBU threshold of the dipole mode with $R_d \leq 10^7$ considering passive damping strategies. Further investigations on fabrication tolerances reduced the threshold shunt impedance to $R_d \leq 10^6\Omega$ to give enough safety margin. This criterion will be met with the proposed damping strategy, which includes Sigradur, a glassy carbon. Passive damping strategies are being studied at TRIUMF.

REFERENCES

[1] TESLA Technical Design Report, 2001.

[2] J. Sekutowicz: "Higher Order Mode Coupler for TESLA", TESLA Report 1994-07.

[3] S. Fartoukh et al: "Evidence for a Strongly Coupled Dipole Mode with Insufficient Damping in TTF First Accelerating Module", PAC 1999.

[4] H. Padamsee et al: "RF Superconductivity for Accelerators", Wiley, 1998.

[5] www.htw-germany.com.

[6] V. Zyvagint et al: "Nine-cell Elliptical Cavity Development at TRIUMF", these proceedings.

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