MEASURING THE HIGHER ORDER MODE SPECTRUM OF THE TRIUMF 9 CELL CAVITY

P. Kolb, B. Amini, R.E. Laxdal, Y. Ma, Z. Yao, V. Zvyagintsev
TRIUMF, 4004 Wesbrook Mall, V6T 2A3 Vancouver, BC, Canada

Abstract

The ARIEL eLINAC consists of five nine cell cavities, produced by PAVAC, and will accelerate 10 mA electrons to 50 MeV. This 500 kW beam will be used for rare isotope production. Future upgrade plans include a recirculating beam line. Recirculating the beam, for either energy doubling or energy recovery to drive a FEL, brings the risk of multi-pass beam break up (BBU). Therefore it is necessary to avoid higher order modes (HOMs) with high shunt impedance. The goal of the cavity design is to reduce the highest shunt impedance of any dipole HOM to $1 \cdot 10^6 \Omega$ or less. Measurements on a 7 cell copper prototype cavity with bead pulling are done to identify dipole modes and their geometric shunt impedance R/Q. Results of these bead pulling measurements will be shown and compared to computer simulations done with ACE3P.

INTRODUCTION

ARIEL will complement the existing accelerator complex at TRIUMF with its rare isotope program. With the addition of the eLINAC [1] up to three out of ten experimental stations (currently one out of ten) can receive rare isotope beams (RIBs). The production of the RIBs is done via photo fission that utilizes the 50 MeV 10 mA continuous wave (cw) e^- beam from the eLINAC. In the finished eLINAC three cryomodules house five 1.3 GHz nine cell cavities. The cryomodules are split into one injector cryomodule (ICM) with one cavity and two accelerator cryomodules (ACM) with two cavities each. In the first phase only one ACM is available and recirculating the beam to use the first ACM a second time is an attractive option to reach 50 MeV. After the eLINAC is completed the reciurulating beam line can be used to excite an FEL and run the eLINAC in an energy recovery LINAC (ERL) mode which layout can be seen in fig. 1. Both operation modes, recirculating and ERL, are vulnerable to multi-pass BBU [2]. Therefore it is necessary to study the HOM spectrum of the cavities.

Beam dynamic calculations have shown a limit in dipole shunt impedance $R_{Sh,d}$ (as defined as in Ref. [3]) of 10 MΩ to have a high enough threshold current. A fabrication tolerance study showed uncertainties of up to a factor of two in shunt impedance [4] therefore a lower limit of 1 MΩ is set as goal. Simulation with ACE3P [5] show that this can be reached using the TRIUMF cavity design [6] which utilizes beam line absorbers to reduce the quality factor Q of the HOMs. The damping material CESIC has been tested for its RF properties in a cryogenic environment [7] and found adequate to reach the goal.

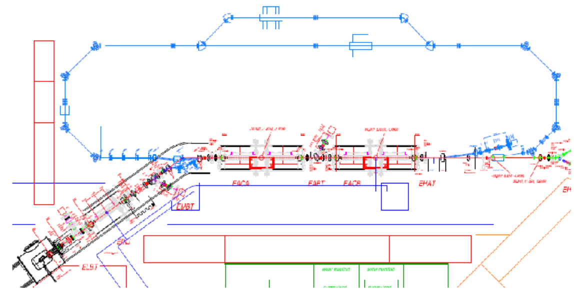

Figure 1: Proposed layout of the ARIEL accelerator with future recirculating beam lines for additional energy gain or ERL operation.

HOM SIMULATION

Simulations have been carried out with ACE3P for dipole modes up to 4 GHz. Results of those simulations are shown in fig. 2. Those results correlated well with previous CST Microwave Studio simulations, which were limited to modes up to 3 GHz due to very large computing times for high frequency modes (multiple days for a single mode).

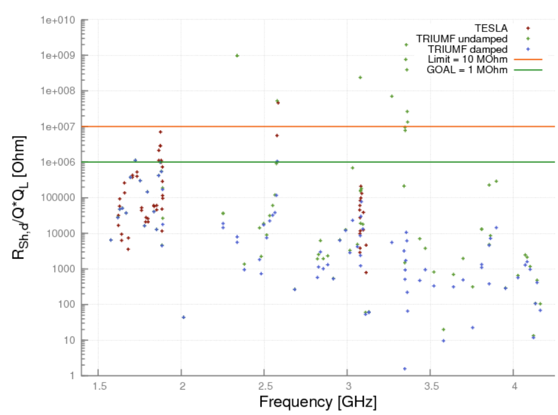

Figure 2: The simulated dipole shunt impedance spectrum for the TRIUMF nine cell cavity shows that without reducing HOM Qs the limit for BBU is exceeded. For reference the TESLA cavity dipole modes are not usable for this application due to a trapped mode at 2.56 GHz with high shunt impedance.

HOM MEASUREMENTS

Measurements are carried out using bead pulling. A bead pulling stand for the TRIUMF nine cell cavity was designed and built with the ability to move the string radially and azimuthally. Dipole modes of the TM011 class do

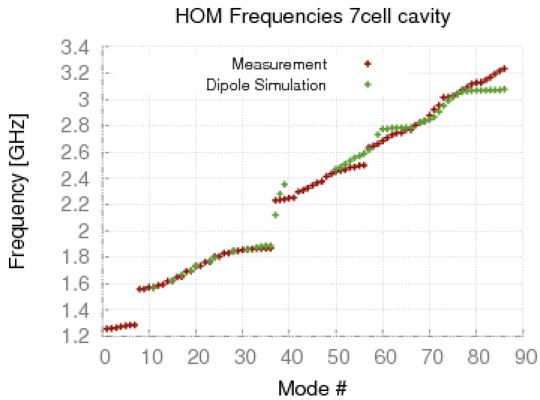

Figure 3: Measured frequency distribution of the resonant modes in the 7cell copper prototype and simulated dipole mode frequencies with ACE3P. The simulated values are fitted closely to the measured values in terms of mode number.

not have any electric field on the beam axis. Therefore it is necessary to measure the field distribution with an offset to the beam axis. Since the bead probes the field amplitude, a dipole mode can be identified by a $sin^2(\alpha)$ dependence of the maximum amplitude, quadrupole modes with $sin^2(2\alpha)$ and so on, where α is the azimuthal angle with respect to a starting point.

This bead pulling stand has been tested on a 7 cell copper cavity with ARIEL end groups. The string is aligned to the beam axis on the center of the cavity using targets on both sides of the cavity. Both fixed points of the string can be adjusted in the horizontal and vertical direction. In addition the whole string holding system including stepper motor is mounted on a rotational disk to allow azimuthal variation in the measurements. The stepper motor is controlled by a computer via Labview, which also controls the HP network analyzer used for this measurement. The software records Q, frequency and reference phase of the rf signal for the selected mode, and then proceeds to the actual bead pulling. Speed and travel distance can be adjusted to suit different cavities. During the bead pull measurement the phase of the RF signal is recorded. The phase shift from the reference phase is proportional to the electric field (using dielectric beads) or electric and magnetic field combined (using metallic beads). For a flatness tuning of the accelerating π-mode metallic beads can be used as this mode does not have any magnetic field on the beam axis and the metallic bead gives the true electric field. However for dipole modes this is not true and dielectric beads should be used to isolate the electric field on the chosen axis.

Figure 3 shows the frequency distribution of resonant modes up to 3.3 GHz along with ACE3P results for dipole modes up to a similar frequency of the 7 cell prototype cavity. A combination of electric symmetry in the horizontal and magnetic symmetry in the vertical symmetry axis of the cavity forces the simulation to only result in modes with

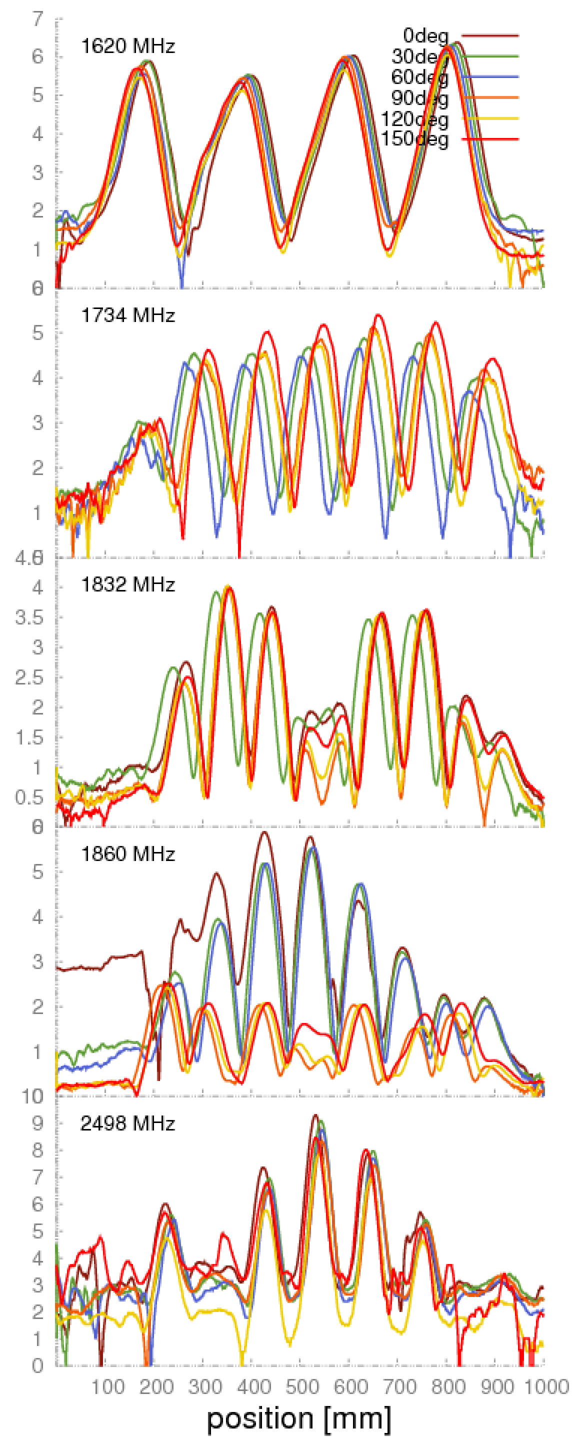

Figure 4: Field profile measurements on different HOMs.

those symmetries (i.e. dipole and sextupole modes). The differences between measurement and simulation are the result of a detuned cavity. Flatness and frequency of the operational π mode were not tuned like they would have been in a production cavity.

Some of those modes were selected for bead pulling.

ISBN 978-3-95450-143-4

The step size in azimuthal angle is set to 30 degree between two measurements, which should be sufficient resolution to differentiate between a monopole or dipole behaviour. The bead is displaced 1 cm off the beam axis. In figure 4 field profiles for five different HOMs are shown at different angular positions of the bead. The modes at 1620, 1832 and 1860 MHz show no clear variation in peak amplitude of the electric field over the 150 deg covered in the measurements despite having a good correlation between measured and simulated frequencies. Due to these results modifications to the bead pulling stand have been made. The hypothesis for the changes that the string forces the dipole mode into a specific polarization and that this polarization follows the string whenever it changes its position. Based on this concern additional strings have been added to eliminate the changes in polarization due to the change in string position. The new system has in total 13 strings: one at the beam axis for alignment and twelve strings along a circle around the center with r = 1 cm in 30 degree steps. In this way whenever the holder is rotated there will be always a string in every position, eliminating the effect of the singular string and allowing the cavity to set the polarization.

Measurements with this new system on a mode at 2498 MHz show significant different results as can be seen in figure 5. The peak around 500 mm follows roughly a $\sin^2$ function for the multi line setup while it is flat with the single line system. The field distribution is identical with the same peaks in the same positions. This confirms that it is the same mode and the single line polarizes the excited mode which makes a multipole mode identification difficult. The multi line setup eliminates this and provides an increased variation in peak field amplitude.

OUTLOOK

In this paper the capabilities to identify dipole modes via bead pulling has been shown on a 7 cell copper prototype cavity modelled after the ARIEL 9 cell production cavity. Using a multi line bead pulling system compared to a single line system helps identifying multipole modes. Identifying dipole modes and estimating their shunt impedance is important for the ARIEL ERL option and will be done with the ARIEL cavities. In addition to bead pulling results, beam based measurements using the ICM are planned for as soon as the cryomodule is finished.

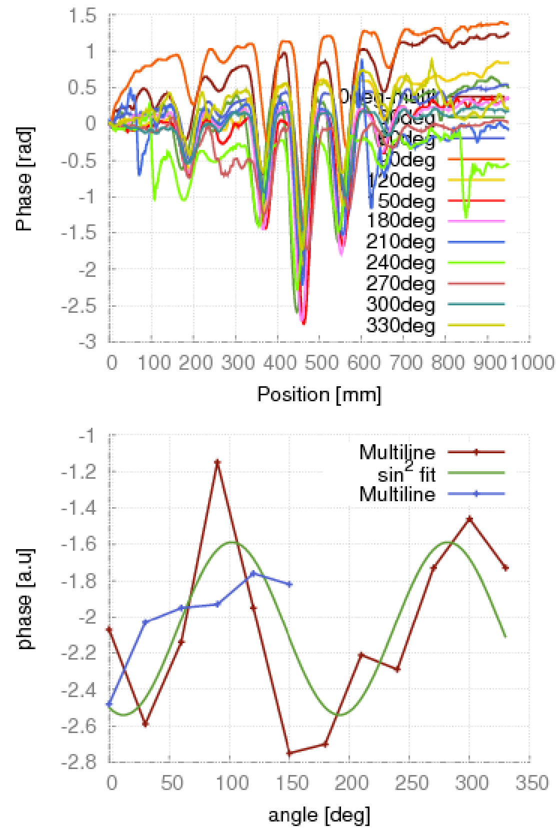

Figure 5: Field profile of the 2498 MHz HOM. The peak amplitude around 500 mm has been plotted to identify the dipole characteristic of the mode

REFERENCES

[1] S. Koscielniak, An Electron LINAC Photo-Fission Driver for the Rare Isotope Program at TRIUMF, Proceedings of SRF09, 2009.

[2] G. Hoffstaetter, I. Bazarov, Beam-Breakup Instability Theory for Energy Recovery LINACs, PR ST-AB 7, 054401, 2004.

[3] H. Padamsee, et al., RF Superconductivity for Accelerators, John Wiley & Sons,Inc, 1998.

[4] P. Kolb, et al., HOM Cavity Design for the TRIUMF eLINAC, Proceedings of SRF11, 2011.

[5] K. Ko, Advances In Parallel Electromagnetic Codes for Accelerator Science and Development, Proceedings of LINAC10, 2010.

[6] V. Zyvagintsev, et al., Nine-cell Elliptical Cavity Development at TRIUMF, Proceedings of SRF11, 2011.

[7] P. Kolb, et al., Nucl. Inst. & Meth. A (2013), http://dx.doi.org/10.1016/j.nima.2013.05.031 .