RESONATOR SYSTEM FOR THE BCSI TEST STAND CYCLOTRON

G. Gold, LAC Piazza, V. Sabaiduc, J. Zhu, BCSI, Vancouver, V6P 6T3, Canada
J. Panama, Best Theratronics Ltd., Ottawa, ON, K2K 0E4, Canada

Abstract

Best Cyclotron Systems Inc. (BCSI) is presently developing a test facility for beam injection into a center region cyclotron operating at maximum 1MeV [1]. The test stand cyclotron will operate at various fixed frequencies that will cover the entire range from 49MHz to 80MHz as estimated for the current cyclotron models under development at BCSI. The resonator was designed with a variable coaxial section allowing for the frequency to be continuously adjusted as required for the particular model in study. Having interchangeable dee tip geometries presented various thermal management challenges which have been addressed. Three operational frequencies, 49MHz, 56MHz and 73MHz have been simulated with CST Microwave Studio. The paper is reporting the theoretical parameters of the cavity, resonator mechanical design considerations and radiofrequency system integration with the amplifier and LLRF control.

INTRODUCTION

The resonator system has been designed and optimised driven by the following requirements:

- Simplicity and modularity of the system (mechanically simple to easily switch between the three operational frequencies).
- Lower power dissipation (to reduce costs of amplifiers).
- Optimization of the quality factor of the cavity.

The entire resonator structure is operational for all frequencies with the exception of the dee tips and center region that are replaced for each particular case. The resonator structure operates on the 4^{th} harmonic and half-wave design for all frequencies. A general view of the resonator system is represented in Fig. 1.

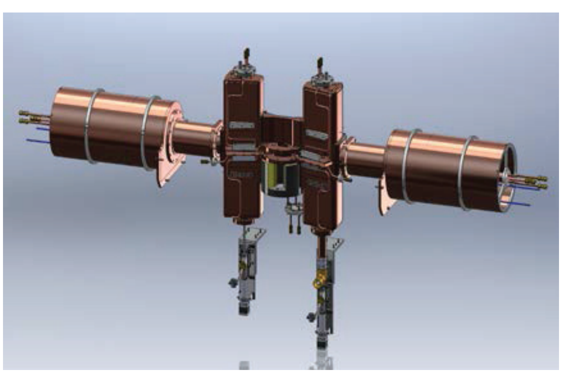

Figure 1: Test stand resonator system

The resonators are connected together at the dee tip and driven by a single amplifier. The accelerating field amplitude and phase stability is controlled by the standard LLRF control circuit designed for BEST cyclotrons [2].

MULTI-FREQUENCY SIMULATIONS

The simulations were performed in CST Microwave Studio environment using the Eigenmode solver. No symmetry planes were used. To speed up and simplify the simulations, just one cavity was simulated per case.

All solid materials were treated as Perfect Electromagnetic Conductor (PEC) via the electric boundaries condition to find the resonant frequency, EM fields and radial voltage distributions of the simulated structures.

Power dissipation, quality factor and numerical evaluation of the EM fields were estimated considering the structure made of copper. The copper surface conductivity value was reduced to $5.0 \cdot 10^7$ S/m to include the roughness imperfection of the copper surface.

The simulated output results were normalized to the voltage distribution values as per the input requirements listed in Table 1. The radial voltage distribution was evaluated increasing the radius with a step of 30mm and the R(1MeV) indicates the radius at which the beam reaches an energy slightly below 1MeV.

Table 1: Input Requirements

	14MeV	70MeV	60MeV
Frequency	72.8MHz	56.2MHz	49.2MHz
Dee voltage	40kV	60kV	70kV
Dee angle	32 deg	30 deg	28 deg
R(1MeV)	11.9 cm	15.6 cm	26.8 cm

Design Parameters

The complete set of design parameters for the variable frequency resonator has been compiled with the particular design characteristics of each of the three frequency resonators resulting in a coherent unique design with very similar quality factors that are listed in Table 2.

Table 2: RF Cavity Simulated Performance

	14MeV	70MeV	60MeV
Frequency	72.6MHz	55.9MHz	48.8MHz
Quality factor	6225	6156	6131
Power/cavity	1.67kW	3.76kW	4.97kW
Max Surface currents	44 A/cm	66 A/cm	75 A/cm
Max Electric field	3.3MV/m	12.3MV/m	8.3MV/m
Cavity length	810mm	950mm	1050mm

Copyright © 2013 CC-BY-3.0 and by the respective authors

The frequency variation has been achieved by extending the resonator with a coaxial section with a movable short end as shown in Fig. 2. This end section operates in air as it is separated from the vacuum cavity by a custom designed ceramic insulator. The insulator ensures the dee/stem assembly mechanical support and vacuum insulation.

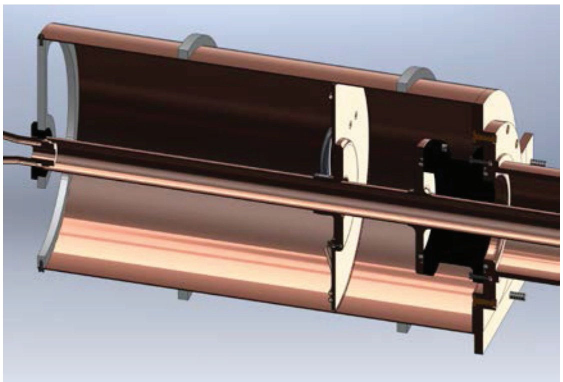

Figure 2: Variable coaxial section.

The sliding short position versus resonant frequency has been studied and a characteristic compiled in Fig. 3.

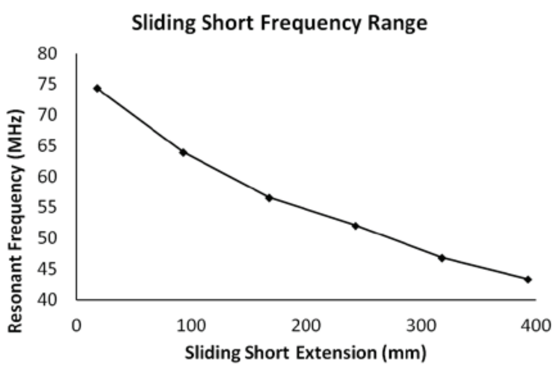

Figure 3: Frequency versus sliding short extension.

To exemplify the electromagnetic model simulation results we represent the 60MeV case only since this mode has the highest power dissipated requirements hence the highest current distribution. Figure 4 shows the EM field distribution and Fig. 5 shows the surface current distribution.

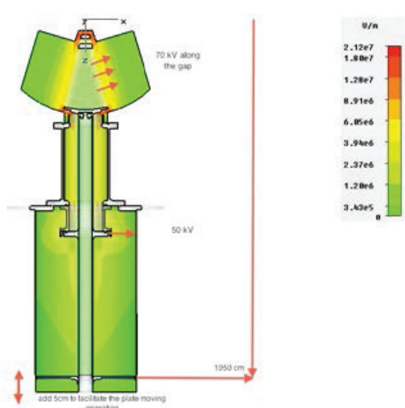

Figure 4: EM Field distribution 60MeV.

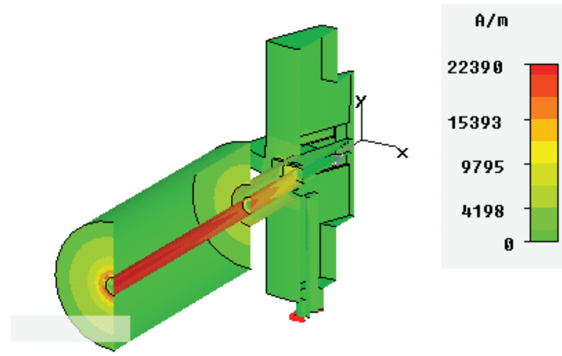

Figure 5: Surface current distribution 60MeV.

Mechanical and Thermal Simulations

Due to the complexity of the mechanical assembly and relatively high dissipated power for the 60MeV operation mode we ran mechanical and thermal simulations with ANSYS to ensure that resonators will operate safely. A similar analysis method was used as described in [3]. Dee plates cooling made the object of a separate study since the plates are exchanged with the frequency therefore cooling has to be ensured without water in the plates. The dee plates are cooled through copper conductivity only to the base and the addition of a specific cooling device called heat pipes (Isobar®) as seen in Fig. 6.

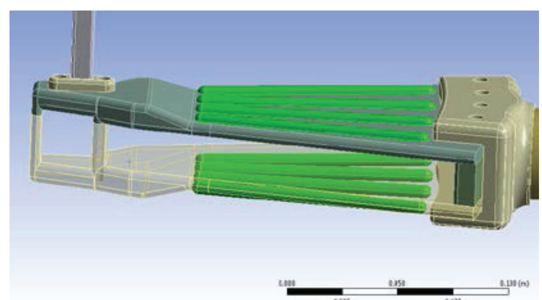

Figure 6: Dee plates with heat pipes (green).

Figure 7 shows the results for the thermal simulation when using four isobars on each dee plate (upper and lower).

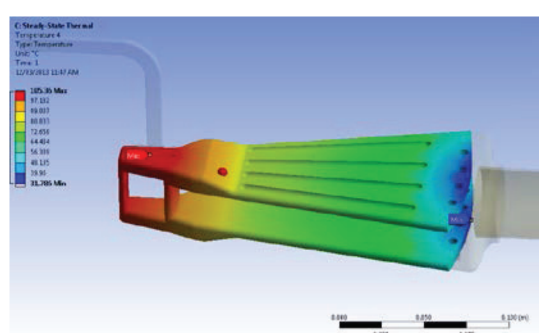

Figure 7: Dee temperature profile for hottest case, min 32°C and max 105°C.

ISBN 978-3-95450-128-1

Copyright © 2013 CC-BY-3.0 and by the respective authors

As noticed the water cooling is ensured only at the base of the stem and through copper conductivity to the dee plate. This method of cooling resonators is novel and will require some testing and adjustment during commissioning to ensure safe operation.

Resonator Assembly in Magnet

The resonator system is assembled in the magnet in the horizontal direction with the main assembly permanently fixed on the front side of the magnet as seen in Fig.8.

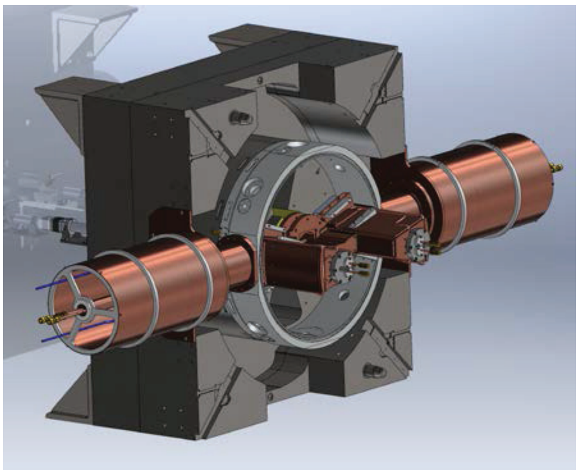

Figure 8: Resonators installed in magnet.

The magnet poles and center plug changes for each particular configuration. Correspondingly the resonator dee plates and center region are changing for the same configuration. The coupler and tuner are placed on the magnet movable side and opens with the magnet.

Coupling and Tuning Mechanisms

Due to the multiple frequency use of the test stand resonator system both the capacitive coupling and tuner mechanisms had to be designed with extended matching and tuning ranges. The mechanical movement allows for an adjustment of 50mm through the use of bellows for vacuum separation. Both coupler and tuner have been designed with replaceable tips to further allow for coarse adjustment of the matching and tuning range. Figure 9 and Fig. 10 show the coupling and tuning assemblies. Both mechanisms are driven with high precision stepper motors.

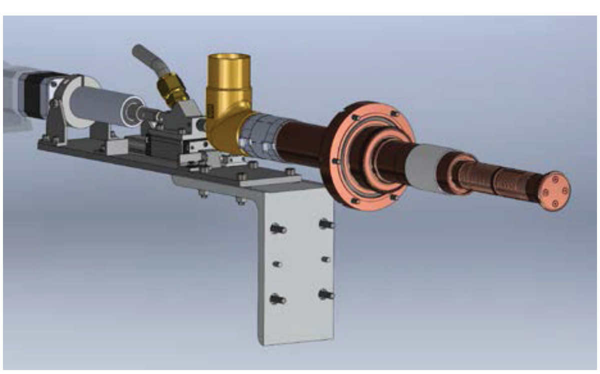

Figure 9: Coupling mechanism.

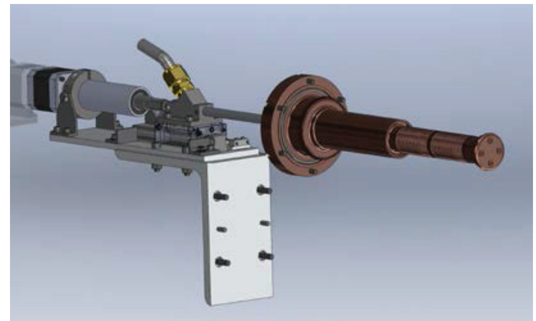

Figure 10: Tuning mechanism.

AMPLIFIER

The test stand amplifier is a modified model of the BEST 20kW standard amplifier equipping the 14MeV cyclotron. The amplifier is based on the Eimac 3CW20000A7 tube and strip line cavity design. The final stage cavity strip line has been modified for each frequency and the driver stage has been replaced with a 500W wideband solid state amplifier reducing the amplifier tuning to a single component change, the strip line. The amplifier is retuned each time when the frequency mode is changed.

While the amplifier is delivering 20kW of power at the nominal operation frequency of 73MHz, through retuning the efficiency is reduced and the maximum power tuned at 49MHz and 56MHz is 16kW. Circulators have been installed for each frequency to minimise the tuning changes and protect the solid state driver for high reflected power in case of a cavity spark. This is an additional protection to the internal VSWR protection and spark protection in the LLRF control.

INTEGRATION

The resonator, transmission line, amplifier and LLRF control are integrated to ensure the correct operation at any of the design frequencies through internal changes and tunings in each individual component. The LLRF control is specifically designed to operate at any of the three frequencies and will only need to update the variable parameters in each case. The RF system is a complex design that will require approximate three to four days to change between frequency modes in addition to magnet configuration changes.

REFERENCES

[1] F. Labrecque et al., “Configurable 1 MeV Test Stand Cyclotron for High Intensity Injection System Development”, Cyclotrons 2013, Vancouver, Canada, MOPPT016, these proceedings

[2] G. Gold, V. Sabaiduc, “Design of a Digital Low-level RF System for BEST Medical Cyclotrons”, Cyclotrons 2013, Vancouver, Canada, TUPPT024, these proceedings.

[3] G. Gold et al., “Simulation and Design of a 70MeV Cyclotron RF System,” IPAC 2012, New Orleans, USA, THPPC001, p. 3269.

Copyright © 2013 CC-BY-3.0 and by the respective authors