Design of the new IBA S2C2 RF System

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INTRODUCTION

IBA is currently developing a compact superconducting synchrocyclotron (S2C2) that will be the engine of a new, low cost, Proton therapy treatment system called Proteus One.
Like for all synchrocyclotrons, the RF frequency must vary during acceleration: in our design the frequency must span from 60 MHz to 90 MHz. This is realized thanks to an innovative and patented rotating capacitor (Rotco) design. The RF power is supplied by a triode-based oscillator capacitively coupled to the resonator.
The RF resonator as well as the oscillator have been optimized thanks to a simplified model in Excel and then refined with the help of CST Microwave Studio® 2011-SP6 running on a computer equipped with 16 GB RAM.

Specifications and constraints

Specifications and constraints are numerous…

❑Specifications
❑Repetition rate: 1kHz
❑Fmin: 61.5MHz
❑Fmax: 87→ 90 MHz
❑F capture: 87.5 MHz
❑F extraction: 63.5 MHz
❑Vdee capture: 10.5kV
❑Vdee ejection: up to 12,5kV
❑df/dt capture: 60-70 MHz/ms
❑df/dt ejection: 20-30 MHz/ms
❑Vdee modulation: 3kV→ 14kV
❑Vdee modulation swiftness: 15µs

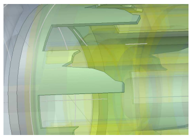
❑Constraints
❑Power oscillator place at r>1450mm
❑Rotco at r>1550mm
❑V peak Rotco < 20kV
❑P Rotco < 300 W (<120°C)
❑PRF peak< 10kW
❑Avoid cross mode excitation
❑DC insulation of Dee structure
❑Mechanical stability, cooling, mountability,…

Working principles

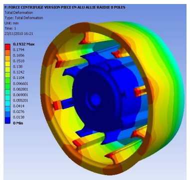
The synchrocyclotron RF system accelerates the particles on the first harmonic mode. It gives a RF frequency in the centre of 87.5 MHz and 63.3 MHz at the ejection radius. The principle of the RF resonator is based on a half-wave transmission line with:

- A nearly 180° Dee electrode attached at one end. The Dee and its resonator are DC biased in order to avoid multipactoring issues.
- The variable capacitor connected at the other end. As some parts of the Rotco rotate at high speed, it is located outside of the cyclotron and is further shielded from magnetic fields: this is required to avoid eddy currents heating.

➢**The Rotco:**
The Rotco is of coaxial type that optimizes the RF currents flow and consequently reduces the RF dissipation. The size of the Rotco has been chosen as a trade-off between excessive centrifugal forces and RF current densities. Due to its small average power dissipation the rotor can be mainly cooled by radiation.



The stator blades are shaped in order to get a df/dt law that keeps the bucked size constant for a given Dee voltage.



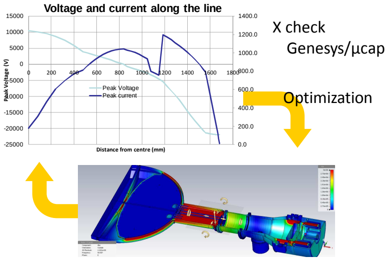
Rotating at 7500 rpm, the calculated deformation under centrifugal forces and thermal expansion is not negligible.

➢ **RF excitation**

The RF power is provided by a triode based oscillator capacitively coupled to the Dee resonator. A careful choice of the capacitance value together with a defined anode inductor allows a constant tube loading impedance versus frequency.
The tube, generously dimensioned to improve lift-time and maintenance issues, is operated in grounded grid. Its cathode is then fed-back by a signal provided by a pick-up loop emerging in the main resonator. This way, we obtain a more or less constant phase and amplitude across the complete frequency band.
The oscillator power is controlled thanks to a variable voltage anode power supply. The response time is in the order of 10µs. The stability of the oscillator is ensured by a mix of cathode and grid self-biasing. The cathode resistor helps avoiding excessive anode current if the oscillator doesn't start or in case of sparking.

Design optimization

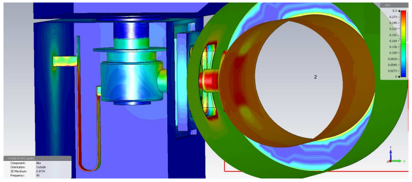
The optimization of such a resonator is not a trivial task due to the large number of constraints and the variable frequency. In order to help the convergence, a simplified model of the resonator based on transmission lines in series has been made in Excel. The results have been cross-checked with µCap and Genesys. The values of Z0 and l for transitions or complicated parts like the Dee have been calulated from currents and voltages taken from CST. The result is a transmission line having a variable and well defined impedance across its length.



X check
Genesys/µcap

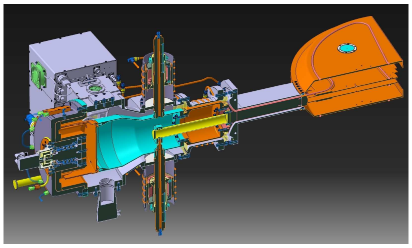
Optimization

When the dimensions were satisfying with respect to the requirements, a full 3D model (with no symmetries applied) has been run in CST. The model took all details of the Rotco as well has the oscillator into account. Fine tuning of the coupling circuits has been also done in CST®. A bit more than 200,000 tetrahedrons where enough to obtain a good precision.



Mechanical design

Extensive simulations have been realized in order to guarantee a good mechanical stability of the structure. The Rotco has been calculated with ANSYS in order to evaluate the deformation under centrifugal forces and to predict the temperature of the rotor. Mechanical resonance modes have also been studied.



The complete resonator is made in OFHC copper. Some parts are E-beam welded. The central conductor is supported by two alumina rings at a place where electric field is low.
Two vertical stubs have been added for fine tuning the maximum frequency of the sweeping range. Their movable shorts are equipped with a thin copper-plated Kapton® sheet allowing the DC bias of the whole structure.
The rotor of the rotco is supported on three pre-loaded ceramic ball bearings.

PRESENT STATUS

At this stage, all mechanical parts have been realized. The oscillator is fully assembled. A special gig has been realized in order to test the complete resonator outside the cyclotron. It will allow to test the Rotco, check the frequency span as well as the oscillator coupling. The hot tests are scheduled for this summer.

CONCLUSIONS

Intended for a compact proton therapy system, the RF has been designed to target a certain cost and simplicity. The choice to drive the system by a self oscillator contributes in large amount to this cost optimization. All the system has been designed and fine-tuned thanks to the last generation of computer codes. It should reduce the cut-and-try approach and shorten the debugging period.

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