DESIGN OF THE Cyclone® 70 P

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Abstract

The IBA Cyclone® 70 P is a high intensity 70 MeV proton-only cyclotron dedicated to the production of radioisotopes for PET generators and SPECT. The nominal power of the extracted beam goes above 50kW (750μA@70MeV). The proton-only cyclotron was developed based on the previous experience of the multi-particle Cyclone® 70 XP running in Nantes, France.

Numerical tools have been extensively used to optimize the magnetic field, to avoid potentially harmful resonances during acceleration and improve the acceleration efficiency of the cyclotron. In addition, electromagnetic and mechanical calculations permitted to obtain a low dissipated power and electromechanically robust design of the RF system. The vacuum computations have permitted to optimize the beam transmission, the placement and type of cryopumps.

This new development of Cyclone® 70 P was the initial part of the successfully finished IBA project also presented during this conference [1].

MAGNET DESIGN

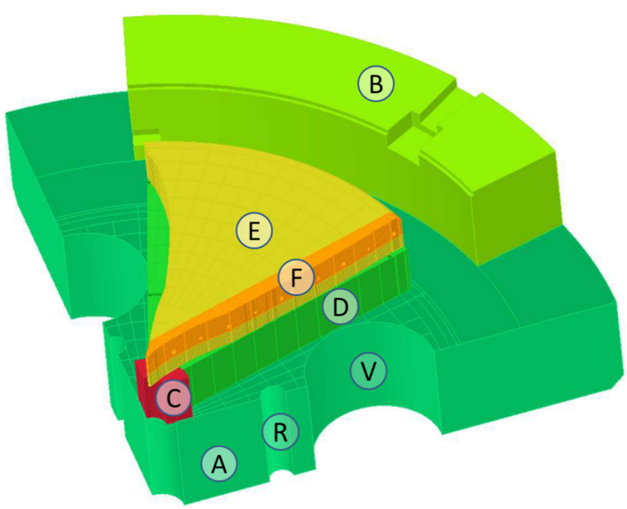

Figure 1: Cyclone® 70 P – lower (or upper) one period of the four-fold rotational symmetry.

The Cyclone® 70 P magnet, Figure 1, consists of: top (bottom) return yoke (A) having diameter of 3820 mm. The lateral return yoke (B) closes the magnet of 1700 mm high. The central plug (C) and the sector (D) create the base for the pole (E) with the outer radius of 1240 mm.

The removable pole edge (F) attached to the, stair-like, lateral pole edge is iteratively milled during mapping process to obtain the isochronous magnetic field for accelerated H^- ions.

The total iron weight is about 108 tons and the resistive coils add next 4 tons.

The cyclotron vacuum chamber and the coil fill the space between the outer radii of the pole and sector and the inner radius of the lateral return yoke.

The vertical gap between poles and between removable pole edges is constant 40 mm and more than 40k Ampere-turns are necessary to reach the required field level in the median plane.

Two ports are located in each valley. The vacuum pumping port (V) diameter is large (520 mm). The dee stem, the dee cooling tubes pass through the small diameter (100 mm) port (R).

The shape of the second lateral pole edge is fixed and its small spiralization helps to obtain higher vertical tune ν_z and to avoid dangerous resonances.

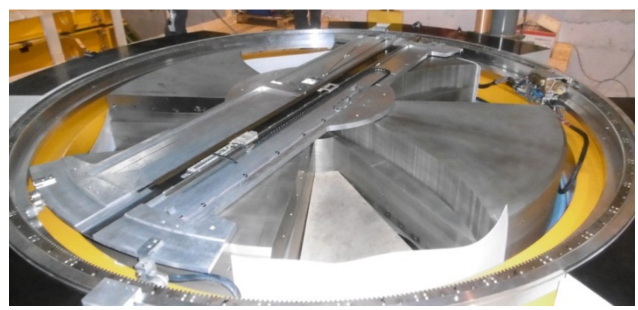

Figure 2: The lower half of the Cyclone® 70 P and the mapping system.

The new mapping system, Figure 2, measuring the magnetic field axial component in the cyclotron median plane on any chosen radial and azimuthal grid was also developed in this project.

The mapping system is supported by the cyclotron lateral return yoke and allows magnetic field measurements practically to the radius where magnetic field values are close to zero between resistive coils.

The magnetic field of the cyclotron model was used to determine the central region geometry. The measured field was used for the crosscheck and the optimization of the spiral inflector of the axial injection system.

The same fields have been used to find positions of the strippers to extract 30-70 MeV protons and to determine the position of the port in the lateral return yoke where the extraction system shaft passes and pivots.

Magnetic field values for radii beyond the outer coil radius, necessary for extraction calculations, have been taken from the calculated models.

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ISBN 978-3-95450-167-0

VACUUM SYSTEM DESIGN

Models for vacuum computation, residual gas stripping and magnetic stripping have been developed, based on accurate orbit length using the closed orbit analysis, the dee voltage and different vacuum levels on poles, RF valleys and non-RF valleys.

The residual gas stripping model, including the outgassing effect of various pole surface finishing, has been used to optimize the number of pumps, their positions, their pumping speed and the pole finish material.

Various resonator configurations have been studied for a single-stem design and an optimal solution was selected with excellent electromagnetic properties, electrical and mechanical stability and minimized mechanical construction and operation costs.

The final configuration of the system is based on the 100 kW tetrode amplifier with a direct capacitive coupling to the cavity.

The RF system frequency is 60.83 MHz ±1 MHz.

The nominal dee voltage in the cyclotron center is 50 kV. The dee voltage increases about 40% at large radii to produce larger turn separation. Larger turn separation reduces energy spread, facilitates beam extraction and beam transport downstream.

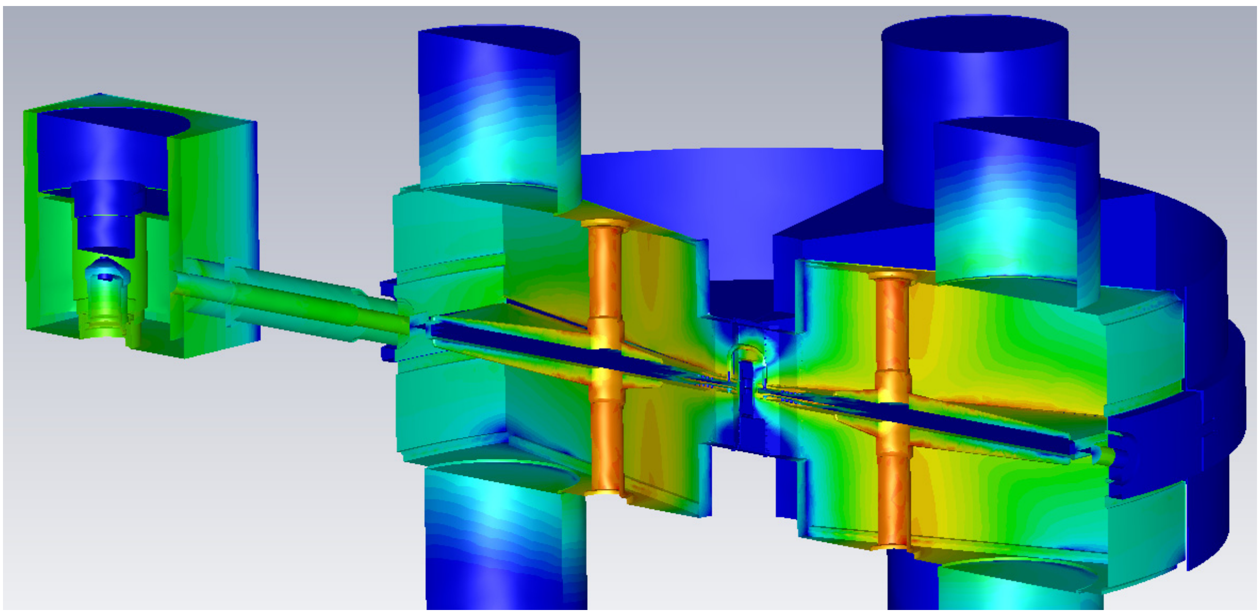

Figure 3: Cyclone® 70 P – the distribution of RF currents in the cavity and final amplifier.

The results of calculations of the magnetic stripping were used to confirm the choice of cyclotron magnetic field.

The models of the residual gas and magnetic stripping losses are dependent on experimental data. The calculated combined effects have been firstly crosschecked with measurements in cyclotrons already produced by IBA. A good agreement between calculation results and experimentally measured data added confidence to apply the same method in the new Cyclone®70p. The results indicated the benefit of the nickel plating of the poles, defined the minimum requirements concerning the vacuum pumps and showed that the total beam losses will not exceed 3% in total.

RF SYSTEM DESIGN

The electromagnetic and the mechanical design of the resonant cavity for the Cyclone® 70 P has been done using CST Microwave Studio to define the shape of the cavity geometry and deduce the accelerating voltage profile, surface current distribution, Figure 3, and total power loss.

Water-cooled dees are connected in the cyclotron center to simplify the configuration using one amplifier, one cavity tuning, one single LLRF control system, one 5 kW solid state driver. The connection of the dees in the center is shielded to avoid the penetration of the RF electric field between electrodes of the spiral inflector.

To be cost-effective, the RF design reused the maximum high-reliability IBA standard components to ensure long life and spare parts service.

The RF system has been assembled. The resonance frequency was adjusted to specifications by machining the dee pillars and then the all system was tested to nominal voltage and power.

The RF system frequency given by CST results is very close to the reality. The dee voltage was measured using a collimated X-ray detector at various positions along the acceleration gap. The quality factor was 20% better than expected and about 32 kW were needed to drive the cavity to a nominal dee voltage of 50 kV.

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CONCLUSIONS

Cyclone® 70 P cyclotron was designed in a short time thanks to extended IBA know-how and experience. Then the cyclotron was produced rapidly. IBA factory acceptance tests and acceptance tests during commissioning at the customer site confirmed that all cyclotron subsystems works as requested. Today (Sept 2016) the cyclotron and the rest of the system is already used by the customer [1].

REFERENCES

[1] B. Nactergal *et al.*, "Installation and Commissioning of the Cyclone® 70 P", presented at Cyclotron'16, Zurich, Switzerland, paper TUP05, this conference.

ISBN 978-3-95450-167-0