Cold Tests and Magnetic Characterization of a Superconducting Magnet for a Compact Cyclotron for Radioisotope Production

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Abstract

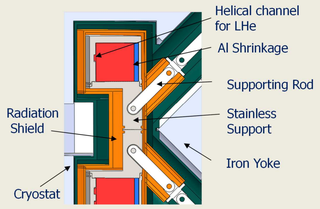
A superconducting magnet able to provide the required field of 4 T has been developed for a compact cyclotron to produce radioisotopes for medical imaging, in the framework of AMIT project. It consists of two coils in Helmholtz configuration, embedded in a stainless steel casing to hold the Lorentz forces. The cooling scheme is based on a low pressure forced internal flow of two-phase liquid-vapour helium through a narrow channel machined in that casing.

This paper reports on the cooling tests and the preliminary magnetic measurements of the magnet. Regarding cooling tests, liquid Helium from a Dewar has been used first to train the magnet and to estimate the thermal losses. Later, refrigeration will be accomplished from a stand-alone cryogenic supply system that would allow a user-friendly operation of the cyclotron, without external supply of cryogens.

Regarding magnetic measurements, a custom magnetic measurement bench, developed in collaboration with ALBA/CELLS, has been used to map the magnetic field and first results are presented and discussed in the paper.

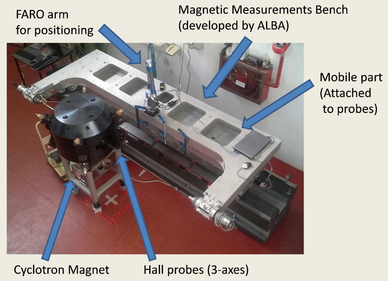
The cyclotron is based on a NbTi superconducting magnet producing a nominal field of 4T. It is cooled down with two-phase helium circulating in a closed circuit, which is recondensed externally later by means of a single cryocooler installed in Cryogenic Supply System (CSS) developed as a collaboration with CERN.

Main components of the accelerator have already been finished and are now under testing and commissioning.



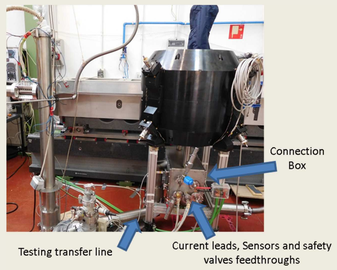
The most challenging specification to meet is the low thermal losses allowed for the magnet, so its design was aimed at optimizing this requirement.

Testing Assembly

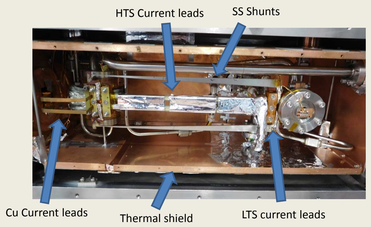


General overview of the cyclotron magnet ready for the tests:

- Cyclotron magnet and magnetic bench are both attached to the ground.
- Faro Arm and Hall probes are attached to the mobile part of the bench.
- 6 parameters alignment procedure (position and orientation) is needed to relate magnetic measurements of the probes to the magnet coordinate system.

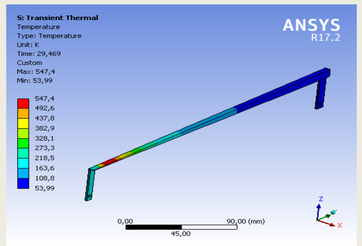


Cryogenic cooling and electrical powering of the magnet were done by means of a tailored transfer line and a connection box.



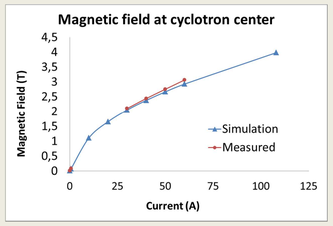
High thermal efficiency connection box was developed:

- HTS current leads anchored to refrigeration cryogens at two different temperatures.
- NbTi current leads for 4K feedthrough into the casing.
- Safety valves for overpressure protection in case of quench.



- Shunt resistors are mounted in parallel to the HTS current leads to overtake the magnet current during the discharge of the magnet in case current leads quench.
- Steady-state and dynamic response were studied for their design, including both thermal and electrical behavior.

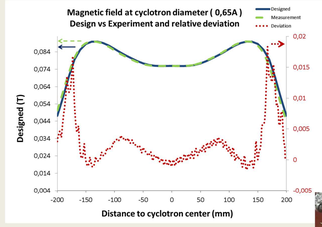
Magnetic Field tests



Magnetic field at cyclotron center was measured for different current values. Measured absolute values are not exactly the same as expected from simulation (less than 5% deviation):

- Iron properties were not measured after machining, and no data on them are available beyond 2T.
- Hall probes were calibrated up to 2T and linearity has been assumed for higher fields according to supplier information.

Absolute magnetic field value is not critical as it can be tuned by trimming coils current. Homogeneity and field shape are the relevant specification to fulfill.

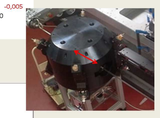


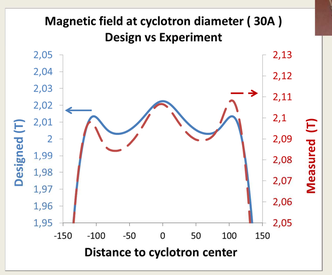
Magnetic field at cyclotron mean plane was measured and compared to the designed field at low current.

Measured magnetic field along a cyclotron diameter shows less than 0,5% deviation for distances up to 150 mm to the center.

Beam Target is designed to be at 110 mm.

Maximum deviation occurs at 170 mm from the center.



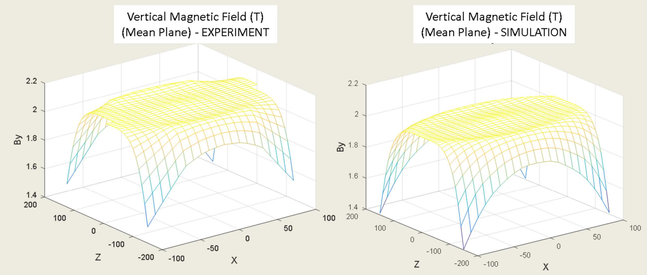


Magnetic field at cyclotron mean plane was measured and compared to the designed field at medium current (30A).

Measured magnetic field along a cyclotron diameter shows less than 0,5% deviation for distances up to 150 mm to the center.

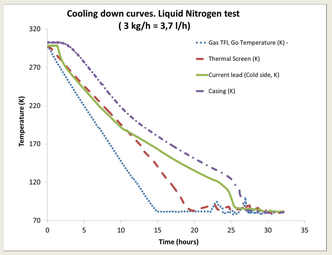
Beam Target is designed to be placed at 110 mm.

Maximum deviation occurs at 170 mm from the center.



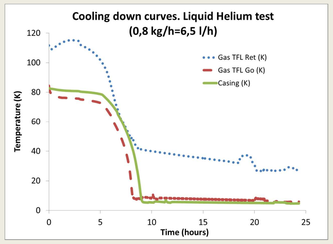
Overview of the complete 2D magnetic measurements for cyclotron mean plane at 30A.
Comparison between experimental data and simulated values shows great coincidence of the magnetic field shape.

Thermal Tests



Cooling down curves during Liquid Nitrogen test:

- Good agreement between expected time and flow needed. 3 kg/h results in 27 hours needed. About 29 h expected.
- After 15 h, first circuit is full of two phase Nitrogen.
- Thermal screen reaches liquid temperature before casing:
- High thermal inertia of coils compared to the cooling capability of the forced flow inside the casing is the limitation for improving cool down rate.



Cooling down curves during Liquid Helium test:

- Expected time needed for a 0,8 kg/h flow was around 11h, while casing reached liquid temperature in just 10h.
- Steady thermal state conditions are achieved just after more than 20 hours, as confirmed by the temperature evolution of helium outlet, which is lower than the nominal temperature at real cyclotron conditions.
- Given this test, a value for the total losses of the cyclotron at both circuits (Enthalpy absorbed by the Helium) can be evaluated as 31 W. It can be compared to the nominal design value of 34 W.
- Conditions for real temperature distribution inside the magnet and heat generation at the current leads differ from this test to nominal operation.

Conclusions

This poster shows results concerning thermal and magnetic design and testing of the AMIT cyclotron.

Measured magnetic field and its shape are shown.

During cool down, temperature curves are included for both cryogens used: liquid Nitrogen and liquid Helium.

The magnet was driven to superconducting state reaching up to 3T. Further measurements up to nominal field will require new adjustments to deal with magnetic forces and mechanical alignments.

Real cooling down time using a Dewar fits quite well expected cooling down time. The cooling down time using the CSS will be very long because of the limited cooling power. Then, further works will include the modifications on the CSS system in order to optimize the cooling down time.