SUPERCONDUCTING FOCUSSING CHANNEL FOR THE AGOR CYCLOTRON

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ABSTRACT

The AGOR cyclotron will be equipped with a focussing channel consisting of two superconducting coil systems, placed inside a shielding tube. The channel will focus the beam during its passage through the magnet yoke. Magnetic, cryogenic and mechanical aspects of the design are discussed.

1. INTRODUCTION

Extraction of the beam from the AGOR cyclotron is performed by three channels: an electrostatic deflector (ESD), a room-temperature electromagnetic channel (EMC-1) and a electromagnetic channel with superconducting coils (EMC-2). The lay-out of these channels is shown schematically in fig.1.

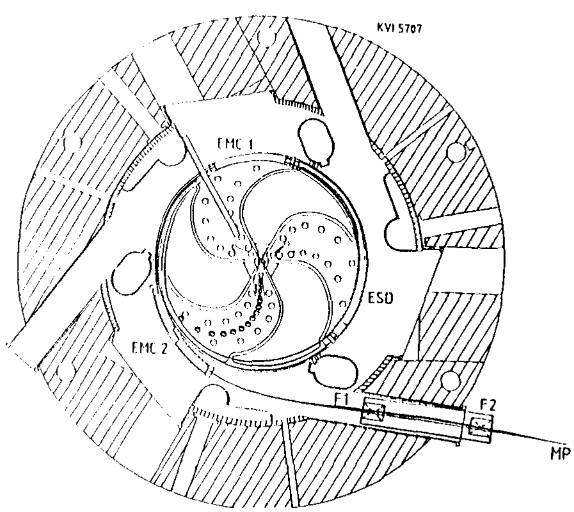

Fig.1. Median plane section of AGOR, showing the elements of the extraction system.

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After the exit of EMC-2, the beam enters a passage through the magnet yoke through which it passes to the outside of the machine. In order to provide focussing for the beam on its 3.4 m long trajectory between the exit of EMC-2 and the beginning of an external beam guiding system, a set of two quadrupoles is foreseen inside the yoke passage. Various aspects of the design have been described in AGOR internal reports, one of which[1)] presents a summary with references to the other reports.

2. FOCUSSING AND BENDING DURING THE YOKE PASSAGE

2.1. Beam Focussing

The first order optics of the extracted beam along the extraction path bears resemblance to a periodic structure with a FD lattice. The extraction channels EMC-1 and EMC-2 provide horizontal focussing by means of their gradient coils, the fringe field being horizontally defocussing. The first focussing element, located at the entrance of the yoke passage, is horizontally focussing, the second, situated just after the beam has left the magnet yoke, provides vertical focussing. Since the orbits of the different ions are not far apart geometrically, focussing strengths could be chosen to be approximately proportional to beam rigidity with a maximum gradient of 36 T/m at a magnetic length of 0.2 m.

2.2. Beam Bending

The degree of saturation of the magnet yoke varies considerably over the operation range of the magnet. For the lowest excitations, associated with the acceleration of protons, the magnetic field in the yoke passage is nearly zero. However, at the maximum cyclotron field of 4 T the field in the yoke passage is 0.22 T. The trajectories of different beams in this passage therefore have different radii of curvature. In order to allow alignment of the beam onto the axis of the external beamline, the deflection produced by the final extraction channel EMC-2 is adjusted in such a way that all beams, regardless of magnetic rigidity, pass through one common point on this axis. At this location, situated 1 m beyond the magnet yoke and called the 'Meeting Point' (MP), a small bending magnet is foreseen to provide alignment with the axis of the beam line. Inside the yoke passage, the variations in orbit curvature are associated with a spread in the transverse position of the different central orbits at the entrance of the first quadrupole, requiring a corresponding positioning range for this element. Calculations[2)] have indicated the feasibility of reducing the positioning requirement by the introduction of a soft iron shielding tube inside the yoke passage, inside which both quadrupoles are mounted. The calculated remaining field inside the tube is only 7.8 mT, resulting in straight trajectories inside the shielding tube leading to a reduced positioning requirement at the channel entrance of 18 mm. In addition, since all (straight) orbits pass through the MP, positioning is equivalent to a rotation around this point.

3. STEERING

Since the strength of the magnetic field along the trajectories of the extracted beams will not be known with adequate precision until measured field maps are available, the calculated field strengths in the extraction channels necessarily have a certain margin of uncertainty. In addition, the cyclotron's magnetic field may prove to have horizontal field components, due to misalignments or constructional tolerances, leading to vertical deflection of the beam. It is therefore necessary to provide steering in both horizontal and vertical planes before the beam leaves the cyclotron. For this purpose, a horizontally steering dipole coil, capable of a deflection of 5 mrad, is integrated in the first quadrupole. In addition, 2.5 mrad of vertical steering will be provided in each of the quadrupoles by operating the upper and lower coil sets at different currents.

4. DESIGN

4.1. Coil Configuration

Figure 2 shows a cross-section of the shielding tube at the location of the first focussing element.

The beam aperture is 30 × 20 mm. All coils have a racetrack shape. The four windings with a flat cross-section constitute the steering dipole, which can produce a maximum field of 0.1 T. The focussing gradient inside the beam aperture consists of the stray fields produced by the two sets of four windings at both sides of the beam aperture, which simply are dipole coils with fields of opposite signs.

Each winding carries 49000 Ampere×turns at the nominal gradient of 36 T/m, which is constant within 1% over a total width of 20 mm. The difference in current between upper and lower coils for the required 2.5 mrad of vertical steering is 10%.

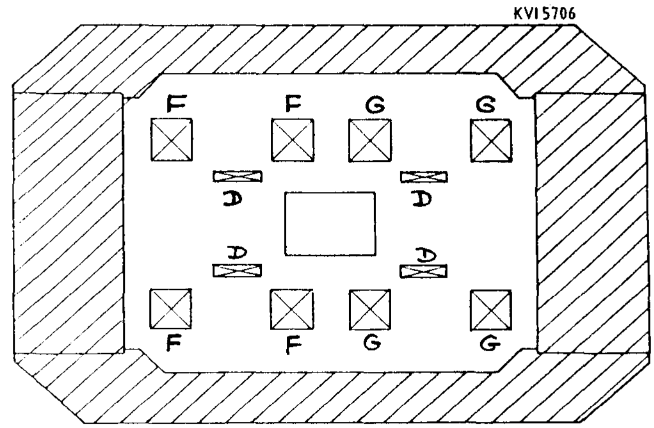

Fig.2. Cross-section of shielding tube and first focussing element. F and G are gradient coils, D is the dipole coil.

4.2. Cryogenic Design

The coils will be fabricated in-house, using the wet-winding technique using wire with a diameter of 0.5 mm, including insulation. The wire itself has 561 NbTi filaments with a diameter of 10.3 μm and a copper to superconductor ratio of 2.4. The need for unequal currents in the upper and lower coils, required for vertical beam steering, implies that three current leads are required for each focussing element, one of the leads being shared between top and bottom coils. Two additional leads are used for the dipole coil in the first element. The cryogenic equipment associated with the channel is housed in a vertical cylinder connected to the beam pipe at the outside of the magnet yoke. It has a reservoir for liquid helium, the level of which will be regulated. The coil mandrels receive their liquid helium from this reservoir, the tube for the return gas being connected to the same volume, which also houses the current leads. A separate tube supplies cold gas from this volume to the thermal shield surrounding the coil mandrels. The return gas from the shield cooling and the gas emanating from the current leads is returned at room temperature to the suction side of the compressors of the helium liqufier. The liquid helium consumption of the channel is estimated at 4 l/h.

4.3. Mechanical Design

The mechanical structure of the channel has been designed to satisfy the positioning requirements, to cope with the magnetic forces and with the weight of the system. As explained in section 2, positioning is reduced to a rotation about the MP. This point, however, is not physically accessible since it is the location of the first steering magnet in the external beam line. Also, the location of the MP is defined with respect to the magnet pole, while the vacuum tube in which the channel is located is part of the main cryostat, whose position with respect to the magnet is not accurately known. As shown in fig.3, these problems were solved by cantilevering the shielding tube containing the lenses from a picture frame support outside the magnet.

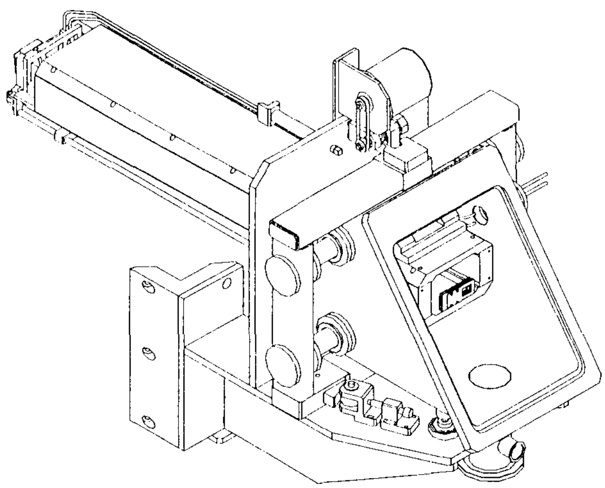

Fig.3. Perspective view of the channel with its support structure. The buffer volume for liquid helium is not shown.

This frame is positioned on a short section of a circular track centered on the MP and supported by the magnet yoke. In this way, positioning is done with respect to the magnet, independently of the walls of the cryostat beam pipe. The shielding tube, located in the machine vacuum, is fixed to the picture frame, which is in air, by means of two horizontal rods passing through the vacuum wall using bellow seals.

5. DIAGNOSTICS

In operation, the beam must pass on the axis of the channel. The beam position with respect to the axis must therefore be measured at the entrance and at the exit of the channel. At the entrance, the channel is aligned on the beam by a rotation around the MP and the steering dipole in the first quadrupole is used to aim the beam at the MP. This dipole may turn out to be redundant, since the deflection produced by EMC-2 can also be used for horizontal steering. In the vertical plane, the vertical steering capability of the first lens is used to position the beam on axis at the location of the second quadrupole. The vertical steering of this element is then used to align the beam to the geometric median plane. The vertical position must therefore be measured at the second quadrupole and at a point further down the beam line.

In summary, the following diagnostic equipment will be integrated in the channel:

At the channel entrance : one harp for horizontal beam position. At the channel exit : one harp for horizontal beam position, one harp for vertical beam position.

The quadrupoles will be protected from incident beam by means of a diaphragm at their entrance. The diaphragm will be equipped with beam current read-out and is be capable of safely accepting the dissipation of 200 W of beam power.

6. REFERENCES

1) H.W.Schreuder, "The Quadrupole Channel"
AGOR technical note NT/EXT/14/02/92.
2) S.Gustafsson, "Proposition de quadrupole supraconducteur blindé."
AGOR technical note NT/AIM/15/10/90 (in French).