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# MODEL MAGNET FOR THE PROPOSED SUPERCONDUCTING CYCLOTRON AT THE UNIVERSITY OF MILAN

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## Introduction.

A project for a superconducting cyclotron, for heavy ions, has been under study for a couple of years at the Cyclotron Laboratory of the University of Milan. The machine is conceived as a booster for a 16 MV Tandem to be installed at the Laboratories of Legnaro (Padua) of the Italian National Institute for Nuclear Physics (INFN). A detailed description of the project has been published elsewhere(1), while major features of the anticipated magnetic field configuration and proposed injection and extraction schemes are the subject of papers presented at this conference.(2,3,4)

The K design value is ~ 540, thus allowing maximun energies between ~ 55 MeV/nucleon and ~ 14 MeV/nucleon for light and heavy ions respectively. Pole diameter is 1.8 m and maximum average field should be around 41 Kgauss, to be obtained by a total of 6.5 x $10^6$ Aturns in the superconducting coils. At present a three spiral sector polar configuration is envisaged, with a 7 cm hill gap and 70 cm valley gap. Three dees, in the valleys, should provide a peak accelerating voltage of 100 kV, allowing a 3rd or 9th harmonic operation.

While funding for the machine is still under discussion, a program centered upon the construction of a superconducting model magnet, and a full scale R.F. model was started in 1976. The purpose of this paper is to report on the design features of the model magnet, whose construction is now completed.

## General Characteristics

The main purpose of the model magnet is to allow a detailed study of the magnetic field generated by a saturated iron configuration, and henceforth to optimize sectors and yoke geometry with respect to cyclotron requirements. The pole diameter is 30 cm,scale factor is 1:6,with superconducting coils providing a maximum of 1 x $10^6$ Amperturns. At present a fourfold open yoke geometry is available, while a closed yoke, of the type proposed in the MSU(5) and Chalk River(6) projects, will be built after the start-up of the model.

A cut-away view of the model in its present form is given in fig.1. Yoke and poles are manufactured out of C10 cast iron, while ARMCO plates are used for polar sectors. The yoke consists of six pieces, i.e. the four legs, having a cross section of 19 x 19 cm$^2$, and the upper and lower plates,19 cm thick, to which the poles are attached. A three spiral sector geometry, scaled down from the one described in (2),will be tested first. Four holes are provided in the poles, one along the vertical axis, and three at about midradius in the valleys, which correspond to those needed for stripping foil or internal ion source insertion, and for the three R.F. coaxial lines. Plug-in iron rods are available in order to fill the holes and therefore check, against the calculations, their effects on the magnetic field properties.

## Coils and Cryostat Features.

As shown in fig. 1, the superconducting coils are contained in a single helium-bath cryostat. This solution turns out to be the only practical one for the model, while for the real cyclotron a hollow superconductor, with supercritical helium cooling, can also be envisaged. Considerable effort has been put in the design of the coils, manufactured by Brown-Boveri Co, in order to keep the overall geometry as close as possible to a scaled one. This requirement calls in turn for rather large values of current density in the coils.

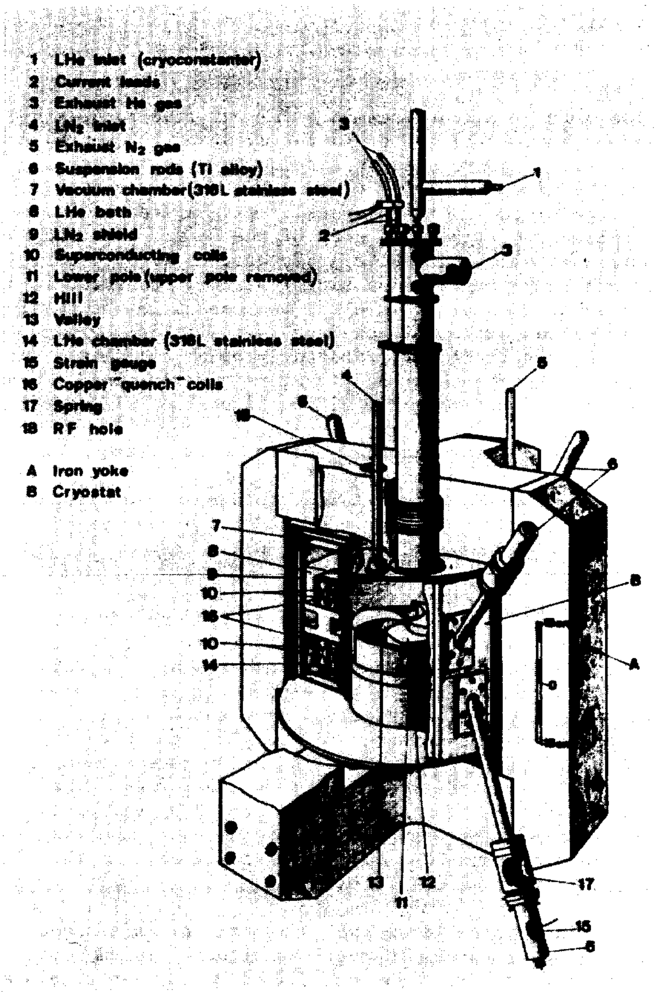

Fig.1. Cutaway view of the 1:6 model magnet.

The main characteristics of the solution adopted are listed in Table 1.

The coils are epoxy-impregnated, and should withstand maximum tensile stresses of the order of 11 Kg/m$^2$. As shown in fig. 1, each coil is actually wound in two radially adjacent parts, which are electrically series connected. A number of axial holes between the two parts allows adequate helium passage.

A power supply, with current stability of better

TABLE 1.
Superconducting Coils Parameters.

Maximum excitation = $1.10^6$ At
Superconducting wire, Nb-Ti ∅ = 0.66 mm
Copper to superconductor ratio = 2.48 : 1
Critical current at 4.5 T, at 4.2°K = 170 A
Operating current at max excit. = 147 A
Turns per coil = 3400
Max current density = 185 A/mm$^2$
Stored energy (max) = 250 k Joules
Inner coil diam. = 364 mm
Outer coil diam. = 466 mm
Coil height = 83 mm

than $1\times10^{-4}$ and programmable current rise rate, is used to excite the coils. In the event of a "quench" a fast switch, developed by Ansaldo Co.-Genua, with an opening time of ~50 msec is activated by a quench detection system. This consists of pick-up copper coils wound concentrically on each of the main coils, and auxiliary electronics. Coil discharge current flows then through a 26 Ohm outside resistor, connected in parallel to the coils. In order to keep as low as possible the temperature reached by the coils following a quench, a pair of low resistance copper coils is wound around both the upper and lower main coils, along a scheme proposed by Brown Boveri Co. Given the large electrical coupling with the main coils, these auxiliary coils, which are series connected and shortcircuited, should dispose of part of the energy released during a quench. The anticipated maximum temperature of the coils, after a quench, should then be confined to an average of 100° K, with a "hot spot" limit of 180°K.

The cryostat structure can also be seen, schematically, in fig. 1. It consists of the inner liquid helium container, and an outer radiation shield, liquid nitrogen cooled, in a vacuum chamber. Only few details can be discussed here. The helium container is made of AISI 316 L stainless steel, with a thick ring, in correspondence of the magnet median plan, to which the coils are fixed, each with 48 titanium rods of 2 mm diameter. This in order to withstand the forces which at low excitation tend to drive the coils away from the median plane. At high excitation, instead, the ring should withstand the compression force between the coils, estimated at 27 tons.

The entire liquid helium container is suspended to the outer vacuum chamber by eight titanium rods, 5 mm in diameter, 4 above and 4 below the median plane, and at 45° with the latter, as shown in fig. 1. A spring system, shown in more detail in fig. 2, takes care of the sizable contraction (~ 2 mm) of the liquid helium structure during cooldown. The rods are then blocked, at cooldown completed, thus allowing a precise axial and radial positioning of the coils.

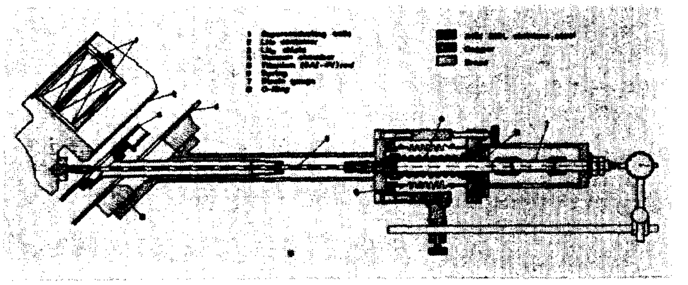

Fig. 2. System for suspending coils to outer vacuum chamber (See text for details).

The cryostat is provided with two, room temperature holes, 180° apart, in correspondence of the median plane and approximately 11 cm (30° deg) wide and 2 cm high, for allowing fringing field measurement in the radial range occupied by the cryostat.

## Cryogenics.

Lack of a helium liquifier calls for operation from dewars reservoirs. Liquid helium and liquid nitrogen consumptions should be respectively around 3ℓ/h and 5ℓ/h. Automatic refilling of the liquid helium bath, keeping the helium level constant within a few mm, is obtained with a Leybold Cryoconstanter, (see fig. 1). The cryoconstanter draws the helium from a 30 liter dewar, which is in turn refilled periodically from a 500 liter dewar. A sketch of the cryogenics is given in fig. 3. In the event of a quench, safety valves and calibrated rupture disks make sure that gas can flow out allowing a maximum overpressure build-up, in the cryostat, of about 1 bar.

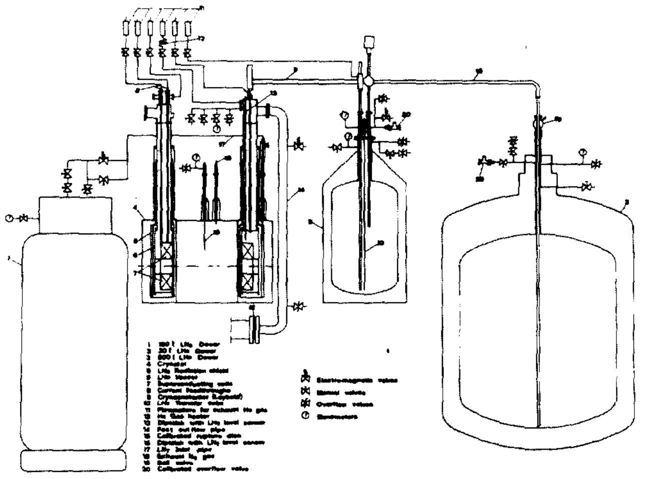

Fig. 3. Sketch of cryogenics equipment for the model cryostat.

For temperature monitoring, four couples of carbon and platinum resistors are mounted on the surfaces of the coils, and two on the inner walls of the liquid helium container. Additional platinum resistors are mounted on the liquid nitrogen radiation shield.

## Field measurements apparatus

Magnetic field measurements will be carried out using Hall plates, type SBV-585-S1 by Siemens, having a sensitive area of about 0.1 mm$^2$. Calibration runs, made at CERN up to 42 Kgauss, show that linearity is quite good, (within 0,1%). With a plate current of 160 mA, Hall voltage is 10 mV/Kgauss, while the thermal coefficient is only 0.005 % /°C.

For measurements inside the cryostat, i.e. up to the pole diameter, a positioning gear, in a polar coordinate frame, has been built. Main design features are shown in fig. 4. In order to cut down on measuring times, three Hall plates can be used simultaneously along a radius, at radial intervals of 5 mm. The bronze plate carrying them is fixed to a beam, 24 mm in

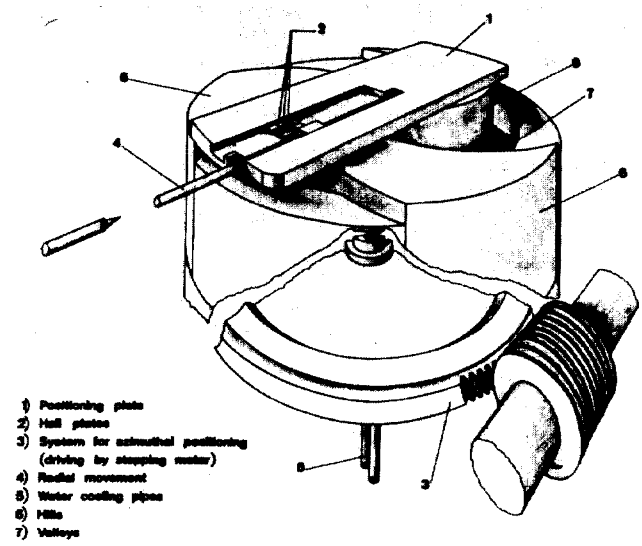

Fig. 4. System for Hall plates positioning in the magnet gap.

diameter, passing through the center hole in the magnet. In this way the Hall plates can be moved azimutally in steps of 2° or 4°, by rotating from the outside the entire gear, through a wheel coupled to a stepping motor. Magnetic field data, together with other relevant information (magnet current, position data etc.) are automatically stored on magnetic tape.

For measurements of the fringing field a manual positioning gear, located externally to the cryostat, is also being built.

## Program status.

Delays in the manufacturing of the cryostat have stretched the original time schedule, which called for start-up of field measurements by the end of January. All components are however now available.

The yoke has been tested with a compression force up to 50 tons, in order to simulate the forces between the poles at high fields, and has shown elastic deformations contained within 0.2 mm. After leak testing of the cryostat, the coils will be mounted at the beginning of March. Power supply, protection devices, control instrumentation and cryogenics equipment are already assembled at our Laboratory. The same holds for the magnetic measurement apparatus.

It is anticipated, barring major inconveniences, that excitation of the magnet and field measuring runs can be started around the end of March.

## References.

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5 - H.G.Blosser et al. - Superconducting cyclotron - Proceedings of the VII International Conference on Cyclotron (Birkhäuser, Basel, 1975) pg. 584.

6 - J.H.Ormrod et al. - The Chalk River superconducting heavy ion cyclotron. - Proceedings of the VII International Conference on Cyclotron (Birkhäuser, Basel, 1975) pg. 595.