PROGRESS REPORT ON THE MILAN SUPERCONDUCTING CYCLOTRON

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Abstract

The construction of the K800 superconducting cyclotron at the University of Milan is underway since February 1981. The delay in the construction of the new building and a defect of the weldings of the helium vessel have caused a shift in the project schedule of about two years. Nowday the cyclotron magnet and the cryogenic plant have been completed and installed. First operation of the magnet and magnetic field mapping are to begin shortly.

Introduction

The cyclotron is a three sectors, three dees machine with a K=800 and Kfoc =200. It has been designed as a booster for the 15 MV Tandem in Catania, and will provide beams with maximum energies ranging from 100 MeV/n for fully stripped light ions, to 20 MeV/n for Uranium. The machine will also be equipped with an external ECR ion source and an axial injection system, both for testing purposes and for the acceleration of light ions. The pole radius of the machine is 90 cm; the hill gap is 8.6 cm and the average spiral constant is 1/45.7 rad/cm. The magnetic field level is between 22 and 48 kgauss. The corrsponding RF range is 15-48 MHz, for 100 kV peak voltage, and harmonic operation from h=1 to h=3. More detailed information on the cyclotron project can be found in other general reports [1,2]. The status of all the major components is presented in the following.

Magnet and Cryostat

All the main components of the magnet, i.e. yoke, poles, coils, and the cryostat have been completed since 85. A large delay in the assembling resulted from a defect on the circumferential weldings of the helium vessel. After the repair, which was completed at the end of 86, all the efforts have been devoted to assemble these components. The helium vessel has been positioned inside the vacuum chamber and the liquid nitrogen screen and superinsulation have been mounted. The 16 platinum resistance thermometers have been positioned on the shell of the helium vessel in order to control the temperature distribution during the cool down. Moreover two strain gages have been mounted on the injection and extraction channels to control mechanical deformations. In this phase a dummy vacuum chamber has been used, without the holes for the radial penetrations needed for the operation of the cyclotron, in order to minimize any minor inconvenient which could occur during the first operation. The definitive vacuum chamber is already completed and will be mounted after the first magnetic field mapping. The cryostat has been positioned in the cyclotron yoke as shown in fig. 1 and vacuum test have been satisfactory carried out. The cryogenic power plant is completed and tested. Ancillary equipment for the operation of the magnet (main coils and trim coils power supplies, quench detection system etc.) have been connected. The installation of the transfer lines for liquid nitrogen and helium is in progress and the first cool down of the magnet is expected during this month.

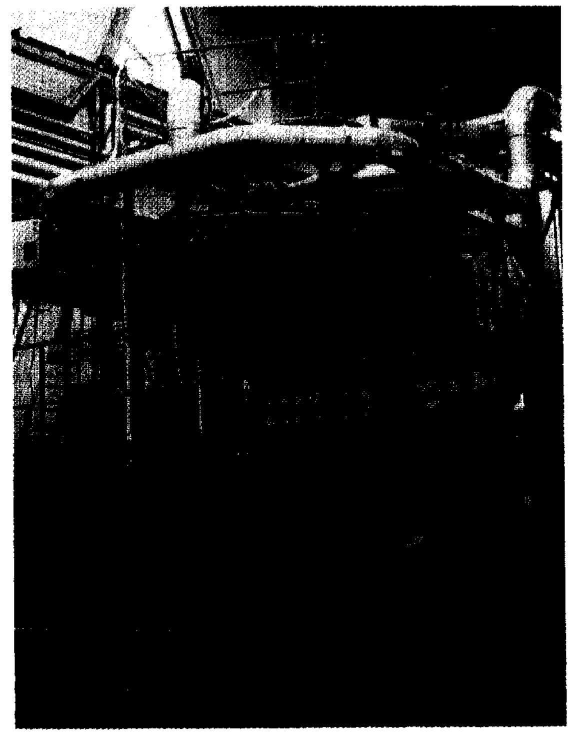

Fig. 1 - View of the cyclotron magnet with the upper pole cap raised.

Magnetic field mapping system

The magnetic field will be measured by means of flip coils with analog integrator at radial step of 1 cm (from R=0 to R=91 cm) and azimuthal step of 2°. The system is described in detail elsewhere in this conference [3]. The flip coils are calibrated at about 15 kGauss against a NMR probe in a dedicated magnet. The average calibration coefficient is 5.5 kgauss/V. Short term accuracy and long term stability have been studied as well as the temperature effect on the flip coil sensitivity. The deviation of the calibration coefficient is typically +/-50 ppm for the short term variation, while for the long term variation is about +/-100 ppm. These results fit well our requirements, though long term shifts on the calibration coefficient have still to be understood. The system has already been installed inside the cyclotron: a preliminary test has been performed. The total time required for a full 360° map is about 2 hours.

ECR source and axial injection

The design of the axial injection system was extensively presented at the Tokyo conference [4]. The ECR compact source, with two stages operating at 5 GHz, has been completed in summer 86. The operation of the source has been satisfactorily for low charge state light ions. Analyzed beams in excess of 100 eμA

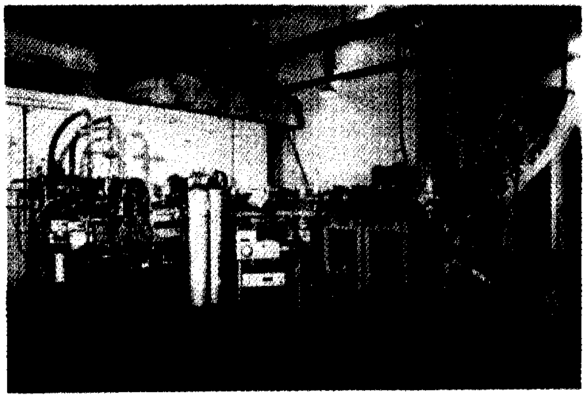

Fig. 2 - View of the ECR source and axial injection line installed for testing.

are easily obtained for charge states 1^+, 2^+, 3^+, for gaseous elements up to argon. The current strongly decreases for higher charge states; typically we obtain 20 eμA for $O4^+$. We are now modifying the design of the first stage of the source in order to improve its performances at higher charge states. The gas mixing operation mode of the source will also be investigated. Preliminary measurements of the emittance of the beams have been carried out at the exit slit of the analyzing magnet. With a N4+ beam at 10 kV of the extraction voltage emittances of =300 mm*mrad have been measured: these values are compatible with the acceptance of the cyclotron. The construction of the optical elements of the axial injection line has been completed at the end of 87, with the exception of the two solenoids near and inside the yoke, whose parameters will be defined after the mapping of the axial field of the cyclotron. The injection line, up to the 90° vertical bending unit, has been assembled and transmission tests of the beam are in progress. A view of the source and of the axial injection line is shown in Fig. 2. Emittance and beam profiles measurements at the exit of the vertical line are planned shortly, in order to verify the beam matching conditions for axial injection. The installation of the ECR source and of the axial injection line in the cyclotron pit is scheduled for the end of this year.

Extraction

The extraction system consists of two electrostatic deflectors splitted into two parts followed by eight passive magnetic channels. The mechanical design of the passive channels together with their actuators have been completed and all parts are now in construction. Extensive tests on a prototype deflector with the length reduced to 1/3 of the nominal value have continued after the results reported at the Tokyo conference [5] and some details have undergone significant revision. Long term reliability of the deflector has been investigated and it has turned out that a safe limit on electric fields, which can be sustained for periods longer than one month in a 1 Tesla magnetic field, is around 100 kV/cm, whereas the peak design value was 140 kV/cm. We have then tried a reduction of the radial gap of the HV electrodes changing the inter-electrode distance from 8 mm to 6 mm, thus reducing the energy stored in the deflector at a given electric field. The results obtained with the 6 mm gap have been very promising and the deflector prototype has been running for months at an electric field of 138 kV/cm, a value which is very close to the design requirements. Finally a new design, overcoming the severe space limitations, has been adopted for the high voltage feedthrough. We have used as center conductor of the high voltage feedthrough a commercial 150 kV cable with a diameter of 12 mm with the grounded shield removed. A vacuum tight sealing has been mounted at the ends of the cable and this has been screwed to the HV electrode by proper threading of the cable insulator. A view of the prototype deflector with the cable used as a high voltage feedtrough is shown in Fig. 3. The feedthrough has been tested alone and connected to the deflector prototype and has proved to work reliable at least up to 100 kV voltage. Moreover the flexibility of the cable helps in the design of the movements of the deflector. The construction of the deflectors is underway: they will be ready for installation at the end of this year. The deflectors have been designed with a gap of 6 or 8 mm by proper changing of the length of the supporting insulators. The possibility of using the 6 mm gap will be checked after beam size measurement in the extraction region.

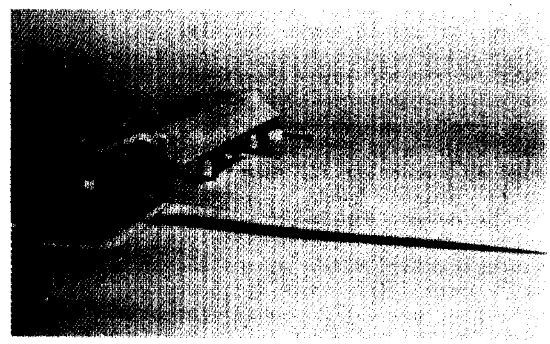

Fig. 3 - View of the prototype deflector. The mountin of the HV feedthrough is shown.

RF system

After the success of full power tests of the R prototype system, reported at the Tokyo Conferenc [6], the final construction of the main components ha been started. The RF status can be summarized a follows:

i) RF cavities. - The six half cavities have bee constructed, assembled and a complete leak test ha been performed (see Fig.4). The modification of th insulator region geometry, resulting from th optimization carried out with the computer cod SUPERFISH, has been included. The coupling an trimming capacitors as well as the high curren sliding shorts, have been realized. The dee geometr has been modified: since the splitted cryopumps hav proved to work reliably, the dee copper part has bee reduced and it has now a cylindrical symmetry.

ii) Liner - Some problems have been encountered wit the design of the liner, because of the very poo tolerance of the impregnated trimming coils, whos

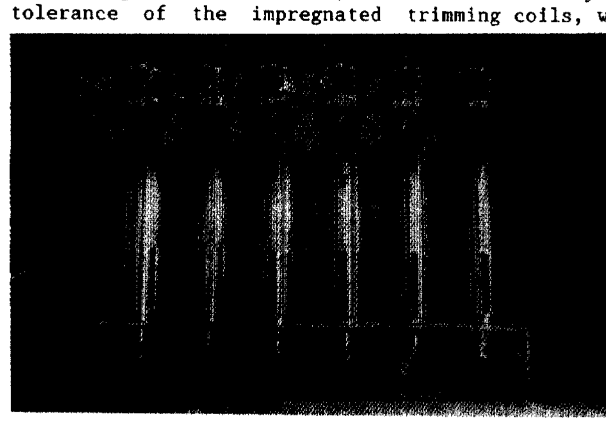

Fig. 4 - View of the RF cavities assembled.

profiles are out of the expected ones by a few millimeters. Therefore we designed the liner profile in a way compatible with the maximum envelope of the six set of trim coils. The liner is now under construction and we expect to perform the assembling test on the magnet poles by the next autumn.
iii) Power amplifiers- The three 90 kW power amplifiers are in operation since one year and they are routinely full power operated on a soda water dummy load, to prevent their deterioration.
iiii) Control electronics- The electronics has been redesigned in order to include the computer control. Assembling and testing of all the circuits for the three cavities is now under way, together with their connection (software and hardware) with the computer control. More details are given in two dedicated papers, presented at this conference [7,8].

Vacuum

The vacuum system design has been completely defined and the major components successfully tested. There are three independent vacuum systems: the cryostat insulation chamber, the acceleration chamber and the liner pole region. The vacuum system of the cryostat insulation chamber is in operation since four months and at the present the pressure inside the cryostat at room temperature is below $5{*}10^{-6}$ mbar. The acceleration chamber is pumped mainly using split refrigerator cryopumps fitted into the RF cavities, and able to operate in the magnetic field of the cyclotron. The definitive version of these pumps has been successfully tested for few thousands hours in our laboratory. The pump has doubled both first and second stage refrigerator power (15 and 2.0 W respectively) with respect to the prototype. The increase of the pump cooling characteristics raises the pumping speeds and the sorption capacity of 30%. Moreover this pump can be completely tested out of the cyclotron and then assembled into the RF cavity without any refilling or refrigerator disassembling. The vacuum control system together with the connection to the computer control is in progress. An extensive description is given in another paper [9] .

Diagnostic

The design of the diagnostic devices for the internal beam is almost completed. A movable probe, presently under mechanical test, will provide integral and differential measurements of the current pattern along an hill center line from R=15 cm up to the extraction region. Two sets of fixed probes (located at R=40 cm and R=60 cm of the other two hills) will allow a control on the beam centering. These probes, whose frames are screwed on the liner of the lower pole, are pushed on the beam by the Lorentz force acting on a movable pin fed by a short current pulse. Sixteen phase probes, now under design, will be distributed on two hills (eight of them cover the region from R=33 cm to R=72 cm on the first hill, the others from R=72 cm to R=88 cm on the second hill).

Computer control

The computer control design has been completely defined and the first phase of the project, including the elements needed for the magnet excitation and the magnetic field measurements, has been running error free for more than 500 hours. The basic structure of the computer control is a distributed, intelligent network of control units connected on an optical Ethernet, with a measured throughput of 1.1 Mbit/s, more than 1/10 of the Ethernet physical bandwidth. Cyclotron hardware is controlled by dedicated microcontroller based boards connected to the control unit on a serial, hierarchical field-bus (Bitbus). Throughput of 350 kbit/s has been measured for order/reply messages between the master node and a slave node. The transmission media is a twisted pair cable and a fiber optic interface has been developed too. Local control nodes are Multibus I based and are equipped with 80286 8 MHz microprocessor single boards, dedicated to the real time control, and with an 80186/82586 based Ethernet interface board. Exchange of data between processes on different boards has been implemented using a dual port memory and interrupt driven protocol. The Multibus has been utilized at nearly its maximum bandwidth, with a measured exchange rate of 5 Mbit/s. More details are given in a dedicated paper [10].

Shielding

The reference beam selected for the shielding calculations is a 200 MeV deuteron beam, striking a thick carbon target. Only partial self-shielding is ensured by the cylindrical yoke and the cryostat, since several penetrations, some of which of relevant dimensions, have been provided in the median plane. Therefore Monte Carlo calculations have been performed using the CERN version of the MORSE code and the HILO cross section library in order to estimate neutron leakage in occupied areas, through the machine yoke and the surrounding shielding. Extensive variance reduction techniques have been applied in order to simulate neutron transport over about 10 mean free paths of iron and concrete. Lateral shielding of 2 m of concrete is necessary up to 5.6 from the median plane. No roof is anticipated at the moment. The interlock and the radiation monitor systems have been designed. The hardware related to the interlock system is now under construction.

Conclusions

We expect in the next month to have the magnet in operation and to complete the field mapping by the end of the year. If the magnet operation will proceed without any problem, we hope to assemble the cyclotron in a short time, since the status of all the major components is well advanced.

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