PROGRESS REPORT ON THE MILAN SUPERCONDUCTING CYCLOTRON

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ABSTRACT
A K = 800 superconducting cyclotron is under construction at the Milan University in a new laboratory (L.A.S.A.). The cryostat and the superconducting coils have been tested successfully at the end of 1988 and a complete set of magnetic field measurements has been carried out at the beginning of this year. The main features of the cool-down, coil excitation and magnetic field are reported. Finally the status of the project with a review of the other major machine components is presented.

1. INTRODUCTION.

The general features of the project, consisting in the coupling of a K = 800 superconducting cyclotron with a 15 MV Tandem installed at the Laboratorio Nazionale del Sud (LNS) in Catania, and a detailed review of the cyclotron characteristics have been already presented in several papers [1-3].
The most important milestones recorded by the cyclotron project from the last International Conference on Cyclotron and their Applications, held in Tokyo, are represented by the completion of the new laboratory L.A.S.A. (Laboratorio Acceleratori e Superconduttivita' Applicata) in the summer 1987, by the cool-down and first excitation of the superconducting coils at the end of 1988 and by the magnetic field campaign concluded in march of this year. At the same time also the other components of the machine have approached to the final stage with several improvements advised by tests and operational experience.
Because details of the machine components and tests are given elsewhere [4-13] at this Conference, this paper will present only a general overview of the progress made so far in the cyclotron project.

2. MAGNET OPERATION.

For the first cool-down and excitation of the superconducting coils a dummy vacuum chamber has been used, without the radial penetrations needed for the cyclotron operation (deflectors, magnetic channels, diagnostics devices,injection and extraction pipelines) in order to make easier and more quick the cryostat disassembly in case of cryogenic component failure.
The cryostat has been positioned in the cyclotron yoke by centering mechanically the internal wall of the vacuum chamber with the poles within 0.1 mm. The Fig. 1 shows the magnet with the installed cryostat during the closing operation of the upper cap.
The vacuum in the cryostat was below $5*10^{-6}$ mbar at room temperature and fell to approximately $5*10^{-8}$ mbar when the vessel was filled with LHe: the spectrometric analysis of the residual gases has shown [4] that the He leakage is below to 10^{-8} cm^3/s.
The cool-down operation, carried out on 24 hour/day, 7 day/week basis, is described in details elsewhere [5]. The low cool-down rate (about 1 K/h) has been determined by the limit on the He pressure in the vessel (3 bar) arising from the safety valves. The most important results consist in the successfull operation of the aluminum LN shield with incorporated channels [2] for liquid flow, built with the technology of the industrial refrigerator cells, in the continuous operation of all components of the cryogenic plant for about 4000 hours without failures and in a reasonable helium boil-off rate (23 l/h) which allowed the magnet operation without problems.

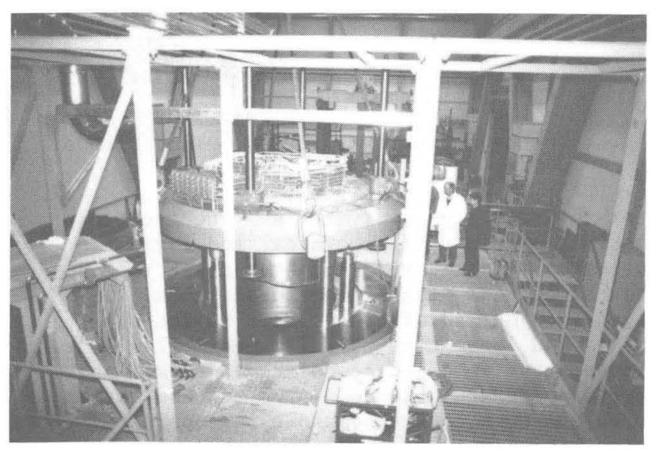

Fig. 1 Upper view of the magnet with the installed cryostat.

The first excitation of the superconducting coils has required about 3 weeks in order to adjust the power supplies to the pure inductive load, to verify the quench detection system, the coil protection and the computer control. The Fig. 2 shows the operating diagram (full line) of the currents in the two sections (alfa and beta sections) of the superconducting coils and the way (dashed line) followed in order to reach the extremes points of the diagram.

Strong radial forces and torques, that may be attributed to a coil decentering and tilting, have been measured with good precision and reproducibility by means of compensated strain gauges sticked on three horizontal and prestressed tie rods and three vertical suspension tie rods. The forces and torques have been minimized by suitable radial and axial shift of the superconducting coils [5]. The maximum unavoidable force has a strength of about 1600 daN and produce a radial shift of about 0.25 mm of the coils in respect with the pole axis.

The maximum torque has a strength of 600 daN*m and produces a tilt of the coils of 0.1 mrad. These values seem acceptable but an attempt will be made with the final configuration of the magnet and vacuum chamber in order to further reduce them.

Systematic magnetic measurements have been carried out over a 32 point grid and the results are extensively discussed in a paper presented at this Conference [6]. The Figs 3 and 4 show respectively the measured average field and the first harmonic for the complete set of measurements.The full and dashed lines correspond respectively to positive and negative currents in the β section. The agreement between calculated and measured field is very good so that little corrections on the pole geometry are foreseen. The first harmonic is negligible up to 0.75 m (3-5 Gauss) and blows up to a maximum of 25 Gauss at the extraction radius (R_e = 0.86 m).

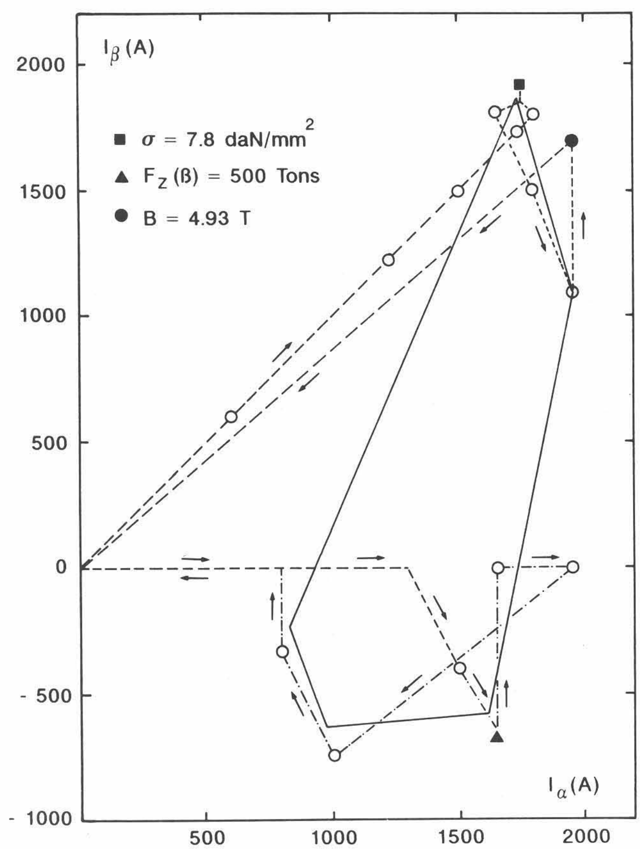

Fig. 2 Operating current diagram of the cyclotron and pathways followed during first coil excitation. Dots represent the dayly steps.

3. RF SYSTEM.

The RF system status can be summarized as follows:

- the six half cavities are completely assembled, including the high current sliding shorts, and vacuum tested;
- the dees are under construction, including the central region for Tandem injection, while the central region for axial injection has been stu

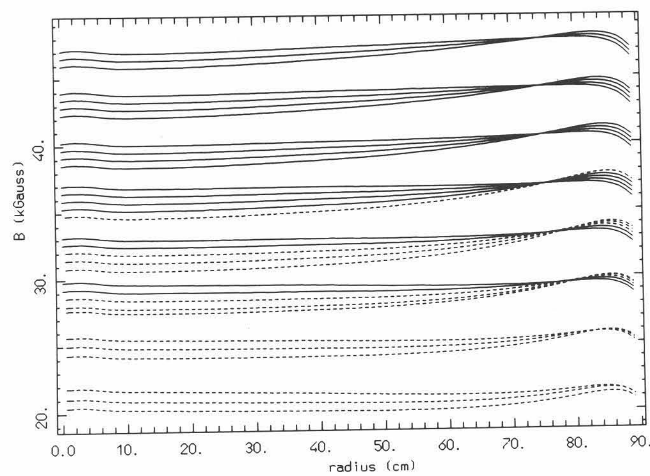

Fig. 3 Average magnetic fields at 32 different current levels (dashed lines correspond to negative current in the β section).

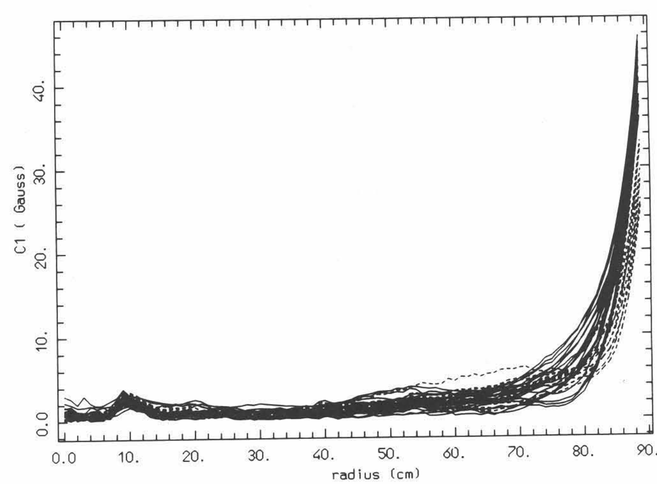

Fig. 4 First harmonic of the magnetic field at 32 different current levels. The reported values include the systematic errors of the measuring apparatus.

died from mechanical, electrical and thermal point of view. When the final geometry will frozen, the three dee noses will be realized from a bulk CuBe alloy;

- the liners, covering the magnet poles, have been constructed and they will be tested on the poles and machined in the near future. A picture of the liner is presented in Fig. 5;
- the control electronics in the new version fully computer assisted, has been completed and it is now under test. Hardware and software developments are given in two paper presented at this Conference [7,10].

4. ECR SOURCE AND AXIAL INJECTION SYSTEM.

The construction of the compact ECR source, with two stages operating at 5 GHz, has been completed since summer 1987. The source has been tested in a test stand and its operation has been satisfactorily for low charge states of light ions. Beams in excess of 25 µA of N^{4+} are presently obtained and they are sufficient for beam acceleration tests. The source and the axial injection line up to 90 degrees vertical bending unit have now beenassembled in the cyclotron pit. Transmission test of the beam and beam emittance measurements in order to verify the beam matching conditions for axial injection are in progress. A view of the ECR source and of the axial injection line installed in the cyclotron pit is shown in Fig. 6.

5. ELECTROSTATIC DEFLECTORS.

After the results reported at the Tokyo Conference on the maximum attainable voltage for the deflector prototype, efforts have been mainly devoted to the long-term reliability of the deflector and to development of a suitable high voltage feedtrough. Long term tests of the deflector have clearly shown that the maximum achievable voltage on a time scale of a few weeks is not above 80 kV, for our geometry with a 8 mm gap. This value is considerably below the design requirements of 140 kV/cm. The phenomena which are mainly responsible for the lowering of the deflector performances in a magnetic field are the strong magnetic focusing on the dark current electrodes and the critical

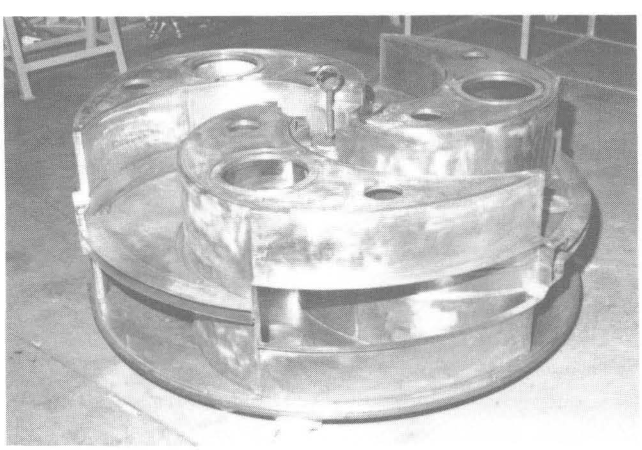

Fig. 5 Upper parts of the liners before the welding of the cylindrical skirts.

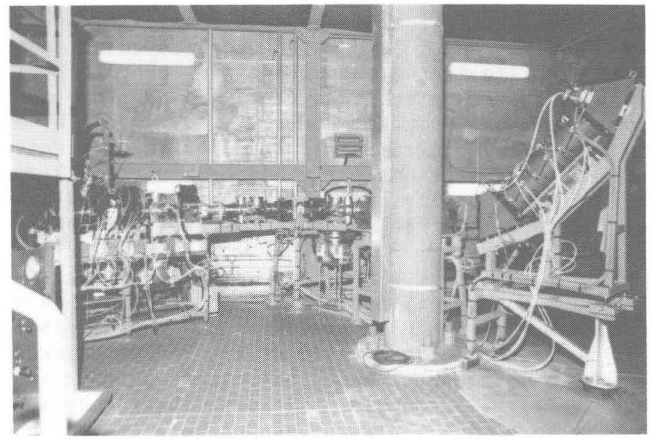

Fig. 6 ECR source and axial injection line in the cyclotron pit. In the foreground one of the pillars (6 m high) which support the magnet.

effect during a discharge of the energy stored in the system. These drawbacks can be partially overcome by reducing the electrode gap. A 6 mm gap has been successfully tested by running for months at an electric field of 138 kV/cm. During these tests a commercial high voltage cable has been used as the high voltage feedthrough, and it has proved to work satisfactorily, overcoming the severe space limitations of the cyclotron. The mechanical design of the electrostatic deflectors has been completed and the construction will start at the end of the magnetic field mapping [9].

6. COMPUTER CONTROL.

A schematic layout of the Milan control system is shown in Fig. 7. At the process level control stations perform high speed data acquisition from sensors, convert measurements to engineering units, provide complex real time controls and maintain a local database of the variables in use. In the control stations a standard Multibus I and a CPU from Intel family (16 bit microprocessors) have been

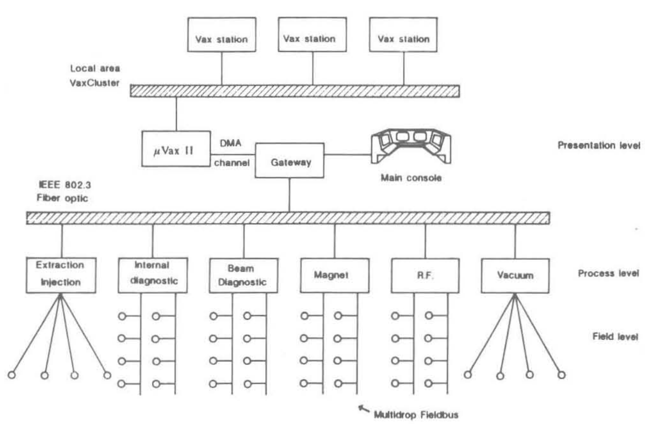

Fig. 7 Schematic layout of the control system of Milan cyclotron. The system is divided in three levels (field level, process level and presentation level).

adopted. At the plant level equipments incorporate a microcontroller board which communicates with the main related unit on a fast serial link (Bitbus). At the supervision level, a console mode provides fast acccess to every machine parameter, by means of interactive devices, data display and alarm information. A DEC µVAX II is the supervisor of the control system and maintain a global image of the accelerator in the main database. General choices defined for the Milan control system are the use of a real time operating system (iRMX 86) on EPROM in every CPU board, the use of PLM as a programming language, the development of a support for multicomputer structure and the organization of data in a database. Real time operations of the control system are managed by means of the iRMX 86 operating system. Performances for some critical operations have been measured on a target SBC (8 MHz 80286). Execution time of nearly 100 µs for interrupt latency, 200 µs to send a message to a mailbox and 190 µs to receive the control of a common resource have been obtained.
A global test of the performance of the whole control system s/w is the time needed to exchange data between the console and a control station. Measurements have shown that to send 5 kbytes of data, from the µVAX II to a control station 130 ms are required, while a knob command is made effective to the field in 30 ms. When a task in the supervisor computer reads a data location in shared memory such information is never more than 175 ms old.
The experience gained on the computer control during cool-down and magnetic measurement operation, has shown that the architecture is well suited.
Progress in RF and vacuum systems are described elsewhere at this Conference [7,8].

7. VACUUM.

The structure of the Milan Cyclotron vacuum system has been extensively reported elsewhere [14]. We recall that the main vacuum system works on the cryostat chamber (as insulation for the cryogeny) and on the acceleration chamber.
The cryostat vacuum system, composed of two liquid nitrogen baffled diffusion pump plants, has worked for 1 year (more than 1 month in a magnetic field of 0.15 T) without any problems. The performances of this system have been previously reported.
The acceleration chamber is pumped by means of 3 split refrigerator cooled cryopumps, assembled into the RF cavities [15]. The cold head of the pump with a moving piston is immersed in the accelerator magnetic field (5 T). Computer calculation and a test performed in the AVF Milan cyclotron showed that the magnetic field has no influence on the pump characteristics. Moreover a test of the pump in the real magnetic condition has been performed during the magnetic field measurements. The cryopump was fitted into the magnet and placed in the working position. No change in the cool-down time, in the cooling power and in the final temperature has been measured [4].

8. BEAM DIAGNOSTIC AND HEALTH PHYSICS.

The internal beam diagnostic has been implemented by increasing the number of current probes and phase probes in order to have more informations on the beam dynamics during the tuning and setting of the cyclotron. The compactedness of the cyclotron has required some special solutions which are described in details elsewhere [11,12].
Calculations to estimate neutron and gamma spectra, fluxes and ambient dose equivalent, in occupied areas, in the concrete bunker and inside specific components of the accelerator have been carried out with MORSE code. The results are presented at this Conference in another paper [13].

9. REFERENCES.

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