TOWARDS THE ACCELERATION OF THE FIRST BEAM BY THE INFN SUPERCONDUCTING CYCLOTRON

L. Calabretta, G. Ciavola, G. Cuttone, M. Di Giacomo, S. Gammino, P. Gmaj, E. Migneco, G. Raia, D. Rifuggiato, A. Rovelli, J. Sura
LNS - INFN V.le A. Doria (ang. Via S. Sofia), Catania, 95125, Italy
E. Acerbi, F. Alessandria, G. Bellomo, A. Bosotti, C. De Martinis, D. Giove, P. Michelato, C. Pagani, L. Rossi, G. Varisco
INFN - Sezione di Milano and Universita' degli Studi di Milano
Laboratorio LASA, Via F.lli Cervi 201, Segrate (Milano), 20090, Italy

Abstract

In this paper we report the progress done in the construction of the INFN Superconducting Cyclotron. In November 92 the cyclotron has been cooled down at the LHe temperature and the cryogenic system is working since then satisfactory. Test on the main vacuum of the acceleration chamber and on the intermediate vacuum have been completed with good results. The RF cavities have been tested inside the machine with the magnetic field on. Problems have been in the couplers operation. Magnet excitation has been completed and the operating diagram is almost fully exploitable with reasonable mechanical stresses. Magnetic field mapping has been completed. The Tandem beam has been delivered at the entrance of the cyclotron and the first beam has been accelerated up to 65 cm radius in June 94. The obtained performances of the main components of the cyclotron and short term program are discussed.

1. INTRODUCTION

The Superconducting Cyclotron project is a collaboration of the Catania and Milan Laboratories of the INFN. The characteristics of the cyclotron have been extensively reported in previous papers [1,2], so we just recall here the main milestones of the project. The cyclotron was moved in Catania in 1990 after the first cool-down and the preliminary magnetic field measurement done in Milan. In May 92 the cryostat was completed with all the radial penetrations, vacuum tested, and reassembled inside the magnet yoke. Two small leakage, (less than 10-5 torr l/s) were detected, but we did not attempt to perform any repair because they are not critical. In fact after two years operation the vacuum in the cryostat is very regular and better than 1.10-7 torr. The most significant steps in the cyclotron construction achieved since the Vancouver Cyclotron Conference are presented.

2. MAGNET EXCITATION

In November 92 we started the excitation of the magnet. We had some minor troubles in adjusting the power supplies to the pure inductive load of the coils, and finally at the end of January 93 we were able to reach the extreme corner of the operating diagram of the machine (4.8 T with positive currents on both coils). The decentering forces on the coils were within the predicted values (less than 1 ton). The next step was to reach the other extreme point of the operating diagram (3 T with negative current on the beta coil). At a field level of 4 T and still with a positive beta current, large decentering forces, estimated in excess of 5 tons, acted on the iron wall of the cryostat vacuum chamber providing a sudden movement of the cryostat and large forces (up to 2 tons) on the coils. The shift of the whole cryostat with respect to the centre of the machine was of about 1.6 mm, as evidenced by mechanical checks. This has been the major accident. In order to re-centre the cryostat, without disassembling the whole cyclotron, a special mechanical structure has to be designed and built. The operation has been positively completed in August 93 and the cryostat vacuum chamber has been secured to the yoke. A view of the cyclotron is shown in fig. 1.

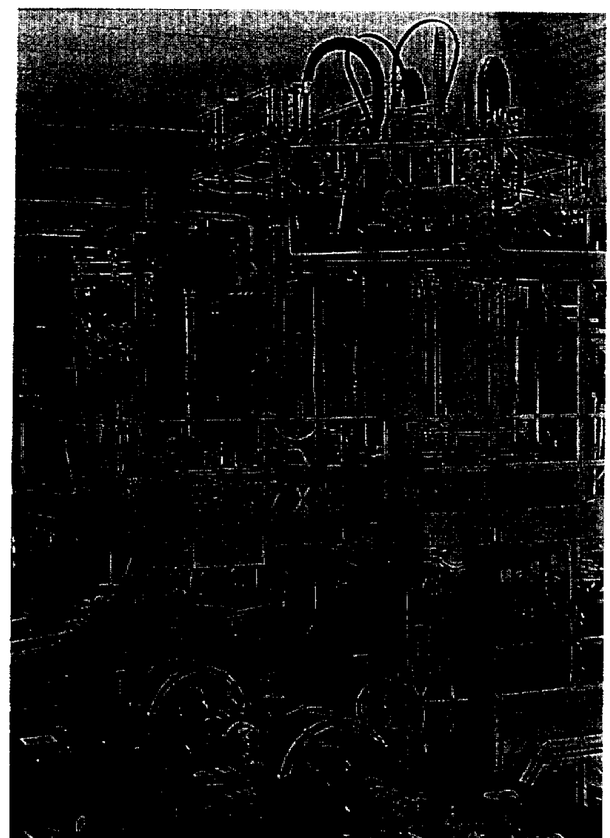

Fig. 1 View of the cyclotron installed at LNS

3.VACUUM SYSTEM

The final test of the vacuum system was completed in May 93, with all the magnetic channels, the current probe, and the injection line connected to the cyclotron. Operating with 3 turbomolecular pumps together with 3 splitted cryopumps a vacuum of 2.10-6 torr has been reached after two days. This value is presently limited by a big leak between the acceleration chamber and the liner vacuum. We located this leak; it would be very long time consuming to attempt a repair, but we will drastically reduce it by improving the liner vacuum. A full description of the vacuum system and its performances are elsewhere presented [3].

4.DIAGNOSTICS AND EXTRACTION SYSTEM

The beam current probe moving on a trail has been completed and inserted into the machine. It has two possibilities of measurement: a scintillating screen allows to look the beam spot shape through a CCD camera, an aluminum head allows to read the beam current. The probe is shown in fig. 2. The two electrostatic deflectors have been checked in the test stand with 1 T of magnetic field . In this situation they work reliably up to 70 kV. In December 93 they have been inserted in the cyclotron with all the movements for mechanical testing. The magnetic channels and the compensating bars for extraction are already in place with their movements.

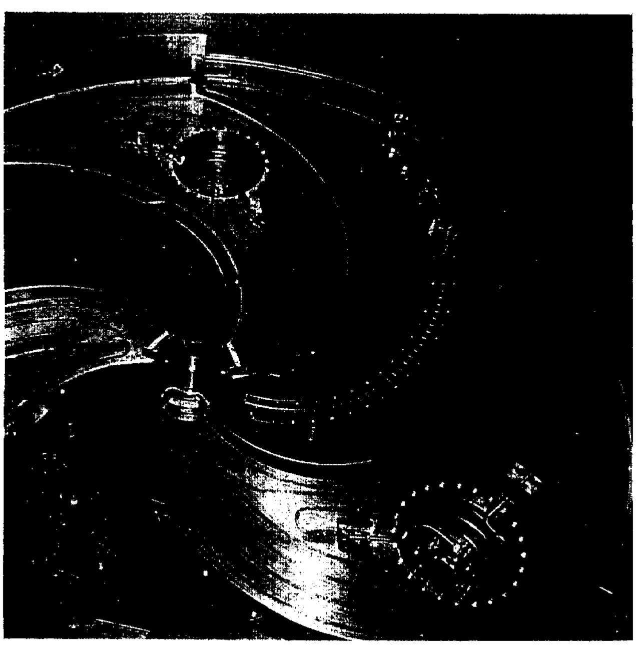

Fig. 2 View of the beam probe installed on the liner of the cyclotron. Visibles are also the dees with the splitted cryopumps

5. RF SYSTEM

First operation in the cyclotron of the RF system has been done in July-September 93. The system was tested cavity by cavity in the full range of frequency, i.e. 15-50 MHz and with power up to 40 kW. Most of the parts of the system proved to be reliable. The sliding short moves smoothly and may be used to set the frequency within 1 Hz. The mechanical and temperature stability are very satisfactory and the multipactoring effects were overcome in a matter of hours without problem. Before to load with power we checked for mutual parasitic coupling. The measurements gave the highest value of insertion loss equal to 55 dB at the upper frequency limit of 49.3 MHz. This value corresponds to an effective mutual capacitance of 2.10-16 F. This measurement proved that the tuning procedure can be done for every cavity independently. At lower frequency the insertion loss is smaller. A complete description of the performances of the RF system is elsewhere presented [4] . A weak point in the RF operation appeared to be the capacitive couplers. Breakdowns on the insulator caused metallization of the ceramics and sparks damaged the cooling tube with water leaks in cavity 1 and 3.

6. MAGNETIC FIELD MEASUREMENTS

Cyclotron field mapping was carried out from November 93 to February 94. The magnetic field was measured by a flying search coil, with voltage frequency conversion, mounted on a motorised cart with an optical incremental encoder giving the radial position. The field is measured up to R=88.7 cm at steps of 1 cm. We spanned the full azimuthal extension at steps of 1 or 2 deg. The absolute measuring accuracy is of the order of 1 G on the average field; reproducibility of the field map is within 0.1 G. An extensive discussion of the results is presented elsewhere [5].

The measurements have been done in two phases. The first has been devoted to the behaviour of the trim coils form factor with the field level and to the investigation of the field imperfection sources (mainly the 1st harmonic). Analysis of the first harmonic is quite complex because one has to separate the various contributions due to misalignment of the measuring system, off-centring of the coils and of the vacuum chamber, holes in the yoke and poles, sectors imperfections. The coils were first centred with respect to the forces, i.e. approximately the same decentering forces (with opposite sign) in the two extreme corner of the operating diagram . In this position we have found that the coils are misaligned by 0.6 mm with respect to the sectors symmetry axis and consequently there is an induced 1st harmonic changing with the main coils current. With the coils in the magnetically centred position (with respect to the sectors) position the 1st harmonic is minimised and is invariant with the excitation. This coils position however limits the operating diagram of the machine to a field level below 4 T, because of large decentering forces on the coils. To keep the coils centred at high fields it will be necessary to reinforce the horizontal tie rods terminals. Nevertheless a good compensation of the first harmonic has been found placing six iron shims on the liner. The residual 1st harmonic is generally lower than 3 G and reaches the value of 7-9 G at the extraction radius; these values are compatible with the acceleration and the 1st harmonic control (through harmonic coils) of the precessional extraction. A typical behaviour of the 1st harmonic is shown in fig.3.

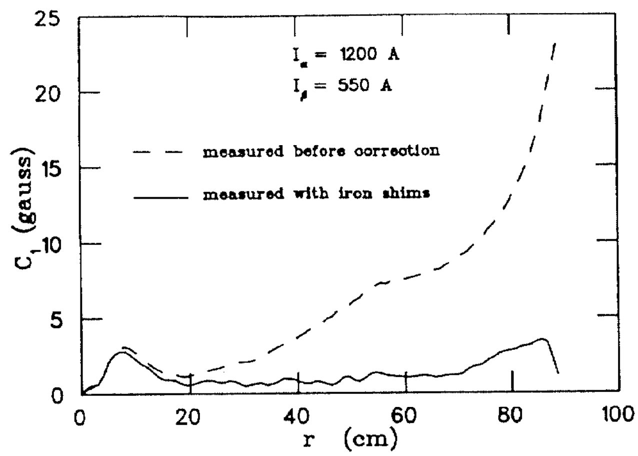

Fig.3 A typical first harmonic amplitude with and without iron shims correction

7. ACCELERATION TEST

At the end of May 94 we started the first acceleration test in the cyclotron. We selected a Ni beam with charge state 16+ and a field level of 3.2 T, which corresponds to a final energy of 30 MeV/n. This beam will be the first one to be used for nuclear physics experiment. A 30 enA beam of Ni, with charge state 4+, was delivered by the Tandem at the cyclotron entrance with an energy of 47.5 MeV, without detectable losses.

Since the final stripper foil apparatus is not yet completely ready, we placed at the nominal injection position in the cyclotron a fixed carbon foil. The control of the beam trajectories, via the steering injection magnet and the horizontal and vertical sizes, via the last two quadrupoles of the beam line, were monitored through an alumina screen placed just nearby the stripper and observed by a CCD camera. Beam dimensions at the stripper are of the order of 2 mm horizontal and 10 mm vertical. The beam is positioned at the stripper with a uncertainty of about 1 mm. Another alumina screen has been placed on the movable current probe positioned at 130° downstream the stripper. In this way we are able both to measure the current and to look at the focusing condition. Different charge states of the beam (Q=14,15,16) produced by the interaction with the carbon foil were observed on the screen. Initially, acceleration test had to be delayed because of the previously mentioned failure in the couplers. We temporarily overcome this problem, removing the water cooling and pumping through the same circuit.

On the 3rd of June 94 we started the first acceleration test, operating the machine through the main control system [6], except for the RF system. The beam was continuous in order to speed up the test, avoiding to phase lock the 2 bunchers to the cyclotron RF. With an RF voltage of 30 kV, at 27.5 MHz in the second harmonic mode, and with a power in each cavity lower than 3 kW, we succeeded in following the beam with the movable current probe up to 66 cm. of radius and recording an ion current of 3-4 enA. At this position the beam was suddenly stopped by an alumina screen previously placed and not removable from the outside. On this alumina the beam left a clear and well vertically centred image. We point out that the beam reached this point with the nominal field setting and without any tuning.

On the 4th of June we opened the machine, removed the alumina and restarted the vacuum pumping, but the day after a valve of the cryogenic plant failed and air went inside the cold box, causing the rupture of the bearings which support the turbines of the liquifier. The accident was very serious, but fortunately the plant supplier (L'Air Liquide) was able to ship two new turbines in a short time.

The liquefier was restarted after a 5 days stop. During the stop the temperature inside the cryostat increased up to 36 K, and after 7 days from the accident we could supply LHe to the magnet. The acceleration test have been however suspended, due to a severe vacuum leak in one of the already damaged couplers.

8. FUTURE PLANS

In the next weeks we will repair the damaged coupler, removing the cooling system of the ceramic insulator and making them vacuum tight also under sparking condition. Acceleration test will then continue aimed to bring the beam up to the extraction radius with an RF voltage of about 50 kV. At the same time the electrostatic deflectors will be installed in the cyclotron and checked with the magnetic field and RF on. The design of a modified coupler is underway and their construction should be completed by the end of the year. In September we will install the definitive stripper system and all the beam diagnostics and the first external beam is anticipated before the end of the year.

9. REFERENCES

[1] E. Acerbi et al., "The Milan Superconducting Cyclotron Project". Proc. of the 9th Int. Conf. on Cycl. and their Appl., Les Edition de Physique, 1981.

[2] L. Calabretta et al., "Status Report on the Heavy Ion Facility at LNS", Proc. of the 13th Int. Conf. on Cycl. and their Appl.,World Sc. Publishing, 1992.

[3] P. Michelato et al., "Operational Experience of the K800 Cyclotron Vacuum System at LNS", prsented at this Conference.

[4] J. Sura et al., "First Operational Experience with the RF System of LNS Superconducting Cyclotron", presented at this Conference.

[5] P. Gmaj et al., "Final Field Mapping of the LNS Superconducting Cyclotron", presented at this Conference.

[6] G. Cuttone et al., "Experience and Trends in Control System for Particle Accelerators", presented at this Conference.