STATUS REPORT ON THE HEAVY ION FACILITY AT LNS

F. Alessandria, G. Bellomo, A. Bosotti, C. De Martinis
D. Giove, P. Michelato, C. Pagani, L. Rossi
INFN - Sezione di Milano, Università degli studi di Milano
Laboratorio LASA, Via F.lli Cervi 201, Segrate (MI),20090,Italy

and

L. Calabretta, G. Ciavola, G. Cuttone, M. Di Giacomo, S. Gammino
P. Gmaj, G. Raia, D. Rifuggiato, J. Sura
L.N.S. - INFN, V.le A. Doria ang. S.Sofia, Catania, 95125,Italy

ABSTRACT

The Milan superconducting cyclotron has been transferred and assembled in Catania. The status of the main components and the results of the tests performed along the radial injection line are here presented.

1. INTRODUCTION

The superconducting cyclotron, which will be commissioned at L.N.S., was moved to Catania after the first cool-down and the preliminary magnetic measurements done in Milan.[1,2] Now the assembling of the cryostat and of the other main components of the machine, which are here described, is completed, Fig. 1.

To save time between the next campaign of magnetic measurement and the tests of RF and acceleration, the cyclotron cryostat was assembled together with the RF liner. The final magnetic measurements will be carried out by a new field mapping system able to fit the small gap of the liner. At the beginning, the beam accelerated by the Tandem will be radially injected in the median plane of the Cyclotron, where it will be stripped by a carbon foil placed near the center. Tests on the beam transfer line, charge state distributions measurements before and after the cyclotron stripper, and on the bunching system were done and are here presented. In Fig. 2 the lay-out of the LNS facility is shown, including the accelerator rooms, the Tandem-Cyclotron coupling line and the experimental rooms.

2. CRYOSTAT AND CRYOGENIC PLANT

At the end of 1990 the assembling of the cryostat started in Catania. We took 16 months to assemble the cryostat with the final vacuum chamber complete of all the radial penetrations for the injection and extraction lines, the electrostatic deflectors, the magnetic channels and the current probe. In May 1992 the cryostat was put in the magnetic yoke in its final position. In the first magnetic measurements done in Milan a first harmonic contribution due to the inner vacuum chamber of the cryostat was detected; now in order to reduce this effect, the center position of the vacuum chamber with respect to the center of the pole has been measured with great accuracy. The position of the center has been extracted by Fourier analysis of the values of the distance between the vacuum chamber and the pole center. After some trials the centre of the vacuum chamber was nominally placed at 0.01 mm from the centre of the poles. Because of unknown possible errors and due to the difficulties to

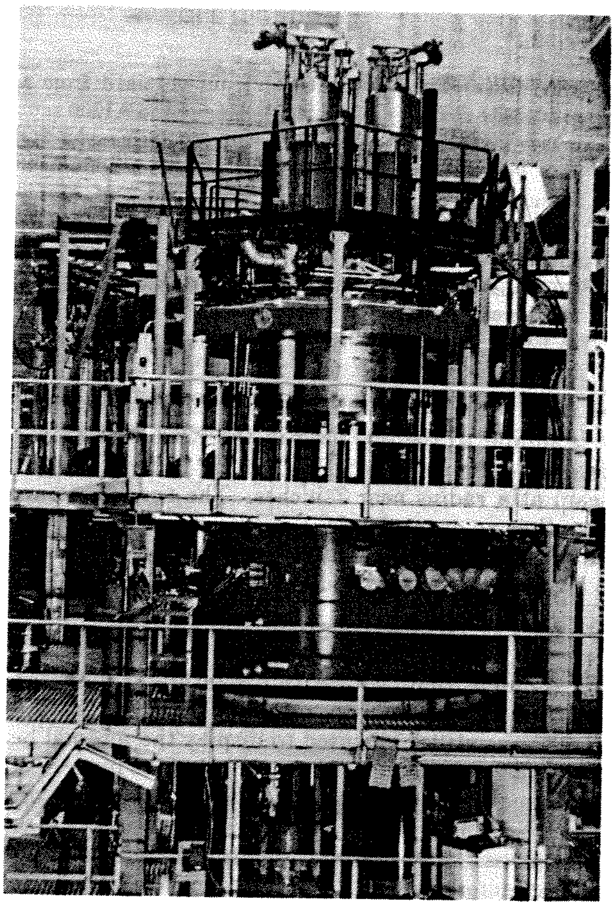

Fig. 1. View of the Cyclotron assembled with the cryostat inside and the upper and lower RF cavities installed.

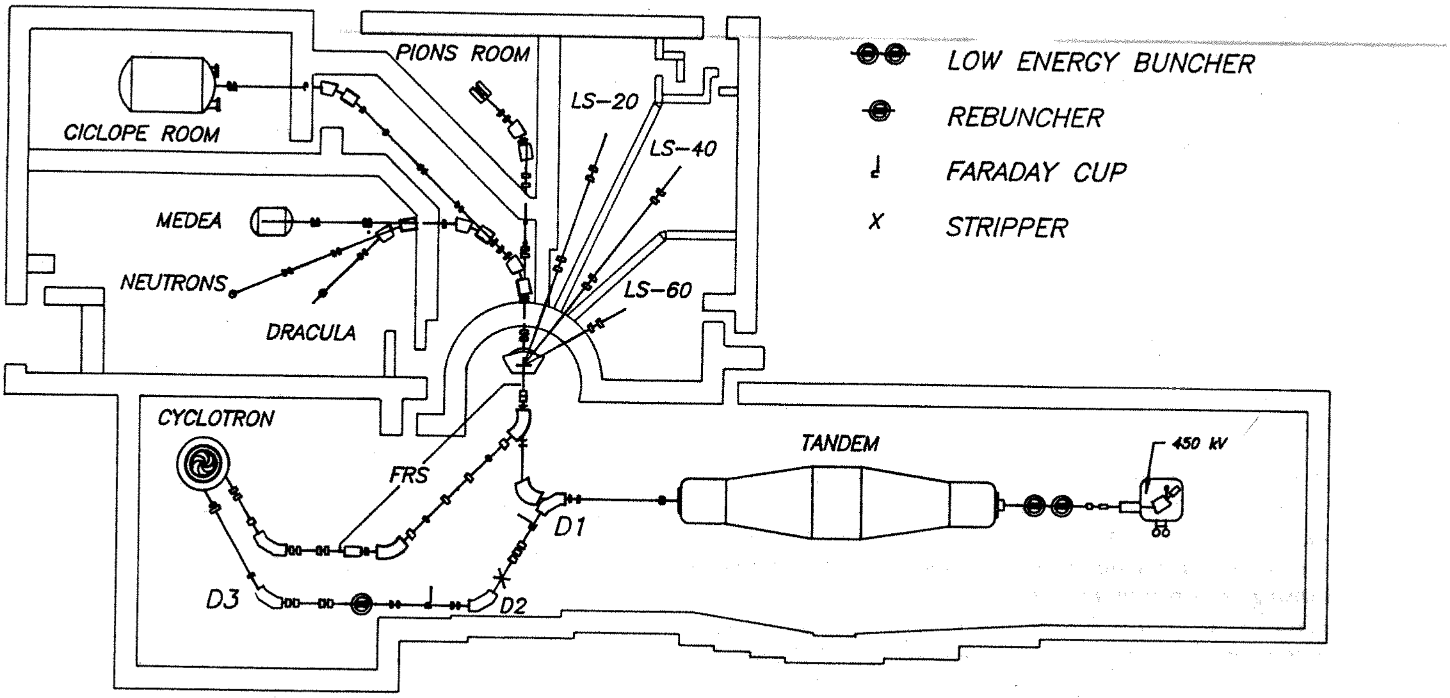

Fig. 2. Layout of the LNS facility.

measure the positions of the poles, covered by the liner, and of the vacuum chamber, we can not rely completely on this result. The final check on the exact position of the cryostat will be possible by magnetic measurements. The cryostat has been vacuum tested before the installation inside the magnet yoke. Two small leakages lower than 10^{-5}mbar·l/sec have been detected, one inside the injection channel, the second inside the channel of a compensation bar. The two leaks have also been measured after the assembling of the cryostat in its final position and no variation has been monitored. We decided that it is not necessary to attempt to perform any repair because of the acceptable low values of the leakages and of their stability.

All the equipments needed for the refrigeration of the cryostat have been installed and separately tested. At present we are carrying out the connection of the cryogenic transfer lines and the tests on the measurement and control systems. The cryogenic circuit is based on a Helial refrigerator delivering 180 W or 53 l/h of LHe at 4.3 K without LN precooling and about 100 l/h with precooling. The refrigerator is equipped with an internal purifier to avoid the treatment of the recovered helium and the risk of valve clogging. Two ejectors, one on the warm line coming from the current leads,the other into the cold box on the cold line from the cryostat, make the operating pressure of the cryostat indipendent of the compressor low pressure. During the normal operation the refrigerator supplies a 1000 l. reservoir from which the LHe is transferred to the cryostat; a regulating valve on the transfer line keeps the level constant and independent of the production and consumption fluctuations. The LN, required for the cooling of the 80^0 K shields ($\sim$10 l/h) is drawn in turn from two 10.000 l. tanks and arrives at the cryostat via a multilayer insulated transfer line and phase separator. During the warm up of the cryostat the gaseus helium is recovered in a 20 m^3 balloon and compressed to 220 bar in large high pressure cilinders (1700 l) by a 50 m^3/h compressor. The storage capacity is $\sim$3000 std m^3 of He.

3. RF SYSTEM

The cavity resonators and the trimming capacitors are already mounted in their permanent positions and the connession to the ancillary equipment and to the electronics are in progress. The transmission coaxial lines connecting the RF amplifiers to the coupler capacitors have been installed too. The trimming and coupling capacitors, the lower and upper stubs of the resonant cavities have also been vacuum tested. During the assembling of the cryostat a lot of work has been done to complete the lower and upper parts of the RF liner. The liner, sealed to the cryostat inner wall constitutes the vacuum chamber of the accelerator.

The copper liner presents a large surface exposed to vacuum in the acceleration chamber and therefore an efficient cleaning procedure of this part is of vital importance on the vacuum conditions of the machine. The liner was first degreased (locally) with acetone for a rough removing of the oils used in the machining. Afterwards the liner was ultrasonic cleaned (fully immersed) in a hot alkaline detergent solution to remove fats; a hot acid detergent solution was then used to deoxidize copper. Thereafter the liner was dried with ethanol after a long rinsing (about 1 hour) with room temperature demineralized water. The liner is now completely installed in the magnet.

4. EXTRACTION

The construction of the magnetic channels and their actuators is completed and they have been already installed in the cyclotron. The construction of the two electrostatic deflectors, Fig. 3. is underway and they will be ready for testing and installation by the end of September. The deflectors have been designed with a gap of 8 mm. This will limit the maximum sustainable field to around 100 kV/cm, whereas the peak design value was 140 kV/cm. After the beam size measurement in the extraction region, we shall evaluate the possibility of turning to a 6 mm gap, which has proved to work satisfactory up to 135 kV/cm on the deflector prototype. A test bench with a 1 Tesla magnetic field has been installed at LNS for further deflector development.

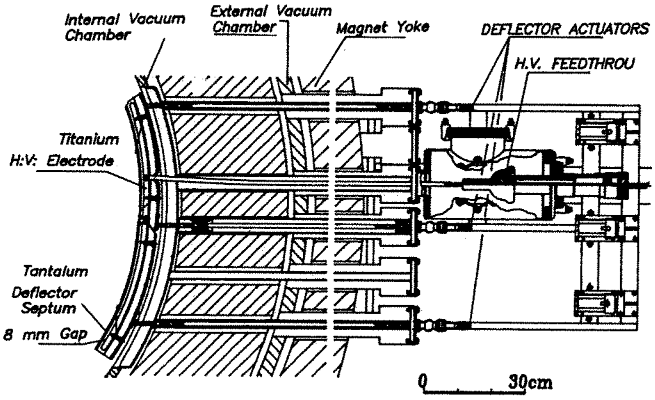

Fig. 3. Design of the electrostatic deflector

5. MAGNETIC MEASUREMENT SYSTEM

The description of the new field mapping system and its test were published elsewhere,[3] therefore herein we will mention only its general concepts and features. Due to the small gap accessible in the median plane of the cyclotron and the great number of field maps to be measured the search coil technique was chosen as a basis of the system. It provides both small vertical size and high speed properties. The system is made up of a coil put on a motorized cart together with an optical encoder sensing the actual probe position by means of a stripped tape fixed to a guiding carbon-fiber bar. The 1800 mm long bar is settled on the motorized axis which ensure an azimuthal positioning accuracy of 10^{-3} deg. The cart controller triggers by means of encoder pulses a digital integrator (PDI5025-Metrolab), which sums up the frequency of an ADC and stores the result each time a preprogrammed number of trigger signals is counted. When calibrated this system gives the field variation from a reference point. The absolute value of the field is read by the NMR probe placed on the symmetry axis of the cyclotron. Another NMR probe is placed in one of the RF holes to allow an on-place calibration of the coil. The misalignment of the coil plane with respect to the symmetry plane of the cyclotron of .8 deg leads to a systematic error of the order of 10^{-4}. For this reason the possibility of calibration inside the cyclotron is important. The whole system is controlled via GPIB bus by a PC386. The PC performs data aquisition, *on line* calculations of average field and harmonics with appropriate graphs. The computer analyzes *on line* the measurement performance and in case of a failure cased by an overrange error or an encoder counter error repeats automatically erroneous azimuthal step.

The main problem encountered during the tests of the system was a nonlinearity of the integrator drift as well as a noise generated probably by the digitization process. It is very difficult to get rid of the last error since it depends not only on a trigger number and temperature but a part of it seems to be clearly casual. Thus the system parameters (coil sensitivity, cart velocity, integrator amplifier gain) was chosen to diminish a casual error. For the best balanced gain value (G=10) and high coil sensitivity (0.13 m^2) the cart velocity is limited by the highest field gradient expected (15 T/m) to 0.2 m/s. To reduce the measurement time and the probability of the casual drift error, the cart starts with the maximal velocity (0.5 m/s) and it automatically moderates only in the region where the gradient is high. This property ensures the measurement accuracy within 10^{-4} for an individual measurement point and better then 3×10^{-5} for average field and harmonic amplitudes.

The system will be tested inside the cyclotron the next weeks and the magnetic field measurements are planned to begin this summer.

6. COMPUTER CONTROL

The establishment of accepted general rules for the lower levels of the control system and the importance of the operator interface in the management of the experiment have stimulated a lot of work in the design of new approaches to man machine interaction tools. The console has been redesigned as an Ethernet segment with a distributed software running on the computers connected to it. The most relevant challenge has been the development of GIULIA,[4] a dedicated package running on top of X-Windows on VMS Based worksations. GIULIA isa modular, object oriented code which provides a set of tools for the management of a plant or of an experiment. The operator is driven,through windows based dialog paths, to the handling of all parameters of concern. There is the possibility to work with predefined tools or with run time user defined tools. Alarm handling, logging monitor capabilities and the management of a database for the different parameters are included. The experience gained using GIULIA during the final assembling of the machine has shown that the package fits all the requirements arised during the first cool-down and excitation operations.

7. BEAM'LINE TESTS

The coupling beam line between the Tandem and the Cyclotron has been tested. The lay-out of the line is shown in Fig. 2, where the diagnostic elements, the Faraday cups (FC), are represented too. Each Faraday cup is accompanied by a Beam Profile Monitor5) The aims of these tests are:

- to verify the agreement of the experimental setting with the theoretical values;
- to estimate the transfer efficiency of the line;
- to evaluate the intensity of the charge state to be injected into the Cyclotron;
- to evaluate the stripping efficiency for the charge state to be accelerated in the Cyclotron after stripping.

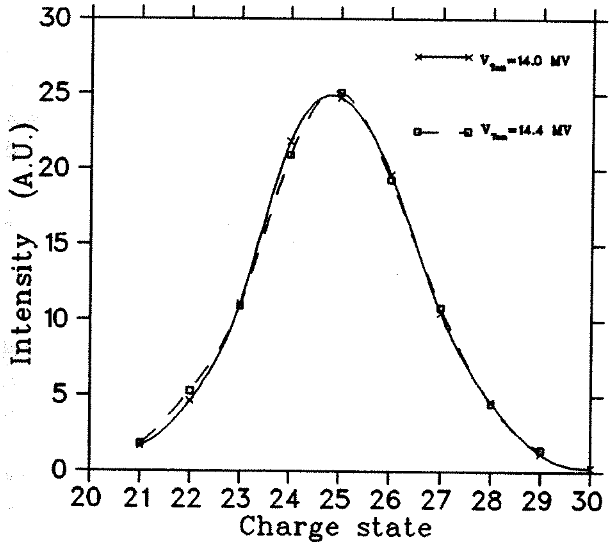

Fig. 4. Charge states distribution after the second solid stripper.

The beam line tests were performed with ^{16}O and ^{127}I, employing a N_2 gas stripper at the Tandem H.V. terminal. They proved that the theoretical setting of the quadrupoles agrees with the experimental one within a few %. A $^{16}O^{2+}$ beam, accelerated with $V_{Tandem}=10$ MV, was transported until the Rebuncher position (Fig. 2), where a double waist is created, and the transfer efficiency resulted to be ~100% for an intensity in the order of 120-140 enA. The most interesting feature of these tests is the easiness of the setting procedure. At 14 MV, injecting a current of 600 nA in the Tandem and extracting a current More extensive tests were done with ^{127}I. of 5000 enA, the current of the 7^+ charge state measured on the FC after the dipole D1 was ~560 enA. In order to simulate the Cyclotron stripper, a foil stripper system was installed in the coupling line in front of the dipole D2. In Fig. 4 the charge state distribution measured on the FC after the dipole D2 is shown. The intensity for each charge state is calculated with respect to the total current measured. The incoming beam was I^{7+}, with energies 112 and 115.2 MeV respectively. The most probable charge state appears to be 25^+.

Considering the results obtained, the commissioning of the Cyclotron is feasible with the injection of a $^{127}I^{7+}$ beam; the acceleration of a $^{127}I^{28+}$ beam is planned.

8. THE BUNCHING SYSTEM

The coupling between the two accelerators requires that the beams coming from the Tandem have to be bunched at the same frequency of the C.S. radiofrequency system, i.e. 15-48 MHz. The goal for the temporal bunch length at the cyclotron stripper is $\pm 1.5^o$ RF, corresponding to Δt=170-560 psec., shorter than the $\pm 3^o$ RF necessary to reduce the energy spread at the extraction and make feasible the single turn extraction. This task is accomplished by a so called Low Energy Buncher (L.E.B.), located just in front of the Tandem and by the Rebuncher, placed between the Tandem and the Cyclotron, Fig. 2. In Table 1 the main parameters of the cavities of the bunching sytem are presented. A complete description of the pulsing system has been presented elsewhere.6) To test the first stage of bunching system an oxygen ion beam was used. The L.E.B. was driven at frequencies of 17.1, 24.7 and 33 MHz. To measure the length of the bunches delivered by the L.E.B. a μ-channel plate has been used. The μ-channel plate gives a timing signal for each ion that strikes a thin wire placed to cross the beam. The time between the μ-channel plate signals and the R.F. generator signals has been measured by a Time Amplitude Converter and monitored on a multichannel analyzer Fig. 5.

Table 1: Main parameters of the bunching system

	Buncher Cavity 1	Buncher Cavity 2	Rebuncher
Frequency	15-48 MHz	30-96 MHz	60-192 MHz
Peak volt.	1500 V	600 V	30 KV
In. Diam.	66 mm	66 mm	60 mm
Out. Diam.	238 mm	238 mm	255 mm
Cooling	air	air	water
Z_{sh} ($K\Omega$)	45-180	70-180	280-380
Q factor	560-2300	900-2300	3300-4400
Refl. power	~5%	~5%	

Temporal lengths as short as 1.32÷1.6 nsec. FWHM, and efficiencies in the order of 55÷65%, have been recorded. The efficiencies here reported are the ratio between the number of event in the area of the peak and the total event recorded during the period of the R.F., corrected for background noise. The results are satisfactory and in good agreement with the theoretical simulations. As foreseen by the calculations for heavyer ions like iodine we observed only small temporal structures on a continuous beam because of the poor uniformity of the electric field in the gaps when the $\beta\lambda$ of the beam is short. To counterbalance this effect, it is planned to put grids on the electrodes.

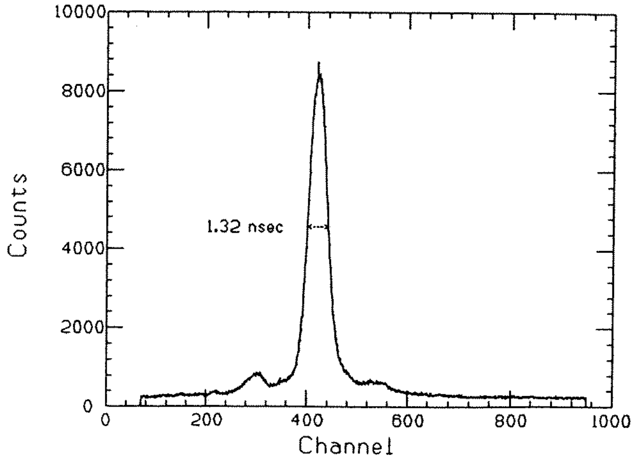

Fig. 5. A typical time spectrum for O^{5+}

9. CONCLUSIONS

The Superconducting Cyclotron was successfully moved from Milan to Catania without any damage. After a long time required to perform the welding of the radial penetrations in the cryostat and the assembling in the new site, we are now ready to restart the cool-down of the machine and to perform in the next months the final field mapping.

10. REFERENCES

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