COMMISSIONING OF THE K800 INFN CYCLOTRON

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The commissioning of the K800 LNS Superconducting Cyclotron, coupled with the 15 MV Tandem, began in May 94. A 30 MeV/n Ni beam was accelerated up to the extraction radius in July 94 and successfully extracted in December 94. The first nuclear experiment took place in July 1995. A short review of the machine history, of the performances of the major subsystems and of the results of the commissioning are presented in this paper.

1 Introduction

The K800 Superconducting Cyclotron (SC) promoted by the late Francesco Resmini, is now operating at Laboratorio Nazionale del Sud (LNS) in Catania. The project was funded in the 1981 and its realization is the result of the collaboration between two INFN laboratories, the LASA in Milan, and LNS. The design of the cyclotron and the construction of the main components were done at LASA. Most of the critical subsystems of the machine were completed in 1984, but the loss of the leader of the group F. Resmini caused a serious delay in the project.
In 1988 the magnet was cooled down in Milan with the cryostat assembled with a dummy vacuum chamber (without radial penetrations). In the first three months of 1989 we carried out a preliminary magnetic field mapping. After that the magnet was disassembled, with the cryostat fully dismounted for security reasons, and in 1990 moved to LNS. At the end of 1990 the assembling of the cryostat started with the final vacuum chamber completed of all the radial penetrations for the injection and extraction lines, the electrostatic deflectors, the magnetic channels and the current probe, see figure 1. In May 92 the cryostat was installed inside the magnet yoke, vacuum tested and by the end of October the cool-down of the coils was completed. Since then the coils have continuously been kept at the liquid helium temperature, so allowing to carry out the magnet excitation and the final magnetic measurements. An accidental movement of the cryostat during the coils excitation caused a delay of about six months, so the final field mapping was completed in April 1994. All the subsystems (RF, vacuum, diagnostic, etc...) were then installed and in May 94 we started the injection, acceleration and extraction of the beam. After a modification of the RF cavities couplers, to avoid discharges and subsequent breaking of these components, on December 22^{nd} a 30 MeV/amu ^{58}Ni beam was successfully extracted. In June 95 this beam was available in the experimental rooms and in July 95 the first nuclear physics experiment was succesfully carried out.

2 General description of the cyclotron

Since all the features of this machine were extensively presented in previous papers [1,2] only a summary is given here. The LNS Superconducting Cyclotron short (SC) is a three sectors compact machine, wich is presently operated as a booster of a 15 MV Tandem accelerator[3]. A layout of the cross section of the cyclotron through the median plane is shown in figure 1. The injection and extraction paths, the stripper position St, the two electrostatic deflectors, E1 and

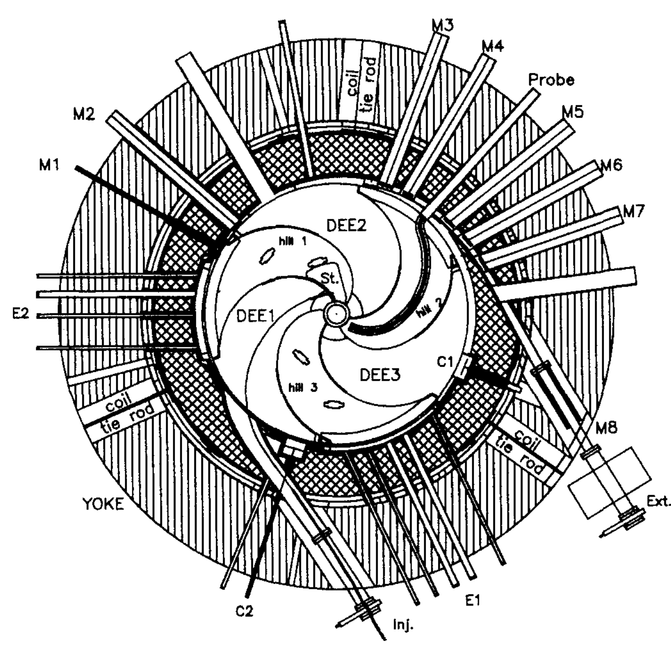

Figure 1: Cross section of the cyclotron at the median plane

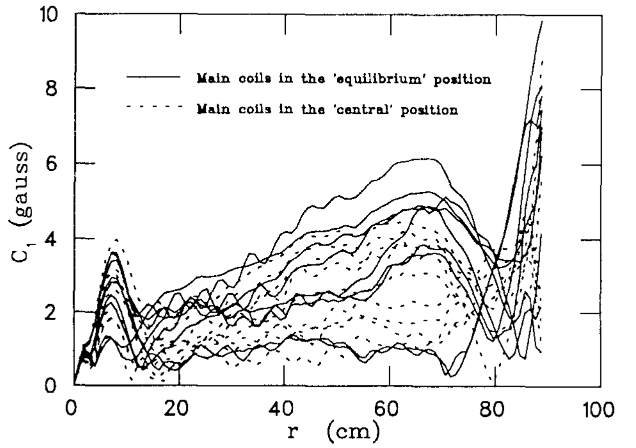

Figure 2: Measured 1st harmonic with coils in the "central" and "equilibrium" position

E2, the magnetic channels, M1-M8, and the main probe are indicated. The expected maximum energies of the machine are of 20 MeV/amu for the heaviest ions, like $^{238}U^{38+}$, and 100 MeV/n for fully stripped ions as given respectively by the bending limit K_b=800 and by the focusing limit K_f=200. The operating range of the radio frequency system is 15-48 MHz, corresponding to ion energies 8÷100 MeV/amu in harmonic mode h=2. The extraction radius is 87 cm (pole radius is 90 cm) and the magnetic field in the center of the machine ranges from 2.2 to 4.8 Tesla.

The main coils are splitted into two sections labelled α section, just below and above the median plane, and β section the further one from the median plane. The two sections are indipendently excited to obtain the required B_{av} vs. R over the wide dinamic range of final energies. In particular β section is designed to run either with positive or negative currents. This feature permits to reduce the power consumption of the 20 room temperature trim coils, wound on the pole tips.

3 Magnet excitation and field measurements

The magnet excitation of the SC started in Catania in November '92. Solved some problems with the matching of the power supplies to the pure inductive load of the coils we were able to reach the upper corner of the operating diagram (field level of 4.8 T). During a down ramping of the current to reach the lower corner of the operating diagram (I_α=1600 A, I_β=−650 A), corresponding to a magnetic field of 3.1 T, the cryostat chamber had sudden displacement of 1.6 mm with respect to the magnet. This was probably due to an initial off-centering of the iron wall of the cryostat combined with a strong interaction with the yoke because of the asymmetric penetration holes. To recenter the cryostat without disassembling the cyclotron a special mechanical structure was designed and built. In August '93 the recentering operation was completed and the cryostat vacuum chamber was secured to the yoke.

A detailed description of the magnetic field measurements, which were completed in April '94, are reported in a dedicated paper at this conference[4], so here only a few considerations are recalled. A particular care was given to the investigation of the field imperfection source (coils and vacuum chamber off centering, yoke holes penetrations, sectors assembly) through the analysis of the 1st harmonic[5]. The magnetic field of the cyclotron was measured by a moving search coil device, consisting in a rotating bar of carbon fiber. A delicate point of field mapping was the mechanical positioning of the measuring device: a position error of 0.1 mm could cause an error of 15 gauss (field gradient 15 T/m). Since it is quite impossible to position mechanically the system within 0.01 mm, a correction procedure was applied on the maps, based on the possibility of the mapper to start the radial scan well before the rotation axis (R= −22÷88.7 cm).

We initially positioned the coils minimizing the forces at the two extreme corners of the operating diagram. In this configuration we detected a coils misalignement of 0.6 mm with respect to the poles simmetry axis. As a consequence there was a 1st harmonic varying with the main coils current. Thereafter the coils were centred with respect to the magnetic field of the sectors, so that the 1st harmonic is invariant with the excitation[4]. However this coils position limits the operating diagram of the machine to a maximum field level of 4 Tesla because of the large decentering forces acting on the coils. This problem could be solved in future reinforcing the horizontal tie rods. With the coils in the centred position there is an unacceptable high 1st harmonic in the extraction region due to the poles and sectors

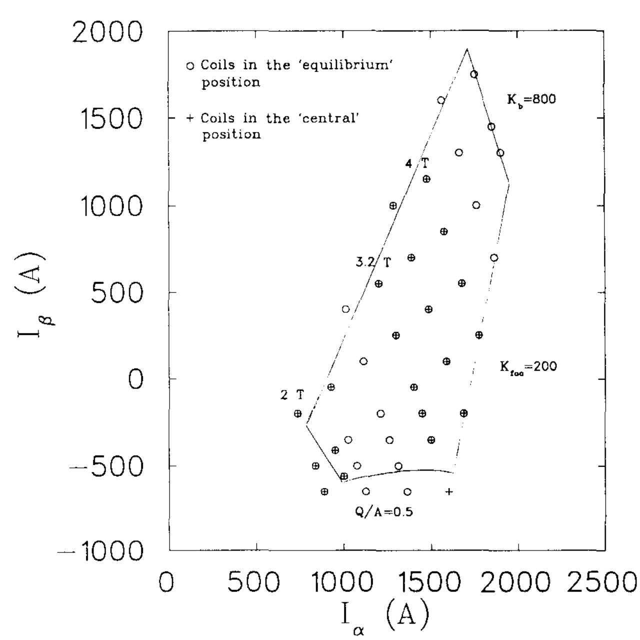

Figure 3: Operating diagram of the cyclotron, and grid map of the magnetic measurements

imperfections. Nevertheless a good compensation of the 1st harmonic was found placing six iron shims on the liner so obtaining a residual contribution of this harmonic generally lower than 3 Gauss and with a maximum value of 7-9 Gauss reached at the last measured point (88.7 cm). In figure 2 two sets of curves are presented. These are representative of the 1st harmonics component measured with the coils placed in the "equilibrium" and at "central" position. These values are acceptable for acceleration and 1st harmonic control of the precessional extraction obtained through the use of the harmonic coils. According to figure 2 it is possible to operate the cyclotron also with the coils placed in the equilibrium position, where the magnetic forces do not reduce the operating diagram of the machine. A total of 70 maps were measured with the coil in both positions.

The position of the measured magnetic maps in the (I_α,I_β) plane are shown in figure 3. The bending and focusing lines are drawn too

4 Diagnostic and extraction system

4.1 Radial Probe

The main beam diagnostic tool is a current probe moving along the central line of a hill so covering the whole acceleration range[6]. The movement of the probe is accomplished by means of a train, whose rails are screwed to the copper liner and whose carriages are realized by graphite slides in order to assure low friction. This probe had originally been designed as a current probe, but stimolated by the MSU experience[7] and based on the experience gained at our laboratory, it was decided to add a CCD camera to the probe head, which permits to look at the beam shape produced on a scintillating screen.

During the commissioning of the cyclotron the radial probe has been operated as an integral current read-out system or as a beam viewer. To select between these two options the scintillator screen is shifted 10 mm exciting a coil inserted in the probe head. The CCD camera works very well at radius larger than 50 cm, while for inner radii a noise generated by RF cavities does not permit a clear observation of the beam spot. The image system permits to evaluate radial and axial beam dimensions with a precision of 0.1 mm. A good mechanical and electronic reliability of the probe have resulted from tests performed during the commissioning.

4.2 Extraction system

The beam extraction occurs in 270° and requires two electrostatic deflectors, seven magnetic channels and two compensating bars, see figure 1. The position of all these elements depends on ion types and their energies. They are moved by stepping motors connected to a screw linear actuator and their position is controlled using absolute encoders. Beam diagnostics along the extraction channel after the two electrostatic deflectors consist of five differential and two integral probes to check the radial width and position. Moreover at the entrance of each magnetic channel an integral current probe is installed.

The electrostatic deflectors have been tested with and without beam. The maximum field needed for the more energetic ions is 140 kV/cm. During the commissioning they have provided an electrostatic field of 75 kV/cm, the gap being of 6 mm for the first one and 8 mm for the second deflector. At this value they showed for a long period of time (at least 8 weeks) a good reliability and no maintainance was needed. During short time tests a maximum field of 100 KV/cm has been reached with 6 mm gap. According to the experience of other laboratories[8] using gas for the deflectors conditioning and also for normal operation, we have recently carried out some tests on the first deflector fluxing O_2 gas. The test performed on a deflector that had already worked in normal operation for more than 8 weeks showed that the use of oxygen gas flow is very effective in recovering the electrostatic performance in case of deterioration. Considering this experience it was planned to design and install a system to flux O_2 gas in both deflectors, in order to achieve the possibility of routine operation at 100 KV/cm. Further developments of the deflectors are in progress aiming to operate safely at values around 120 KV/cm.

5 Superconducting cyclotron commissioning

For the Cyclotron commissioning, a 30 MeV/n ^{58}Ni beam has been selected. The reasons for this choice are both the interest of nuclear physicist in doing experiments with this beam, and the position of this ion in the operating diagram of the machine, well far from the boundaries, which in principle means that limiting values of the parameters are not required.

5.1 Injection line and bunching system

The ^{58}Ni beam, accelerated by the Tandem, at 47.5 MeV, is radially injected[9] into the cyclotron, after having been transported with a line[10] made up of three 60^0 dipoles and fourteen quadrupoles, ending with a steering magnet able to change the direction of the beam by a few degrees. The layout of the LNS accelerators room is shown in figure 4, where the Tandem and Cyclotron, the 450 KV preinjector, the Low Energy Buncher (LEB), the High Energy Buncher (HEB) and the beam lines are outlined. The setting and tuning of the Tandem-Cyclotron beam transfer line is normally made using Faraday Cups and scanning wire Beam Profile Monitors as diagnostic elements. The beam transmission is of the order of 100%. The reproducibility of the beam line setting is satisfactory; the operator has only to recall a file and the computer sets the elements of the whole line in about 5 minutes. To obtain 100 % transmission only the two vertical steerers need to be adjusted and the Tandem parameters need to be slightly tuned. Emittance measurements have been carried out along the transport line with different methods: direct measurements by means of slit or multislit systems and indirect ones by means of the three gradients method[6,11]. The emittance value measured for the Ni beam developed during the commissioning is 0.8 π mm·mrad in both transverse planes.

The continuous Tandem beam should be bunched into the 30°-40° phase acceptance range, with an efficiency as high as possible, to increase the beam current of the Cyclotron. Moreover if the bunch length is shorter than 6° RF, the beam can be accelerated with low energy spread and a single turn extraction becomes feasible. To obtain these goals a Low Energy Buncher (LEB), placed just in front of the Tandem, and a High Energy Buncher (HEB), between the Tandem and the Cyclotron[12], are installed.

The LEB is a double drift buncher, consisting of two cavities in $\lambda/4$ mode separated by a drift space. The two cavities of the L.E.B. were originally designed to work respectively in the ranges 15-48 MHz and 30-96 MHz. In order to increase the interbursts time, as requested by nuclear physics experiments, we decreased the frequencies ranges of both cavities. During the commissioning the cyclotron has been operated in harmonic mode h=2, at frequency of 27.5 MHz and the LEB at the fundamental 13.75 Mhz. Bunch lengths as short as 2.3 ns were measured for ^{58}Ni, and efficiencies in the order of 50% have been recorded. To measure the length of the bunches delivered by the LEB. a μ-channel plate detector and a Time Amplitude Converter (TAC) have been used.

The HEB consists of a cavity resonating in $\lambda/4$ mode in the frequency range 54 ÷ 200 MHz, which drives a drift tube with two accelerating gaps. If the pulses delivered by the LEB are shorter than ±40° of the rebuncher frequencies, it is possible to rebunch the beam with enough linearity to obtain a bunch length shorter than 6° RF. The maximum voltage needed to obtain a time focus at the center of the cyclotron is 30 KV.

High power tests have been satisfactory but tests with the beam were not performed because of a failure of the power amplifier. Moreover because of multipactoring phenomena inside the second cavity the LEB was often operated with only one cavity, with an efficiency of 30%.

5.2 Injection

Injection into the cyclotron occurs through a valley as shown in Figure 1, and the beam then reaches a 30 $\mu g/cm^2$ carbon foil placed in the adiacent hill at a radius of 145 mm. The measured stripper efficiency for the charge state 16+ is of 20%. The stripper foil meanlife is of about 120÷150 hours. The position of the injection trajectory is controlled by a steering magnet, the last element of the coupling line. With a sligth change of the steering magnet the trajectory of the injected beam clears the stripper at its outer side and crosses the path of the moving probe at radius 450 mm in the center of the hill following the stripper. So it is possible to look at the injected beam spot on the moving probe to check position, size and current of the beam.

During the commissioning an injection efficiency of 70% has typically been measured. We believe that the losses inside the injection channel are due to the beam vertical dimensions. To minimize the beam size along the acceleration and extraction path, it is necessary to match the injected beam to the acceptance of the Cyclotron at the stripper position. This is obtained when waist in both radial and axial planes are produced at the stripper position. Unfortunately, in agreement with the computer simulations,

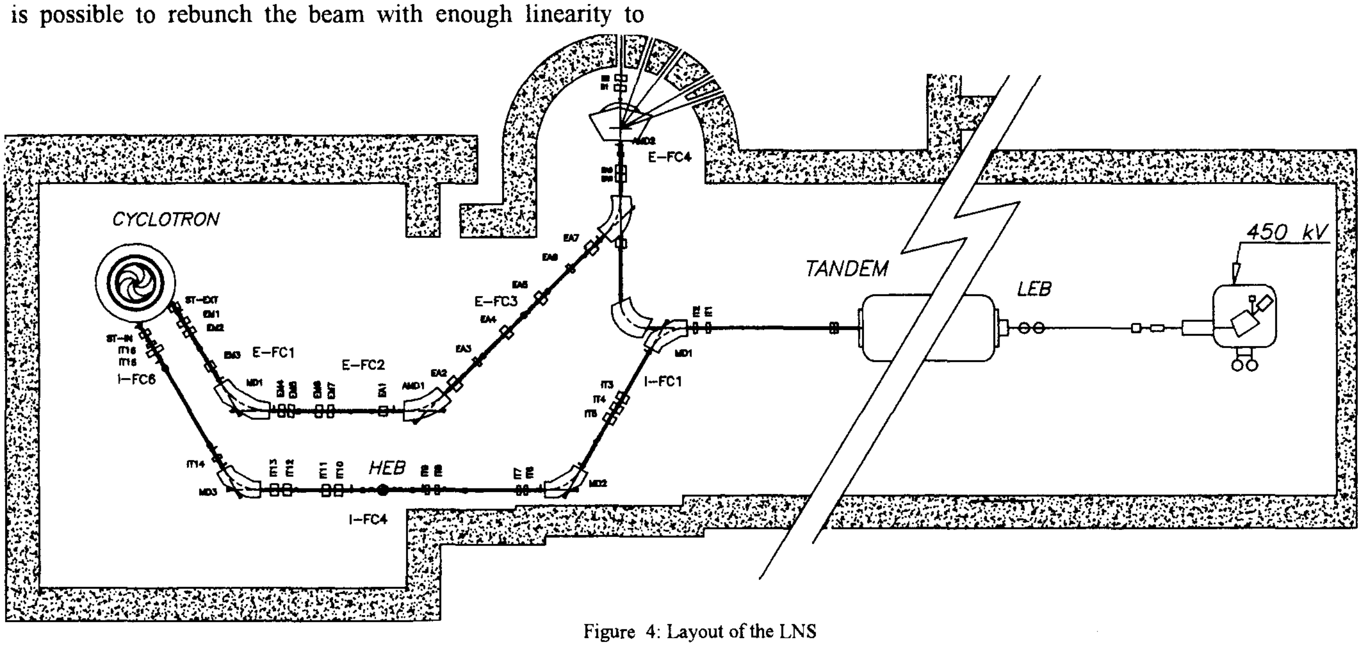

Figure 4: Layout of the LNS

it was experimentally proved that a focus condition at the probe position does not imply a good matching condition for the beam at stripper position. The correct tuning of the quadrupoles of the last part of injection line was been done looking at the stripped beam shape on the first orbit. This is achieved placing the moving probe at the same radius as the stripper, so as to look at the stripped beam about 120^0 after the stripper foil.

The achromatism of the injection line becomes an important aspect when the HEB is operated. In fact the HEB introduces a beam energy modulation of +/-0.1% which should cause a broadening of the beam size proportional to the chromatisme of the injection line . To check the achromatism of the beam line the tandem voltage was changed by +/-0.1% and a shift of the injected beam position less than 1 mm was detected on the moving probe, which proves that the injection line is almost achromatic.

5.3 Acceleration

The parameters used to accelerate the Ni beam are shown in Table 1. To find out the cyclotron parameter needed for the acceleration of the beam a 360° field map was used. This map was obtained from the 120° symmetric one by adding the measured significant imperfection harmonics contribution and the trim coils modulation. Moreover this map takes into account the contribution of the magnetic channels and compensating bars.

Table 1: Cyclotrons parameters

B_0	3.2 42	T	Q/A	0.276	
f_{RF}	27.5	MHz	T/A	29.4	MeV/n
V_{dee}	70	KV	I_a	1290	A
h	2		I_b	270	A

in Figure 5 the beam current against the cyclotron radius is presented. In the first centimeters, R=150÷200 mm, are visible the peaks due to the spurious stripped charges state q=15,14,13. The beam current is then constant for R=200÷750. Unfortunately after this radius the main probe has a failure due to a short circuit between the probe head and the liner. However in the radial region between 800 and 870 mm we have a beam loss mainly due to the crossing of the coupling resonance $\nu_r=2\nu_z$. An axial beam blow-up is generated with current losses on the upper and lower part of the accelerating chamber. An activation has in fact been measured just in this region. This effect is minimized if the orbits are well centered. This is achieved using the harmonic coils number 3 and 4 to produce a first harmonic of proper amplitude and phase. An efficiency of 80% in resonance crossing has tipically been obtained. Mainly the beam loss at this position is due to the phase acceptance of the cyclotron, which is about 40°. The beam current at the extraction radius is given by:

$$I_{ext}=I_{inj}\cdot\eta_{inj}\cdot\eta_{st}\cdot\eta_b\cdot Q_f/Q_i$$

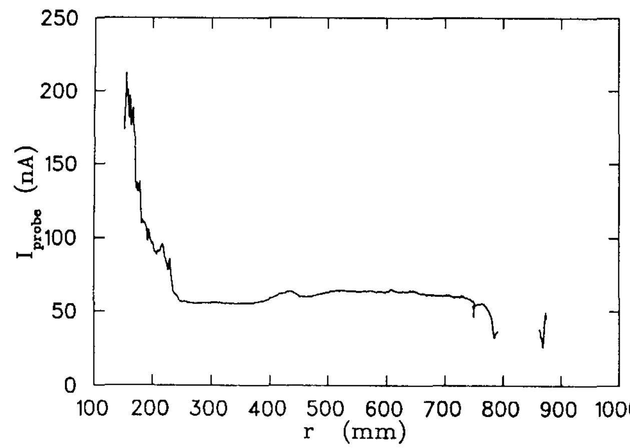

Figure 5: Current measured by the main probe vs. radius

where: I_{inj}=200 nA, is the measured injected current; η_{inj}=70%, η_{st}=20%, η_b=30% are respectively the injection, stripping and bunching measured efficiencies; Q_f=16 and Q_i=4 the charge states after and before the stripper. The expected current I_{ext} at the extraction is 33.6 nA which is in good agreement with the value of 32÷35 nA measured by the moving probe at extraction radius, just before the first electrostatic deflector.

5.4 Extraction

The extraction calculations for the 30 MeV/n Ni beam indicate that an electric field of 65 KV/cm is necessary for both deflectors and only five magnetic channels (M1, M4, M5, M6, M7) are required. We positioned the deflectors and these channels as calculated and with small adjustment in the deflecting voltage we had the beam on the main current probe inside the extraction channel at a radius of 970 cm. With small adjustment of the channels position and removing the main current probe we had the beam outside the cyclotron at the first faraday cup position one meter beyond the yoke. During the commissioning we have tipically measured an extraction efficiency of 30%. We consider these values satisfactory in this commissioning phase. The timing structure of the extracted 30 MeV/amu ^{58}Ni beam was measured with a BaF_2 scintillator crystal placed in the accelerator room near a Faraday cup, 10 m out of the cyclotron[13]. The signal originated by the prompt γ-rays on the scintillator was used as start of a time to amplitude converter and the rf signal of the buncher was sent as stop. The measured temporal beam distribution, shown in figure 4, has a 2.5 ns FWHM corresponding to ≈40° rf and almost equal to the 2.3 ns measured before the injection (the time resolution of the BaF detector was ≈0.8 ns against the ≈0.3 ns of the μ-channel plate detector). The interbursts separation is 72.8 ns. The small satellite peak between the two main peaks corresponds to the cyclotron frequency.

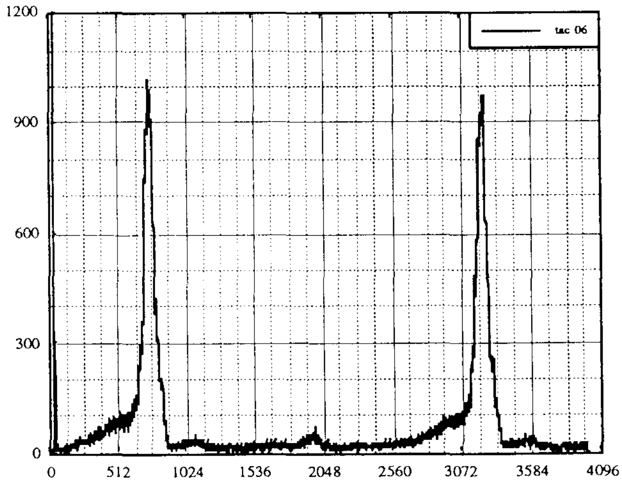

Figure 6: Time spectrum of the extracted beam

During the first nuclear experiment carried out in July 95 a mean value of 4 nA has been measured at the target position. In September a beam current of 10 nA extracted from the cyclotron was transported to the end of the beam line inside the accelerator room (figure 4) with an efficiency of 100%.

6 RF system

The RF system has been presented and discussed elsewhere[14,15], so here will be reported only the advances accomplished during the commissioning. The six identical half λ/4 cavities, assembled at Milan, were tested inside the cyclotron magnet to be in July-September 93. After the magnetic measurements, the RF system has been operated in May-June '94 during the first acceleration tests. Since the SC can be operated in three different harmonic modes (1, 2 and 3), the three cavities must support dee voltages either in phase (harmonic mode 3) or out of phase of 120 degrees (harmonic modes 1 and 2). In the last two cases, the crucial point is the mutual parasitic coupling[16]. A mutual capacitance between dees 1 and 3 of the order of few pF, 50 times smaller than acceptable, has been measured using a Network Analyzer. The operational frequency range fits that of the power amplifiers, being helpfully a little wider than strictly required (15 to 48 MHz). All the other cavity parameters (Q factor, shunt impedance, etc.) are very close to the expected values.
The three cavities are conditioned with the magnetic field on and a vacuum of few 10^{-6} mbar. The lowest levels of multipactoring, which are situated in the region of the dee gaps, are the most critical to be passed and occur for dee voltages ranging between 60 and 200 V. After a long shut-down which includes a machine opening, these low voltage multipactoring levels need for conditioning 1÷3 hours, the time being rather independent either from the power used to pulse the cavity or from the pulse shape and duty cycle. A low power conditioning (10÷50 W) is preferred. A second group of multipactoring levels is situated, for all the three cavities, between 2 and 4 KV. To pass these levels a pulsed input power of few KW is preferred to reduce the conditioning time to less than one hour. No conditioning time is required up to 60-70 KV, while to get a stable operation at 100 KV at least 5 hours are required.
An absolute DEE-voltage calibration has been done[17] measuring the x-rays produced by the electrons, which have been accelerated by the DEE-voltage. We have calculated that in all the operational conditions there are electrons with energy almost equal to the DEE voltage, in the worst case $E_e=0.98V_{DEE}$. The X-rays produced by these electrons form the upper limit of the X-ray spectrum.
In figure 7 the measured x-ray spectrum is presented. The upper side of this spectrum is also magnified just to identify the maximum energy of the X-ray detected.
Since the strong magnetic field forbids the movement of the electrons along the radial plane, they can be accelerated only in the vertical direction and strike the surface of the liner or of the DEE electrode which are out of the median plane. For this reason the X-ray detector was installed inside a dummy hole symmetric to the trimming capacitor, at 350 mm from the cyclotron center. The detector was installed out of the vacuum chamber and the flange which plugs the hole was aluminum made with a thickness of 1.6 mm to reduce the perturbation of the measured spectra.
During the first test, with the magnetic field on, we had atotal of seven coupler failures, all these failures looking similar. The damaged coupler showed a metalized region on the ceramic insulator, while the failure was detected as a sudden pressure increase into the vacuum chamber, caused by a water leak in the ceramic cooling circuit. The failures were caused by the effect of the magnetic field which focalizes and stabilizes the resonant beam of electrons which can carry a significant power (in one case we have estimated a power of the order of 70 W) across the inner and outer walls of the coupler. As a conclusion we decided to modify the coupler design in a way similar to that proposed and successfully tested by other laboratories (TAMU and MSU). With few modifications the insulator. Position and orientation have been changed, to annul the

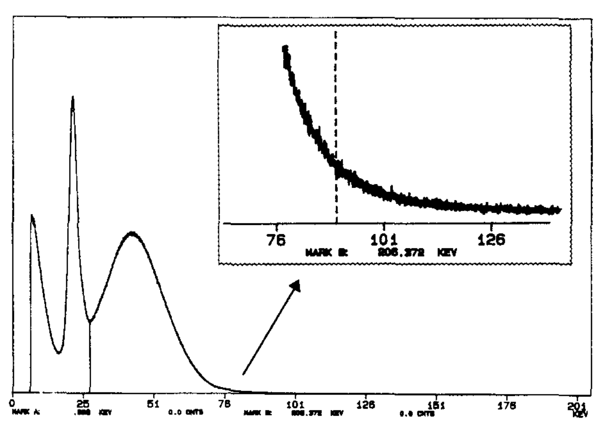

Figure 7: Dee voltage calibration by X-ray method

effect of the magnetic field. The new couplers were installed and succesfully tested inside the machine in December 1994. From their installation up to date they are in operation for more than 2000 hours of operation and no problems have been detected.
The electronic control system of the cyclotron RF system has been upgraded to improve it both in reliability and maintenance time[18]. The three amplitude loops, one for each cavity, are automatically locked, just when the dee-voltage reaches the reference setting value. They ensure an amplitude modulation noise, of the voltage on the dee, below 10^{-4}. Three phase loops maintain the phase difference between the dees, with a stability of ± 0.2°. All these loops are automatically relocked turning-on the RF power after an accidental or not shut down

7 Subsystem

7.1 Control system

The SC and the related beam trasport lines are fully computer controlled. The control system has been designed and realized[19] according to a distributed architecture with a three levels structure: The computing power has been distributed according to functional cryteria with functional accelerators subsystems controlled by a single control unit. The field level of the control system has been implemented using a high speed serial bus (Bitbus) even if GPIB and RS232 connections have been used for particular devices. The control level has been realized with MS-DOS Pcs 386/486 controlling functional accelerators subsytems. The Pcs are then interconnected between them and with the operator console by means of an ETHERNET network. The console has been implemented as a Local Area VaxCluster of DEC 4000/60 Vaxstations and with a 4000/90 Vaxstation as boot member. An object oriented graphic software has been developed allowing the full control of the facility. The system has fully been working since 1992 and it has been used satisfactorly during all the stages of the SC commissioning.

7.2 Vacuum system

The SC structure and the presence of several vacuum subsystem requires the employment of 22 pumps, 70 valves, 53 gauges. The vacuum plant of the cyclotron is divided into the following subsystems:

- acceleration chamber
- liner
- guard vacuum
- injection line
- extraction line
- current probe
- cryostat insulation chamber

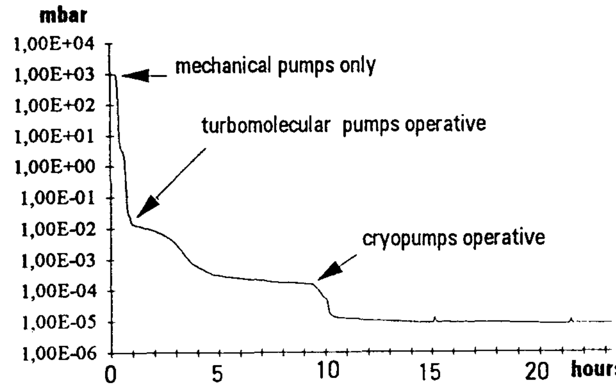

Figure 8: Pressure vs time of a typical pumpdown

An extensive report of these plants is elsewhere presented[20]. The subsystem of the vacuum acceleration chamber consists of three turbomolecular pumps and three so called splitted cryopumps with the cold head and moving piston inside the Dees and the motor drive valve assembled far from it to avoid problems due to the magnetic field. A Stripper device and two high voltage deflectors are assembled in the acceleration chamber. Their low vacuum conductance required to use 3 other standard cryopumps. The pressure in the accelerating chamber after 24 hours pumpdown is $7\ 10^{-6}$ mbar and reaches the operative pressure of $2\ 10^{-6}$ after 48 hours. The measurement of the residual gas pressure in the acceleration chamber after 7 days of pumping shows the presence of H_2O gas (about $4.3\ 10^{-7}$ mbar) as element mainly limiting the final pressure which is about $5\ 10^{-7}$ mbar. The low level of N_2CO and O_2 gas (about $2\ 10^{-8}$ mbar) shows that there are not relevant leaks versus the atmosphere. A pressure of $5 \div 8 \cdot 10^{-7}$ mbar was recorded during the last test of beam acceleration.
Moreover two fast valves having a closing time lower than 0.1 sec, are installed on the injection and extraction line to prevent entrance of air due to accident on the experimental area. These two fast valve are controlled by sensors installed about 20 m ahead on the injection and extraction lines.

7.3 Cryogenic

The cryogenic circuit is based on a helialrefrigerator delivering 180 W or 53 l/h of LHe at 4.3 K without LN precooling and about 100 l/h with precooling. More information on the cryogenic plant was presented previously[21]. During the three years of continuous operation the plant was stopped by small failures, generally half a day long. The main cause of stops were power line and cooling plant failure (about 80%) and failure of the cryogenic plant. Only in June 1994, just during the first acceleration, there was a serious stop due to a valve failure and consequent entrance of air inside the cold box, causing the rupture of the bearings which support the turbines of the liquefier. Thanks to the plant supplier that was able to ship two new turbines in a short time the liquefier was restarted after a 5 days stop, and after 7 day from the accident we could supply LHe to the magnet.

Future plans

Until the end of 1995 we are planning to deliver 30 MeV/amu Ni beam for nuclear experiments. Moreover we will make an effort to increase the energy up to 50 MeV/amu. According to the nuclear experiments requests new beams will be available next year and we will try to make the machine able to span the whole operating diagram. In parallel a work will be done for the installation of a Superconducting ECR source and an axial injection system for the cyclotron to increase significantly its performance both in terms of maximum energy and of intensity. Different new activities are planned and funded for our heavy ion facility. The most significant is the development of a radioactive ion beams (RIB) facility[22] based on the use of SC to produce high energy and high intensity primary beams hitting a thin/thick target producing exotic beams by means of nuclear interactions with thin or thick target. This project foresees to furnish RIBs either at intermediate energy or at energy around coulombian barrier. In this last case the Tandem will be used to accelerate the exotic nuclei produced by interaction on thick target.

In Memoriam

We always remember the skilness and the enthusiasm Francesco Resmini had for his "job" and the way he was able to pass this enthusiasm to his collaborators. We dedicate to his memory the succesful commissioning of the machine.

Acknowledgement

We would like to thank all the people of the LNS Cyclotron and tandem groups and of the LASA Cyclotron group for theirr dedition working at the development of the LNS heavy ion facility.

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