Beam Transfer Lines for the Tandem Superconducting Cyclotron at Laboratori Nazionale del Sud

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At the L.N.S. an MP-Tandem will be used as injector for the Superconducting Cyclotron. The handling beam system for the Superconducting Cyclotron is described. All the lines are designed to be achromatic. Home made beam profile monitor is the main diagnostic device and its design and preliminary tests are presented. The distributed computer control for all the beam lines and bunching system is described too. The status of beam transfer line from tandem to S.C. and of bunching system is presented.

Introduction

The heavy ion facility at the LNS in Catania is based on an MP Tandem [1], upgraded to 15 MV. In future a K=800 Superconducting Cyclotron (S-C), presently under construction at the University of Milan [2], will operate as booster of tandem.

The layout of the facility is presented in fig.1. The tandem beam will be injected radially into the cyclotron by coupling line [3]. The S-C operating as booster of tandem will produce a good quality beam for ions from Lighter to Uranium. The emittance area is expected to be less than 3x mm.mrad, and the beam energy spread $\delta E/E \sim 10^{-3}$. The maximum magnetic rigidity of the beam is 4.1 Tm. The beam bunching system consists of a low Energy buncher (before the Tandem) and of a rebuncher realizes a beam bunch of $\sim 3^\circ$ RF FWHM. We expect the same bunch length at the S.C. extraction because it is isochronous. In order to preserve these properties the beam transport system has been designed in a completely symmetric mode.

Home made Beam Profile Monitors (BPM) are used to set up and tune the beam lines. Their features and tests results are presented in the following. The distributed computer control for the beam handling and bunching system is described too.

Transport lines

We can transfer either tandem or cyclotron beam in all the experimental areas through the same lines. There is a rough division between Cyclotron experimental area and Tandem area, on the left and right side respectively in fig.1). The beam line of tandem area has existed already and no more modification is planned.

In the present paper only the beam handling system for the cyclotron is presented. It is composed of decoupling section, analysis section and experimental area lines. The characteristics of quadrupoles used in present calculations are listed below:

<table>
<thead>
<tr>
<th>Type</th>
<th>$L_{eff}$ (cm)</th>
<th>Aperture (mm)</th>
<th>$B_{max}$ Kgauss</th>
<th>Qt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>QA</td>
<td>20</td>
<td>60</td>
<td>6.6</td>
<td>11</td>
</tr>
<tr>
<td>QB</td>
<td>30</td>
<td>75</td>
<td>7.0</td>
<td>13</td>
</tr>
<tr>
<td>QC</td>
<td>20</td>
<td>75</td>
<td>7.0</td>
<td>6</td>
</tr>
<tr>
<td>QD</td>
<td>40</td>
<td>50</td>
<td>7.2</td>
<td>6</td>
</tr>
<tr>
<td>QE</td>
<td>40</td>
<td>90</td>
<td>5.0</td>
<td>4</td>
</tr>
<tr>
<td>QF</td>
<td>40</td>
<td>120</td>
<td>4.0</td>
<td>2</td>
</tr>
</tbody>
</table>

Decoupling section

In order to simplify the tuning of all beam transfer lines a decoupling section is specially designed to provide an achromatic double waist at $S_1$ for all kinds of beams accelerated by the cyclotron. Therefore, it is possible to set up the following section just by scaling the magnetic field according to the beam magnetic rigidity.

The first 4 quadrupoles of the line combined with a $60^\circ$ deflection wedge magnet are used to compensate cromatism for all kind of ions coming out from cyclotron. The other 4 quadrupoles are used to rotate the tilted beam ellipses in order to obtain a perfect double waist with desired spot of 2 mm at the $S_1$ slit position. Here an emittance meter (EM) will measure the beam emittance and its orientation shape. Simulations of beam transport along this section line for eight representative ions were accomplished using "TRANSPORT" code. The characteristics for these eight ions beams at the Cyclotron exit position are taken from ref.[4], and were calculated using the simulated magnetic field of cyclotron with a passive extraction channel. The beam envelope along the decoupling and analysis line for a representative ion is shown in Fig.2).

Analysis section

This section consists of 8 quadrupoles and two $45^\circ$ wedge magnets placed in a complete symmetric geometry between $S_1$ and $S_3$, so a point to point transport with unitary magnification in both radial and vertical planes is realised.

This section performs an energy beam selection and it can be operated in two modes, achromatic or high dispersive.
1) Achromatic mode. When this mode is selected, the cyclotron beam is analysed at S2 position, where the dispersion and magnification values are $R_{16}=2.88 \text{ cm/\%}$ and $M_x=0.5$ respectively, and an energy resolution $\sim 7\times 10^{-4}$ is expected. Only six quadrupoles are requested to execute general achromatic transport. The quadrupoles Q9 and Q16 will be switched on if a higher resolving power at the intermediate analysing point is required. At this position we plan to measure spread of beam energy measuring radial beam intensity with a BPM. Optimization of the input phase of injected beam and correct running of single turn extraction could be also tested. Moreover measure of radial intensity distribution will be measured vs. beam’s divergence, testing the achromaticity of beam at entrance of this section. This will be performed by selecting different slides of beam with a slit placed in front of the dipole D2.

2) Dispersive mode. In this mode the cyclotron beam is analysed at the end of analysis section at S3 position. This mode is performed using only six quadrupoles of the analysis section and switching off the quadrupoles Q12 and Q13. A point to parallel and then parallel to point beam transportation in both radial and axial planes is obtained from S1 through S2 to S3. The energy resolution of the system is mainly regulated by the quadrupoles Q9 and Q16, the field setting of the two central doublets is almost independent vs dispersion of system so it is quite easy to reproduce the optimized transport’s optics. The magnification of the system is unitary and its typical dispersion $R_{16}=14 \text{ cm/\%}$. In this mode only a low intensity beam is transmitted and the beam can be considered monoenergetic for the following transport elements. This section can also be used as a beam matching section for an energy-loss spectrometer that is to be designed in the future. The main geometrical aberration is corrected by introducing a curved pole boundary at the exit and entrance faces of magnet D2 and D3 respectively.

Experimental area

The lines called Cylope, crystal ball and pions are able to provide an achromatic double waist at respectively different target positions. The starting point for these sections is the slit S3 in Fig.1. Eight dipoles, with a $22.5^\circ$ deflection angle, are used in these lines. Some dipole magnets will have laminated iron in order to switch beam to different experimental rooms at the same time. The beam lines have been designed so we can use the same setting for the common quadrupoles independently from the different experimental rooms to be fired.

1) CICLOPE LINE. The symmetry of this transport line simplifies the tuning of the magnetic elements. Cyclope line is symmetric around the midplane of quadrupole B6, here the condition $R_{50}=0$ is required to perform an achromatic transport. This line can be tuned in three steps:

i) The beam is focused at the BPM placed after DQ1 along the $u'$ line in Fig.1 by the two quads B1/2, (Dipole DQ1 is switched off);

ii) Achromatism is obtained by adjusting only the magnetic fields of DQ1=DQ2 and of B6, this condition is reached when the radial beam envelope in two symmetric points with respect to B6 are equal;

iii) the beam is focused on the target by quads B8 and B9;

2) Crystal ball line. The first part of Cylope line from S3 to DQ4 is commonly used by Crystal ball line and it was designed to work with the same setting in both case. The beam is transported from B6 to G1 by TQ4, four quadrupoles that performs a special antiunitary system transport (telescope). Therefore, the system from DQ1 to DQ2 is like an antisymmetric system around G1. In order to realize the achromatic transport the condition $R_{16}=0$ must be satisfied at the middle of G1 this is obtained by setting fields of the quadrupoles G1 and B6=G2. The last three quads are able to deliver a beam spot of $2 \text{ mm}$ at the target position.

3) Pion line. The first four quadrupoles are driven by the same current but with alternate polarity to obtain an antiunitary transport (telescope) from S3 to S5 as for "crystal ball line". The two $22.5^\circ$ bending magnets with the quadrupole P4 are used at the midplane of quadrupole to obtain the condition $R=-26=0$, thus realizing an achromatic transport. The pion spectrometer is a vertical deflection system and its energy resolution depends on the beam vertical size at the target. Its beam line transport was designed to obtain a vertical beam spot of $1.5 \text{ mm}$.

Beam Profile Monitor

The Home made Beam Profile Monitor (BPM) is formed by a carriage with an insulated frame to hold two tungsten wires perpendicular between them and a third wire at $45^\circ$ to obtain a better reconstruction of the beam image. The carriage is moved at $45^\circ$ with respect to the vertical so that the beam along the X and Y axis is intercepted while the third wire is moved at $45^\circ$. The motion, from motor to the carriage, is transmitted through a vacuum ferrofluidic feedthrough, chosen to reduce friction and overall dimensions and to increase the...
Position control is obtained using a zero signal connected with the rest position of the carriage defined by wires outside of the beam. A stepping motor is used for wires motion and a position accuracy of 0.15 mm along the x and y axis can be obtained. The reconstruction of beam intensity vs position is accomplished counting the number of steps. Measurement region is delimited by a circular shield of 50 mm. This shield is insulated and a bias voltage may be applied to reduce secondary electrons emission. A current to voltage converter with a sensibility of 1mV/100pA detects the current of the beam intercepted on each wire. A noise equivalent to 0.05 pA has been measured at input of ADC. The analogic signal is then converted with a 12 bit ADC according to the features which will be described later. A preliminary version of the control and data acquisition software permits 100 scanned positions along the horizontal and vertical axis with a total data acquisition time of 10 sec. This time will be reduced in the final version to less than 1 sec, optimizing the software and reducing the number of scanned positions at ~100.

A prototype of the BPM was tested in September 1987 using a C12 beam delivered from the tandem at 40 MeV, beam current was of 200 nA. In fig. 3) a beam shape plotted on the computer screen is presented.

Fig.3) Beam profile on computer screen measured by BPM

Computer Control and Data Acquisition System

The computer control for the beam handling and bunching system of LNS has been designed taking into account the modern microcomputer technology and the development of interconnecting strategies among "intelligent" devices. It is thus possible to break big problems into simpler repetitive ones and to specialize hardware and software to specific tasks. We have designed a system able to be connected both to the computer control of the S.C. and to operate in a stand alone fashion. One or more microcontrollers are integrated in each device to be controlled. Their interconnection is accomplished on a serial bus with a hierarchical protocol proposed by Intel and called BITBUS. The main features of the component and of BITBUS which is implemented in firmware on the microcontroller are here listed:

8051 MICROCONTROLLER CORE
- 12 MHz clock, priority interrupts 32 programmable I/O lines, Two 16-bit Timer/Counter
- 4K*8 ROM, 192*8 RAM
- 64 K Accessible external program memory

SERIAL INTERFACE UNIT
- 2.4 Mbps maximum data rate
- 375 Kbps using on-chip phase locked loop
- Communication software in silicon: Complete data link functions and Automatic station responses

In fig. 4) the structure of this control station is shown. Its interconnection with a dedicated console or with the S.C. console is realized according to the hardware and software rules developed for the computer control system of the Cyclotron[6]. Two control stations will be realized dedicated respectively to the injection and extraction lines, and to the experimental lines.

We have recently developed a home made board called Bitbus Motor Control (BMC) to control up to 4 stepping motors. Steps number, speed and acceleration are programmed using a 16 bit counter. The electronic logic interface between the programmable counters and the external motor power sections is integrated on a 1800 gates EPLD. Data acquisition for beam's diagnostic is realized using commercial boards which provides a 12 bit ADC, an 8 differential channels multiplexer and a preamplifier with software programmable gain up to 500. An higher precision Bitbus custom boards, providing a 16 bit ADC, developed for the S.C. control system, will be available too. The coupling line power supplies are controlled by a custom GPIB device, based on an 8 bit microcomputer. Its connection with the host CPU is accomplished by a Bitbus board integrating a GPIB master controller.

Conclusion

At present the coupling line is in progress. The Low Energy Buncher and the phase-amplitude control loops are under test before their installation on the beam line. The rebuncher is also in progress. An Emittance meter device using similar mechanics and electronics as BPM is being investigated. A control system for the vacuum along the beam lines is in progress. The coupling line, BPMs and a simplified computer control will be tested with beam before the end of '88.

References