PERFORMANCES OF THE LEBT OF THE CERN LEAD ION LINAC

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Abstract

The Linac of the CERN Lead Ion Facility has been commissioned. This accelerator complex is the result of a collaboration among several Laboratories and Universities.

The Low Energy Beam Transport line (LEBT), that matches the beam from the ECR source to the input of the radio frequency quadrupole accelerator (RFQ), has been designed and built by INFN-LNL. The main components of the LEBT are the focusing system, the high-resolution spectrometer and the measurement facilities.

A short description of the LEBT and the results of its commissioning are presented.

Introduction

The Low Energy Beam Transport (LEBT), presented in fig.1, guides the beam from the source to the RFQ, allowing the selection of the Pb_{208}^{27+} beam at 2.5 keV/u from the source and the proper beam matching to the accelerator. It is composed of a solenoid (SOL01) and a quadrupole (QDN01), a high resolution spectrometer(BHZ01,BHZ02), a triplet (QFN03,QDN04,QFN05) and another solenoid (SOL02) to match the beam to the RFQ acceptance.

The elements of the line (magnets, diagnostics, vacuum equipment) were installed in June '93, allowing extensive tests of the spectrometer resolution. In November '93 the line was operational and tests and calibration were carried out with an emittance measurement device temporarily located at the RFQ input plane, before the RFQ installation in April '94.

The extensive tests of the optics and of the equipment were of crucial importance for the following RFQ commissioning, since the LEBT is a rather complicated multi-parameter line. Mastering the parameters of the LEBT and having a good knowledge of the setting corresponding to the RFQ input conditions allowed the RFQ to quickly reach its design performances.

The elements of the line

The optics of the LEBT has been theoretically optimized to obtain the required acceptance of 200 π mm mrad, a resolution of .003 $\Delta m/m$ and the matching to the RFQ [1].

In the design and construction of the magnetic elements (done by industry) the most critical item was the spectrometer composed of two 67.5^0 dipoles, with curved boundaries for sextupole correction. The effective field boundary positions were specified with a tolerance of 0.1 mm,and were adjusted with a sophisticated system of 2 x 30 pairs of field clamps positioned according to Hall probe field measurements. In the centre of the magnet a field homogeneity of 0.02% was required in the beam region ($\pm$ 180 mm off axis in the median plane). These specifications were fulfilled in the required field range (50-100% of the maximum field) by the introduction of a "Purcell gap".

Concerning the two solenoids, the radial field homogeneity and the overlapping of mechanical and magnetic axis was checked. For the quadrupoles (200 mm effective length, 120 mm aperture diameter), two items were important: the minimization of the dodecapole component due to fringe fields (0.3% of quadrupole for R = 50 mm) and the measurement of the effective length in the final triplet assembly. In this configuration the central quadrupole is magnetically shorter and the two lateral ones are magnetically displaced with respect to the mechanical centres. A good calibration was indispensable for the use of the triplet, and an even finer recalibration, with the beam, turned out to be necessary during commissioning.

Computer controlled slits are installed in the object (SLH01) and image points (SLH02) of the spectrometer. Profile measurement harps are available behind the spectrometer (MSF02) and between the triplet and the last solenoid (MSF03), see fig.1. The harps have different step sizes (0.85,1.7 and 3.4 mm) according to the nominal beam sizes, but are mounted on a standard printed circuit. Beam currents can be measured using two Faraday cups (MFC01 and MFC02) and a beam transformer (MTR05).

Spectrometer resolution

The line between SLH01 and SLH02 acts as a spectrometer with magnification 0.4 and dispersion 1.4 m. A sextupole correction of the second order optics is introduced in the dipoles.

The spectrum of Xe isotopes, obtained by scanning the current in the LEBT magnets with a slit width of 4 mm (SLH02), is shown in fig.2. The high resolution has the drawback that a small energy spread from the source causes a horizontal emittance increase when the system is used with open slits. Typically a 0.5% energy shift gives a 3.5 mm displacement. An energy spread of this order along the beam pulse would double the emittance. This imposed severe tolerances on the dipole power supplies [1] and the necessity of compensating the source high voltage drop during the beam pulse.

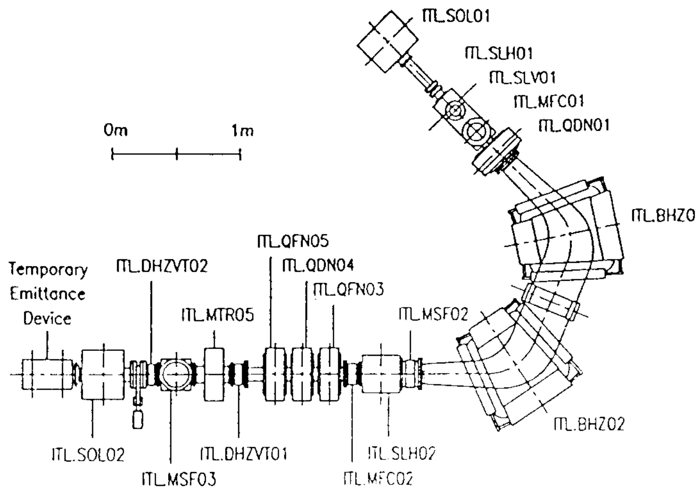

Figure 1: LEBT Layout

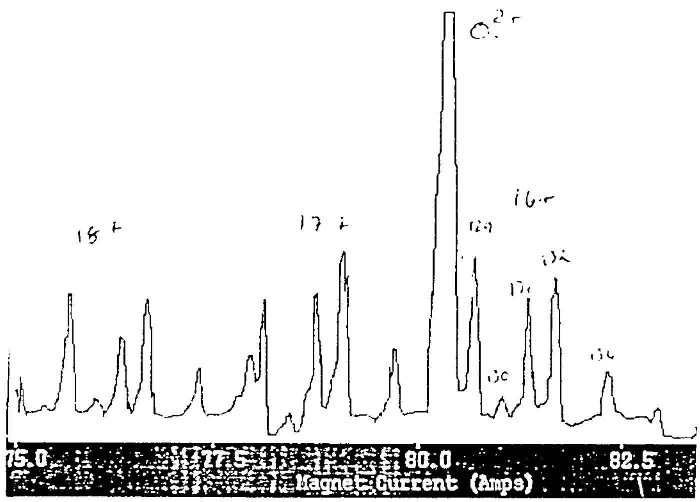

Figure 2: Xe spectrum

Matching to RFQ

A series of emittance measurements were taken in order to check the agreement with the TRACE [2] calculations. All the magnetic elements were varied one at the time to check the calibration of the hardware. Particularly useful in this respect were the measurements taken with the last solenoid off: avoiding the mixing of horizontal and vertical phase plane, the measurements and simulations could be compared also for an optics different from the nominal one, which has cylindrical symmetry and no mixing. Finally a good agreement between TRACE calculations and values measured at the emittance measurement device was achieved.

The steering magnets (DHZVT 01/02) of the line were set with the help of the two profile harps: from the measurement of the position of the beam at these harps the divergence of the centre of the beam could be deduced using the transfer matrix. The steerers could then be set to a value that compensates for the off-axis position as well as for the divergence of the centre of the beam. This set of measurements allowed also to check the linearity and the sensitivity of the steering elements.

All the above measurements led to a standard procedure to match the beam to the RFQ acceptance. This procedure consists of the following steps: first, the two magnets of the spectrometer (previously measured with a Hall probe) are set for the nominal rigidity of the beam, then the values of SOL01 and QDN01 are optimized around the theoretical settings to have the maximum current in the Faraday cup MFC02 and a good emittance at the emittance measurement device. At this point the beam is horizontally centred on MSF02 by slightly changing the extraction voltage (a 0.2 % energy shift corrects for 1 mm displacement); the longitudinal beam dynamics is not changed by this operation since the RFQ energy acceptance is of the order of 5% [3].

The steerers after the source are then set via the measurements on SLH01, SLV01 and MSF02. At this stage all the elements of the line up to the image point are frozen. To set the second part of the line, an emittance measurement is backtracked up to SLH02 and the triplet setting that gives a round beam in front of the solenoid SOL02 is found (this is very important to preserve the quality of the beam). After having set the steeres to centre the beam in front of the solenoid SOL02, the latter is adjusted so as to bring the beam into the RFQ acceptance. In fig.3 the final emittance is shown and compared to the theoretical acceptance. The value of the emittance obtained is about 100 π mm mrad, well within the RFQ theoretical acceptance of 200 π mm mrad.

After having reached the matching to the RFQ with the help of the emittance measurement device, the beam line was calibrated, i.e. a procedure to set the beam for the RFQ without the help of the emittance measurement device was developed. In this part of the work the agreement between calculations and measurements was essential, as for some parameters we had to rely on calculated values.

As seen on fig.1, MSF03 is the last diagnostic tool in front of the RFQ, and so the calibration of the solenoid SOL02 against TRACE calculation was essential. A good agreement was found between TRACE predictions and measured values allowing to match the beam without the help of the emittance measurement device, provided the parameters of the beam (alpha, beta and emittance) are beforehand determined at MSF03 position.

The parameters of the beam at MSF02 and MSF03 were deduced with the following procedure: first the emittance was measured via three profile measurements on MSF03. This method has already been applied and documented [4]. Second, the beta function values at the position of the two harps were deduced from the profile (with the reasonable assumption of no emittance growth between MSF02 and MSF03). Through the TRACE transfer matrix, the alphas at MSF02 and MSF03 position could then be calculated.

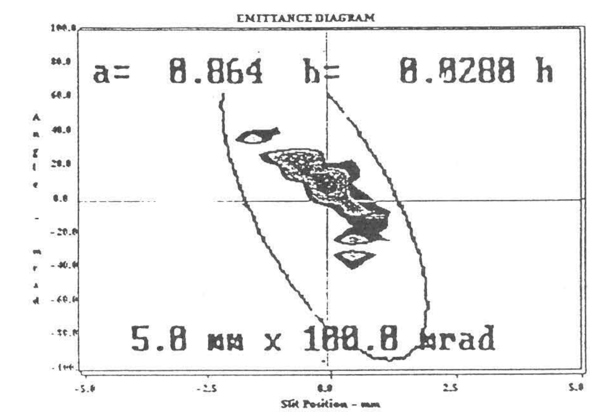

Figure 3: Measured emittance at the RFQ input. The solid ellipse represents the RFQ acceptance.

This process was extensively cross-checked with the emittance measurement device and gave good results: the maximum difference between the values measured at the measurement device and the values calculated from the profile measurements was around 15 %.

Conclusions

The LEBT of the CERN Lead Ion Linac Project has been successfully commissioned, proving that the design choices were right and the construction of the hardware correct. The line is operational since April 94, delivering 80 μA of Pb^{27+} to the following RFQ. Fig.4 shows a photo of the LEBT.

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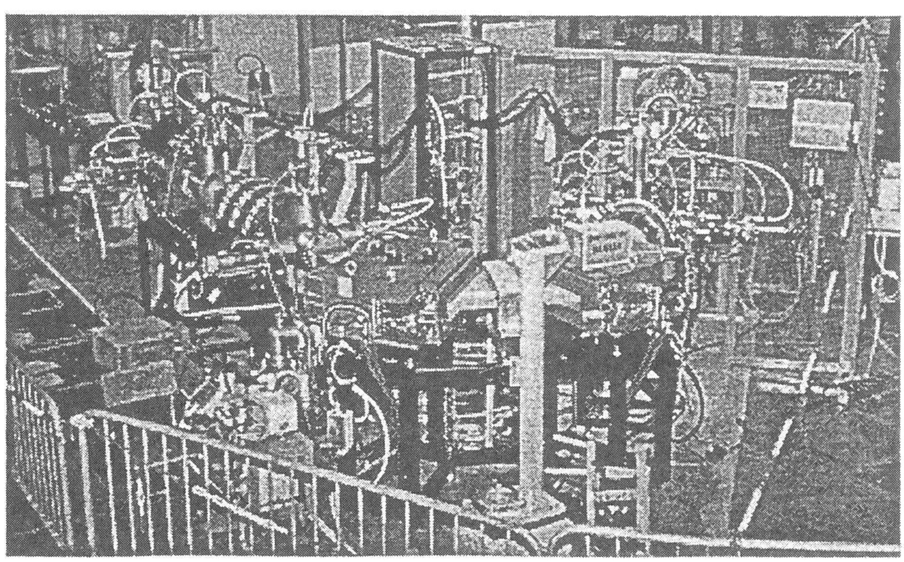

Figure 4: The LEBT