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# A Heavy Ion Linac for the CERN Accelerator Complex

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*Abstract*

The injector linac required by CERN for heavy ions, e.g. $Pb^{28+}$, is being made in collaboration with several institutions in CERN member states. Starting with $Pb^{28+}$ ions at 2.5 keV/u from an ECR source, the beam will be analyzed and matched into a Radio-Frequency Quadrupole (RFQ) which operates at 101.3 MHz and accelerated to 250 keV/u. After a matching section the beam is accelerated to 4.2 MeV/u by a three cavity Interdigital-H (IH) structure. Then follows stripping, beam analysis and debunching to produce a $Pb^{53+}$ beam for the booster synchrotron. This paper summarizes the design, the technical solutions proposed and the present status.

## 1. INTRODUCTION

Increased interest of the nuclear and high energy physics community in heavy ions at relativistic energies has resulted in a project for a lead ion accelerating facility at CERN [1]. This project was the outcome of the acceleration of heavier (than protons) ions in the CERN Linac 1. Deuterons started in 1964, then alpha-particles to the Intersecting Storage Rings [2], oxygen ions to the SPS in collaboration with GSI (Darmstadt) and LBL (Berkeley) [3] and finally sulphur [4]. It was quite clear that these light ions were at the limits of possibilities of the existing Linac and the present scheme is the result of different studies and developments [5,6,7] which, with important improvements on the subsequent CERN accelerators (PSB, PS and SPS), should provide intensities well above what is requested ($5 \times 10^7$ ions / SPS pulse).

## 2. ECR SOURCE

Pulses of $Pb^{28+}$ ions of 100 eµA with 400 µs duration at 10 Hz have been obtained with the GANIL 14 GHz ECR source operating in pulse mode and tuned in such a way as to enhance the so-called "afterglow effect" [8]. It was observed for the first time at Grenoble [9] in 1988 on the 16 GHz MINIMAFIOS source operating with oxygen and confirmed later on the ECR sources of CERN and GANIL. The afterglow is a sudden and brief increase of the beam intensity occurring just after the end of the UHF power pulse.

Experiments at GANIL in 1990 for this design showed that the current in the afterglow was mainly composed of high charge state ions, e.g. pulses of $O^{6+}$ to $O^{7+}$, $Ar^{10+}$ to $Ar^{14+}$, $Pb^{25+}$ to $Pb^{29+}$ could be obtained. The phenomenon is stable and reproducible and the afterglow peak, dependent on the adjustment of the source parameters, is about 2 or 3 times the normal pulse current.

A replica of this source, which has been ordered by IN2P3 (France) for the CERN lead-ion linac, is now completed: the expected afterglow pulsed beams have been achieved with $Ar^{12+}$ (120 eµA) and $O^{6+}$ (680 eµA). Measurements of the beam emittance are being made for matching to the Low Energy Beam Transport (LEBT) and some emittance growth during the afterglow is foreseen.

Tests with lead ions are under way.

## 3. LOW ENERGY BEAM TRANSPORT AND THE RADIO FREQUENCY QUADRUPOLE

The construction of the low energy section of the acceleration chain that connects the ECR source to the following IH accelerating structure has been taken up by the LNL (Legnaro) group. A schematic of the line is shown in fig.1.
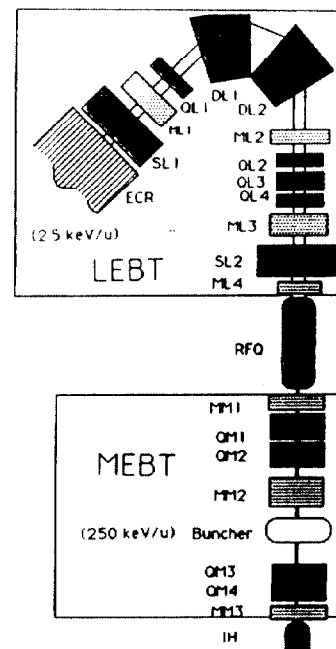


Figure 1. LEBT Layout

Lead ions with a charge to mass ratio of 25/208 are selected in the LEBT, by a mass spectrometer with a momentum resolution of 0.003 composed of two 67.5° dipoles, each with a bending radius of 0.4 m. A combination of two solenoids and four quadrupoles match the beam into the spectrometer and the RFQ [10].

After the LEBT, a 2.5 m, 101.28 MHz RFQ with a transmission of more then 93%, accelerates the beam from the ECR output energy of 2.5 keV/u to the input energy of the IH of 250 keV/u. The RF structure, dictated by the low frequency, is of the "four rods" type with symmetrical supports and "vane like" electrodes [11]. The beam dynamics in the RFQ is part of the design procedure. To reduce the length of the structure, to save in terms of machining costs, power consumption and, at the same time, have the desired maximum surface field, transverse acceptance and output longitudinal emittance, a new design philosophy has been developed [12].

The Medium Energy Beam Transport line, MEBT matches both transversely and longitudinally the RFQ beam to the IH. The 1.6 m long MEBT contains four independently adjustable quadrupoles and a buncher cavity [10].

## 4. LINAC AND RF CONCEPT FOR THE LEAD INJECTOR

After successful beam tests with the Interdigital-H (IH) structure of the new high charge state injector (HLI) at GSI [13] this type of drift-tube linac was chosen for the lead ion injector. GSI has taken responsibility for the linac and for all the RF power amplifiers for the injector (Bunchers, RFQ, IH-sections).
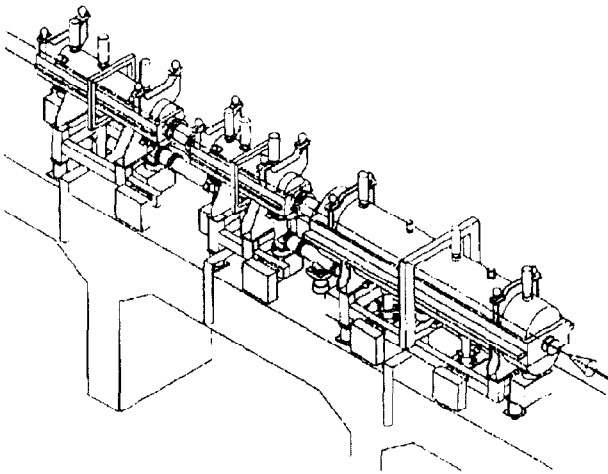


Figure 2. The CERN IH Linac

The concept of a "Combined Zero Degree Synchronous Particle Structure" is used. The first tank (101 MHz) will be similar to the GSI cavity. It contains three drift tube sections coupled by two internal quadrupole triplets. The second and the third tank operate at 202 MHz. The length of the intertank sections is minimized for optimum longitudinal matching. At

the exit, the energy spread is about ± 0.5%, the time spread about ± 50 ps. Calculations, including space charge, showed that this structure can carry beam currents up to 10 emA without particle losses. This capability will be of importance when improved heavy ion sources for highly charged ions become available. The main linac parameters are given in the following table:

| Design ion | $^{208}Pb^{25+}$ |
|---|---|
| Duty cycle | < 1% |
| Total length [m] | 8.1 |
| Eff. voltage gain [MV] | 32.86 |
| Transv. focusing | 4 quadrupole triplets |
| Beam Diagnostics | 2 capacitive, segmented pick-up probes |

| | Tank1 | Tank2 | Tank3 |
|---|---|---|---|
| Length [m] | 3.57 | 1.55 | 2.00 |
| Frequency [MHz] | 101 | 202 | 202 |
| Voltage gain [MV] | 13.4 | 9.77 | 9.7 |
| Drift tube aperture [mm] | 18/20/22 | 22 | 22 |
| RF power loss [kW] | 200 | 280 | 280 |
| Amplifier output [kW] | 300 | 350 | 300 |

Each tank consists of a median frame and two half shells (Fig.2). The mechanical design for the tanks has been completed so that requests for tenders could be sent out at the end of 1991. A detailed schedule was made for all components needed for the copper plating, assembly and tuning stages.

All RF amplifiers will be specified for 1 ms, 10 Hz pulses corresponding to a 1% duty cycle. The two 101.28 MHz amplifiers for the bunchers have to deliver a peak power of only 2.5 kW. Solid state amplifiers like those for the HLI bunchers can be used. For the two high power 101.28 MHz structures, the RFQ and IH1, two identical amplifiers will be built even if the required power differs (100 kW to 300 kW). Modified broadcast-amplifiers may be used as drivers, whilst the final amplifiers have to be developed. Existing amplifier designs with full and quarter-wavelength circuits may provide models for the final design.

The 202.56 MHz amplifiers for the IH2 and IH3 are specified for a peak pulse power of 350 kW. Existing reliable amplifiers, with slight modifications, from the old CERN linac can probably be used as drivers. These amplifiers would be able to deliver 25 kW pulses with a drive of less than 1.5 kW from solid-state pre-drivers. The final layout, however, will depend on the capabilities and experience of the contractors.

## 5. FILTERING, MEASUREMENT AND TRANSFER AT 4.2 MEV

At the exit of the Linac there is a region 10 m long where the ion beam ($Pb^{28+}$) can be measured, stripped and re-measured, in order to check and hence minimize the effects of scattering in the variable thickness stripper foil. The required charge state can be chosen and unwanted species eliminated. It is intended to measure emittance, energy and its dispersion,

and the longitudinal bunch profile not only for the stripped beam but also for the non-stripped beam.

The non-dispersive ion filter consists of four magnets, the first of which will be used as a spectrometer to separate the different charge states for both stripped and non-stripped beams. Only the $Pb^{53+}$ will pass the filter, the other undesirable charge states will be eliminated with a slit placed in the centre of the filter (where the dispersion is maximum) and where the beam profile can also be measured.

Characteristics of the filter magnets:

| Unit | Angle | Length | $\rho$ | $B_{max}$ |
|---|---|---|---|---|
| BHZ11 | 500 mrad | 1.2 m | 2.4 m | 12.5 kG |
| BHZ12,13,14 | 500 mrad | 0.6 m | 1.2 m | 10.2 kG |

Beam dimensions at the filter centre and charge state separation (for E=30 mm.mrad):

| Horizontal (dp/p=0) | Horizontal (dp/p=4*10-3) | Displacement $Pb^{54+}$(or 52+) | Vert. |
|---|---|---|---|
| 9.4 mm | 11.2 mm | 16.2 mm | 27 mm |

Ions will be transferred, interlaced with protons from Linac2 in a multi-pulse mode, to the Booster by a common beam line (LTB). The beam will be centred on a quasi non-destructive "Secondary Emission Wire" beam detector and re-measured in emittance (LBE) and energy dispersion lines. A debuncher after the filter can be used to match the energy spread of the ions to the Booster acceptance.

This debuncher has to provide a peak voltage modulation of 200 kV with a peak power input of 2 kW from a transistorized driver amplifier. It is of the spiral resonator type with 4 gaps and operates at 101.28 MHz.

## 6. CONTROLS

The lead ion injector will be controlled by Unix based workstations and VME-bus based front end computers interconnected through an Ethernet LAN. These computers communicate through the TCP/IP protocol. Equipment access can be done directly through VME interface modules or via MIL 1553 bus, GPIB or Camac. During the commissioning phase as well as for special applications and machine study sessions, PCs running MS-DOS will be employed, in addition to the workstations, to allow fast prototyping of procedures.

## 7. CONCLUSION

Linac 1 will close down in June 1992 when dismantling will start, to empty the building for the new machine. After completion of civil engineering work, installation of the heavy ion injector complex will start with the source (end of 1992). On present planning it is hoped to have beam through the linac and in the other CERN accelerators by summer 1994.

## 8. REFERENCES

[1] R. Billinge, E. Boltezar, D. Boussard, E. Brouzet, R. Cappi, B. de Raad, N. Doble, P. Grafström, H. Haseroth (Ed.), C.E. Hill, K.H. Kissler, J. Knott, T. Linnecar, F. Nitsch, A. Poncet, U. Raich, N. Rasmussen, H. Schönauer, T.R. Sherwood, N. Siegel, U. Tallgren, P. Têtu, D. Warner, M. Weiss, "Concept for a lead-ion accelerating facility at CERN", CERN 90-01.

[2] M. Bouthéon, R. Cappi, H. Haseroth, C. E. Hill, J.P. Koutchouk, "Acceleration and stacking of α-particles in the CERN Linac, PS and ISR", Proc. 9th Particle Acc. Conf. Washington, 1981 [IEEE Trans. Nucl. Sci. NS-28, 2049 (1981)].

[3] H. Haseroth, C.E. Hill, P. Têtu, M. Weiss, B.H. Wolf, K. Leible, P. Spädtke, J. Klabunde, B. Langenbeck, N. Angert, R.A. Gough, J. Staples, R. Caylor, D. Howard, R. MacGill, J. Tanabe, "Ion acceleration in the CERN Linac 1", Lin. Acc. Conf., Stanford, Calif., 1986 (SLAC-Report-303, Stanford, Calif., 1986), p. 355.

[4] N. Angert, E. Brouzet, R. Garoby, S. Hancock, H. Haseroth, C.E. Hill, K. Schindl, P. Têtu "Accelerating and separating mixed beams of ions with similar charge to mass ratio in the CERN PS complex", Proc. Europ. Particle Acc. Conf., Rome, 1988, Ed. S. Tazzari (World Scientific, Singapore, 1988), vol. 2, p. 1367.

[5] H. Haseroth, A. Lombardi, M. Weiss "Feasibility study concerning a possible layout for a lead-ion injector for the CERN accelerator complex", Particle Accelerator Conf., Washington, DC, 1987 (IEEE Catalog No. 87CH2387-9), vol. 1, p. 295.

[6] D.J. Warner, "Heavy ion acceleration using drift-tube structures with optimized focusing", Proc. Linear Acc. Conf., Newport News, VA., 1988 (CEBAF-Report-89-001, Nat. Techn. Information Service, Springfield, VA., 1989), p. 109.

[7] U. Ratzinger, "The IH-Structure and its capability to accelerate high current beams", PAC 1991, San Francisco, IEEE Conf. Rec. 91CH3038-7, p. 567.

[8] M. P. Bourgarel, P. Sortais, P. Attal, M. Bisch, P.M. Cornen, P. Lehérissier, J.Y. Pacquet, J.P. Rataud, G. Schmiechen, "First results of the 14.5 GHz GANIL ECR source with the c.w. and the pulsed operation mode", Proc. EPAC 90, p. 645.

[9] G. Melin, F. Bourg, P. Briand, J. Debernardi, M. Delaunay, R. Geller, B. Jaquot, P. Ludwig, T.K. N'Guyen, M. Pontonnier, P. Sortais "Grenoble ECRis status", Journal de Physique, Colloque C1 tome 50, janv. 1989, p. 673.

[10] G. Amendola, F. Cervellera, G. Fortuna, A. Lombardi, A. Pisent, M. Vretenar, M. Weiss, "Design study of the low energy section of the CERN Pb-ion injector", this Conference.

[11] A. Lombardi, G. Parisi, M. Vretenar, "Comparison study of RFQ structures for the lead ion linac at CERN", this Conference.

[12] A. Pisent, G. Amendola, M. Weiss, "Beam dynamics studies for the CERN lead-ion RFQ", this Conference."

[13] N. Angert, J. Bossler, L. Dahl, H. Deitinghoff, J. Friedrich, J. Glatz, W. Gutowski, G. Hutter, J. Klabunde, H. Klein, G. Kube, A. Nicklas, U. Ratzinger, D. Schäfer, A. Schempp, H. Schulte, R. Schwedhelm, P. Spaedtke, W. Vinzenz, B. Wolf, "Commissioning and first operation experience on the new heavy ion injector of the UNILAC", this Conference.