CHAPTER 34

SOURCE AND LINAC3

Linac3 (Lead Linac, [1]) (Fig. 34.1) will serve as a pre-injector of lead ions for LHC. However, some modifications and improvements are required which are presented in this chapter.

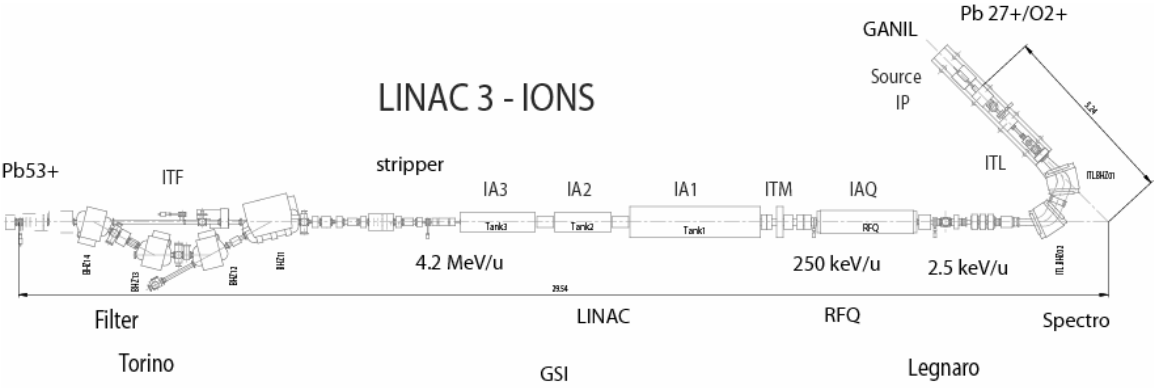

Figure 34.1: Layout of the Lead Linac

34.1 SOURCE UPGRADE (14 – 18 GHz, 100 to 200 µA)

The mainstay for the production of light and heavy multi-charged ions since the inception of the CERN ion programme in 1986 has been the Electron Cyclotron Resonance Ion Source (ECRIS) [2]. These sources were used, initially, to produce oxygen and sulphur ions and were developed to produce high currents of medium charge state heavy ions (e.g. Pb^{27+}) in a pulsed afterglow mode of operation. For practical reasons, ions are extracted from the source at about 2.5 keV/u (20 kV for Pb^{27+}).

The performance of the 14.5 GHz ECR4 ECRIS running in afterglow mode was sufficient for the SPS fixed target programme for Lead ions but falls considerably short of that required for LHC. However, stacking the ions from Linac3 in the LEIR machine is a possible solution. Tests in 1997 with a source current of 100 eµA and with Linac3 running at 2.5 Hz showed that 25% of the required intensity for LHC would be attained without modifications [3,4,5]. Raising the repetition rate of Linac3 to 5 Hz would reduce the gap and, apart from a few components, the Linac3 can work at this higher rate.

Any further gain must come from the ion source and the Linac3 transmission. Operation in recent years has concentrated on maintaining long-term stability of the beam sent to the next accelerator in the chain (PSB). This stability was gained at the cost of ultimate performance of the ion source. It is felt that an increase of 10-15 % could be achieved in the Linac3 output by optimising the source performance, but at the cost of overall stability and the requirement of regular adjustment. Equally, a search should be carried out to find acceptance bottlenecks in the present Linac3 chain, which could be reduced by minor corrections to the optics.

Linac3 was designed to accelerate Pb^{25+} but has always accelerated Pb^{27+} due to the risks of excessive X-ray emission from the accelerating cavities. Nowadays, after the long conditioning experienced by the cavities, this will be less of a problem. Acceleration of the same electrical current of Pb^{25+} would result in a gain of 4-5 % in the number of particles after stripping.

The theory of ECR plasmas predicts that the attainable plasma density (and hence the maximum extractable current) scales as the resonance (microwave) frequency squared. Recent tests in the framework of a European collaboration [4] have confirmed the effect up to 28 GHz [2]. As the resonance magnetic field scales only with frequency, the present ECR4 could operate at up to 18 GHz instead of presently 14.5 GHz with only minor modifications and possibly exchanging a mirror coil power supply. Naturally a new microwave power source would be needed. From the frequency scaling, this should give a potential gain of 1.5 in ion intensity. With these measures it should be possible to push the current to the desired 200 eµA

(Tab. 34.1). A question mark exists over the strength of the hexapole. However, in afterglow mode, the source seems to run with reduced confinement as compared to a CW source, a weaker than optimum hexapole may be an advantage. In any case, upgrading the field in this permanent magnet device would be quite problematic.

Another improvement possibility lies in the fact that the ion source gives a distribution of charge states with a peak around Pb^{26+}. The present analysis spectrometer after the ion source is highly selective for one charge state. Acceleration of more than one charge state in the Linac3 is feasible with lower transmission away from the central charge state. If three charge states around Pb^{26+} could be injected into the Linac3, there could be potential for doubling the beam intensity. A charge state of the plasma gas, O^{2+}, would also be accelerated but would be lost after the stripper. Stripper lifetime could be affected by the increased intensity and repetition rate. The higher intensity of O^{2+} could give rise to emittance blow up problems at low energy due to space charge. Additionally, another potential source of emittance blow up is the mismatch experienced by adjacent charge states with the linac adjusted to an optimum charge state.

The frequency scaling suggests another solution, that of doubling the microwave frequency to 28 GHz, which would result in a factor four in intensity. Currently, development of this type of source is the subject of a European collaboration [6] one of whose objectives is to produce 1 emA of Pb^{27+}. Unfortunately, such a high current, with its attendant adjacent charge states together with ions from the plasma gas would be very difficult to extract and transport at present extraction energies. Hence, an increase in extraction energy by a factor of about three will be needed. This would then require a new (and longer) RFQ and probably a major upgrading of the present Low Energy Beam transport. The costs of these modifications together with the (high) cost of a 28 GHz source system make this option rather expensive. The performance and reliability of these super sources remains to be demonstrated.

Table 34.1: ECR Parameters for $_{208}Pb^{27+}$

Resonance Frequency	18.	GHz
Resonance Field	0.65	Tesla
Extraction Energy	2.5	keV/u
Extraction voltage	20.	kV
Extracted current	~ 200	μA
Typical pulse length	200	μs
Pb ions / 200 μs pulse	$9\ 10^9$	
ε^*_{rms}	0.07	μm

34.2 LINAC REPETITION RATE TO 5 Hz

The Linac3 quarter-wave buncher cavity at 250 keV/u showed some problems at high duty cycle during the 2.5 Hz tests in 1997. The temperature increase in its long inner tube, caused too large a frequency shift which could not be compensated by the tuner. In order to be able to run at 5 Hz, water-cooling of the inner tube will be implemented. A special water-cooling plate has been prepared and tests at 5 Hz are planned, once the connection to the Linac3 cooling circuit has been completed.

The other Linac3 cavities do not present particular problems at 5 Hz. The IH structures and the debuncher were originally designed at GSI for duty cycles an order of magnitude higher, while the RFQ was designed for 10 Hz.

The majority of the magnets in Linac 3 are DC magnets and are thus compatible with 10 Hz operation. The small number of pulsed quadrupoles have been shown to be capable of supporting an rms current at least equivalent to 10 Hz operation either unmodified or with the addition of forced air cooling. Their power supplies were just capable of operating at 2.5 Hz and will be replaced. New power supplies will be needed for the pulsed steering dipoles.

34.3 ENERGY RAMPING CAVITY

During the 1997 tests, a momentum ramping of ± 0.4% of the Linac3 beam was obtained by a 10% modulation of the voltage in the IH Tank3. It will now be provided by a dedicated RF cavity, placed as close as possible to the output of Tank3. This solution will decouple the Linac3 setting from the ramping, simplifying the setting-up of the machine and the operation of the ramping hardware. Moreover, a larger momentum variation could be provided without affecting the beam energy distribution or, for extreme variations, the charge state distribution and hence the beam current.

In order to provide the ramping with minimum voltage and no increase of the energy spread, a 101 MHz cavity has to be placed immediately after the stripper in the ITF line. Space for the new cavity can be found by removing a diagnostics box just after the stripper. This box was only used during commissioning and its removal will not affect the operation of the linac. The space is sufficient for a 4-gap spiral loaded resonator similar to the one used as debuncher at the end of the ITF line, a design that provides high shunt impedance and simple construction and tuning. The required energy variation will be achieved by modulating the cavity phase around the zero-crossing phase. In spite of the higher voltage required, this approach is preferred to amplitude modulation because of the simpler circuitry and a lower risk of multipactoring in the cavity.

Simulations of beam transport for different energies indicate that the ramping cavity can provide the required momentum variation with virtually no increase in the energy spread. The phase of the debunching cavity positioned 11 m downstream of the ramping cavity will need to be modulated too to compensate for the different time of flight.

The ramping cavity (Tab. 34.2) will be built by IAP-Frankfurt, who built the debunching cavity, with a tuner developed and built at CERN. The RF amplifier will be solid-state delivering a maximum of 4 kW at 1% duty cycle. A phase modulator placed in front of the low level RF electronics will allow variation of the cavity phase according to a profile generated with an external GFA.

Table 34.2: Main parameter of the ramping cavity

Operating frequency	101.28 MHz
Max. Momentum variation	± 1%
Nominal effective voltage	250 kV
Duty cycle (max.)	0.5 %
Total length	700 mm
Max. Diameter	250 mm
Min. ramping time	50 µs (for 1% momentum variation)

34.4 SHIELDING

Three radiation sources have to be taken into account: neutrons, x-rays from the source and x-rays from the Linac3. Some dedicated radiation measurements around the source and the Linac3 were performed in 2002.

At present there is no detectable neutron production from ion interaction with the Linac3 structure. This is consistent with the expected dose equivalent rate calculation using [7] with the present beam parameters and assuming that about 5% of beam is lost between 250 keV/u and 4.2 MeV/u. Assuming that the losses remain the same with the possible maximum increase in beam intensity of a factor of 50 (given by a factor of 10 from the new very bright ion sources like a 28 GHz ECRIS times a factor of 5 in the Linac3 repetition rate), the prediction of a neutron dose equivalent rate of around 1 µSv/h is perfectly acceptable in a controlled area. However, about 2/3 of the beam at 4.2 MeV/u is stopped in the dump, so locally the neutron dose rate might reach 10 µSv/h. A local shielding around the dump may be envisaged if the measurements with beam show higher values.

The improvement of the present 100 eµA current to 200 eµA or higher with a future ECR source means an increase of the plasma electron density by a factor of two or more, that is, an increase by the same factor in X-ray emission, i.e. X-ray dose rate. Therefore some more shielding will most likely be required at the source. For an effective energy of about 600 keV as given in [7], a reduction of the radiation by a factor of three can be achieved with about 1 cm of lead or less than 10 cm of concrete.

The X-ray emission induced by stray electrons in the Linac3 structure is proportional to the Linac3 repetition rate. An increase of a factor of five in the X-ray dose rate is therefore expected. Some extra shielding will be required along the Linac3. For an effective energy of these X-rays of about 200 keV as estimated in [8], a reduction of a factor of five in the dose rate can be achieved with about 2 mm of lead or less than 10 cm of concrete.

Extra shielding will have to be defined after measurements on the source and Linac3 under real operating conditions.

34.5 CONTROLS

The control system presently implemented in the Linac3 needs to be extended to integrate the modifications of the Linac3 in view of LEIR operation. Two types of extension are required: a new VME front-end computer with the appropriate modules to drive the new hardware (the amplifier of the energy ramping cavity) and new front-end software to handle the controls and acquisitions of the Linac3 running at 0.833 Hz to 5 Hz rates. Like the controls for LEIR, industrial components based upon PLCs (Programmable Logic Controller) will be used, wherever suitable, in complement to standard VME components.

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