

HOW TO RUN IONS IN THE FUTURE?

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Abstract

In the light of different running scenarios potential source improvements will be discussed (e.g. one month every year versus two month every other year and impact of the different running options [e.g. an extended ion run] on the source). As the oven refills cause most of the down time the oven design and refilling strategies will be presented. A test stand for off-line developments will be taken into account. Also the implications on the necessary manpower for extended runs will be discussed.

INTRODUCTION

The heavy ions for the CERN heavy ion accelerator chain are delivered from Linac3 (see Figure 1) and the GTS-LHC ion source [1].

Operational conditions

To create the lead beam isotopically enriched ^{208}Pb is used (purity 99.6%). After the separation of the charge states Pb^{29+} is accelerated in the linac, which is converted to Pb^{54+} by the stripper.

The GTS-LHC ion source is an electron cyclotron resonance ion source (ECRIS) [2]. It is running in the so called afterglow mode, using the 14.5 GHz microwave plasma heating with 10 Hz repetition rate, 50 % duty cycle, where at the end of each heating pulse, a burst of approximately 1 ms in length of highly charged ions is emitted from the source. In the linac a pulse length of 200 μs is used, with a repetition rate of up to 5 Hz for LEIR filling.

Present performance

Up to now the following record values have been achieved: 215 μA of Pb^{27+} after the charge state separation in the spectrometer (FC2) and 31 μA of Pb^{54+} at the end of the linac (TRA25, with 120-130 μA of Pb^{29+} in FC3). However, both values were not achieved at the same time, neither is it possible to produce them for long term operation, or even on demand. Maximizing the ion current at the output of the spectrometer very often leads to a poor transmission in the rest of the linac. This issue is part of an ongoing study.

For routine operation 100-120 μA of Pb^{29+} out of the RFQ (FC3) and 20-25 μA of Pb^{54+} at the end of the linac (TRA25) are available. The current at the end of the linac corresponds to less than 50 % of the design value.

OPTIONS TO STUDY

To overcome limitations of the machine and to further improve the operation, a number of options have to be studied.

The extraction system of the source may be improved by the re-design of the extraction electrodes. A new design may allow to extract the beam with a lower emittance. Adding an einzel lens directly after the extraction may help to optimize the beam transport. One can also think of a higher extraction voltage. This may allow to extract more beam from the source (if the plasma is not emission limited) and improve the transmission. A higher beam energy would need a new RFQ.

The Low Energy Beam Transport (LEBT), before the separation of a single lead charge state is strongly influenced by space-charge, with the space-charge forces still existing to a lesser extent after the spectrometer. If one could reduce the space charge in this region one may be able to improve the beam quality and to reduce the losses. A possible method would be the control of the creation of compensating electrons with the help of the control of the pressure of the background gas in the line.

The present LEBT is very long, and a new, shorter LEBT adapted to the present source may have a higher transmission.

Before advancing with changes of design of the LEBT, it is necessary to measure the emittance of the beam from the present source, and for this a pepper-pot emittance measurement system is being purchased and integrated into Linac3. Measurements of an argon beam may be possible in 2014, but no lead beam is scheduled until the second half of 2015.

A 10 Hz repetition rate of the linac would help to reduce the filling time of the Low Energy Ion Ring (LEIR). The ion source runs already at 10 Hz and most of the linac elements are designed for 10 Hz. Only some of the power converters in the ITF and the transfer line need an upgrade. All foreseen consolidations of the transfer lines take the 10 Hz operations into account.

At the end of the linac the beam is stripped to Pb^{54+} . This charge state is independent of the charge state in the linac. That's why it may be possible to increase the beam current out of the linac by transporting several charge states (two or three) in the linac before stripping. From the source several charge states around the main one (Pb^{29+}) are available. By cancelling the dispersion of the low energy spectrometer, one could have more than one charge state available for acceleration. Some calculations and very preliminary tests were done to confirm that the RF cavities could accelerate off-charge-state ions. But to have sufficient input for a decision a test with the linac and LEIR in an operational state is needed (to verify the intensity and the energy spread), and either a new low energy spectrometer configuration is needed, or the source should be moved to allow a straight line to the

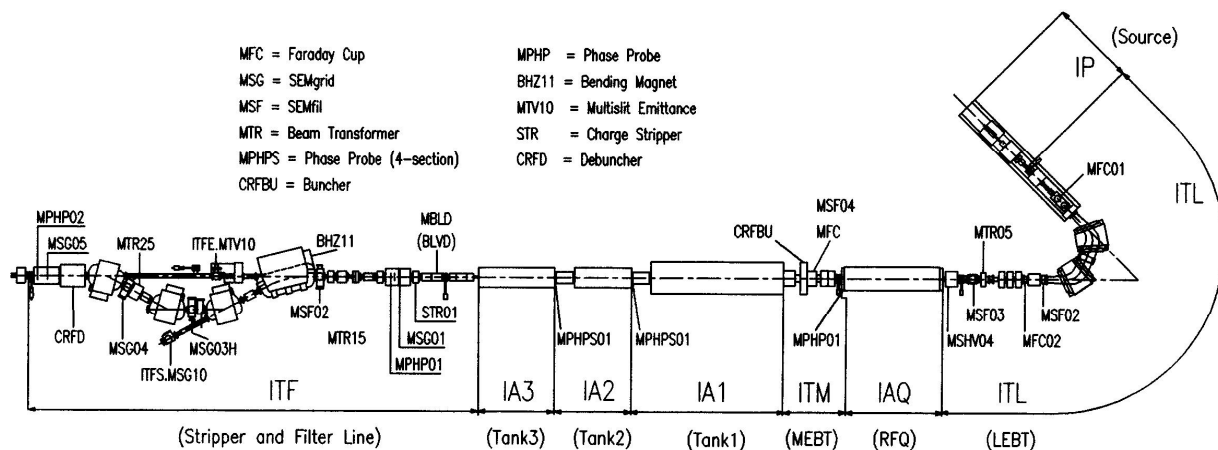


Figure 2: Layout of Linac3.

RFQ input, while still including diagnostics to allow the tuning of the ion source.

HOW ABOUT A NEW SOURCE?

A new source will probably not solve the present intensity issues, as these issues are more linked to the transport and emittance issues of the beam instead of the intensity delivered from the source.

It could be shown that present 3rd generation ECRIS (with superconducting magnets and frequencies up to 28 GHz) needed more than 10 years to reach the peak performance. Besides, they have often a big emittance and unstable beams [3].

Present electron beam ion sources (EBIS) do not deliver enough current. But for HIE-ISOLDE a study is ongoing to develop a source based on the RHIC EBIS which could deliver the required number of ions per pulse. In addition an EBIS has the advantage to be able to switch in principle pulse to pulse the ion species, for which it requires one or more low charge state ion sources to inject ions into the EBIS for charge-breeding.

In general one has to keep in mind that new developments do not guarantee the success (e.g. the superconducting magnets for the MS-ECRIS never reached the specifications due to technological issues). And superconducting ECRIS sources have significant integration issues, meaning that failures of a single part can require substantial and long repairs. For such a source it would be mandatory to run with two sources in continuous operation mode in order to keep a high availability for LHC.

THE OVEN

Two ovens are available during operation for the evaporation of the solid lead into the plasma. There are around 1.5 g of lead in each oven. The consumption is roughly 2 mg/h, but not all the lead in the sample can be used. The 1st oven is good for around two weeks, the 2nd one only for another week, because it sees some plasma during the first two weeks. But there is a flexibility of some additional days after the three weeks.

At the end of the life time usually the tip of the oven is blocked (see Figure 2).

An oven refill takes around 8 h from beam to beam, with the source requiring regular tuning for the next 24 hours. This is down time for the whole lead accelerator chain.

To improve the oven operation several attempts to change the procedures were made. Several filling methods were tested. But only the use of a fresh lead sample in an unused crucible gave some improvements

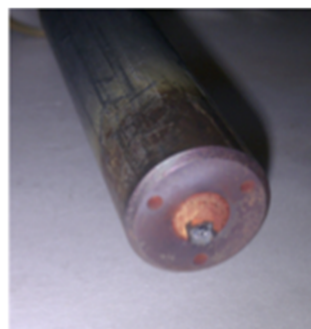


Figure 1: Tip of an oven after two weeks of operation.

concerning the source stability. All other methods (e.g. molten lead cast into the crucible) even shortened the life time.

In the near future an oven test stand is foreseen to study the oven (temperature distribution, relation between oven power and the evaporation of lead). The result of these studies may help to improve the oven and source tuning to get long term a more stable beam. In addition a redesign of the oven is not excluded, but would require a redesign of the whole source injection side (due to the present constraints).

MANPOWER CONSIDERATIONS

At the moment three experts are able to tune and to operate the Linac3 source, which needs a daily tuning. They also serve as linac supervisors. Four weeks of LHC running can be covered through careful planning, but longer times will need more trained staff (to operate the ion source one needs several years of practical experience!). And one has to keep in mind the higher operation workload as several source parameters with tight limits have to be monitored carefully and request a follow-up.

BIOLEIR

Studies are underway to improve the range of ions available from Linac3, to serve as test beams for a dedicated extraction line from LEIR for irradiation studies. The study looks at allowing fast switching between the ion type required by LHC, and lighter ions for BioLEIR, by using a second source and RFQ. The installation of this equipment into Linac3 will increase the complexity of operation and maintenance of the whole of Linac3, and even if priority is for the ion production for LHC, the integration and operation of the whole system must be assessed carefully.

CONCLUSIONS

A number of ideas to further improve the performance of source and linac are available. A dedicated lead operation period in 2015 is now needed to make tests and verify simulations to proceed with them.

The preparation for an oven test stand should start soon.

In addition a dedicated source test stand is needed (a similar request was refused in Chamonix 2006). Such a test stand can be used to test source modifications offline and to train additional source specialists. Based on a very approximate estimate one can assume that such a test stand would be roughly 5 MCHF. In addition one has to take into account 10 man years for the installation and commissioning of the test stand. To make a proper cost estimate a dedicated study with clear objectives is needed.

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