ION ACCELERATION IN THE CERN LINAC 1

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Abstract

Ion acceleration at CERN already has a long history but had been limited in the past to deuterons and alpha-particles apart from the usual proton (or H^-) beams. A review on these activities will be given. Over the last years the possibilities were discussed to accelerate even heavier ions and detailed plans were worked out for an oxygen injector for Linac 1 by a GSI-LBL-CERN collaboration.

This paper will present the scheme including the combination of two injectors which allow independent injection of protons, H^- or oxygen ions using two radio-frequency quadrupoles.

The progress concerning oxygen ion acceleration will be presented together with first results.

Introduction

The first deuterons had been accelerated in the CERN 50 MeV Linac back in 1964. Later on they were injected and accelerated in the PS and transferred and stacked in the ISR (Intersecting Storage Rings). Studies were made several times[1] to investigate the possibilities to accelerate heavier masses but only α-particles were finally used in the PS and ISR. The growing interest of the physics community in (light) ions was made evident with a letter of intent to the relevant CERN committee[2]. At that moment it was decided to have a new look[4] to what might be possible with the CERN machines.

History

Due to a certain interest expressed by some physicists some thoughts were given to light ions[1,3,5] after the first deuteron acceleration in 1964. But it took 12 years before another attempt was made to accelerate deuterons with the Linac (Linac 1), profiting from the fact that Linac 2 (the "New Linac") supplied now the CERN machines with protons and that Linac 1 was available for lengthy machine studies.

Not only was the pulse length increased by a factor 10, but also the current was almost doubled. The deuterons were finally injected into the PS, accelerated and stacked in the ISR. The production of α-particles was also tried, but acceleration in the PS was very lossy. It was only due to the interest of certain experimental groups in the ISR that α-particle production was pursued. The method selected finally was the production of a He^{1+} beam and stripping at 516 keV to produce α's which could be injected into the first tank of the Linac (Linac 1). The result was very good and gave currents similar to running with deuterons, making acceleration in the PS and stacking in the ISR a not too difficult procedure[6]. Table 1 gives a summary of what has been achieved in the past.

Limitations for Ion Acceleration in the CERN Linac 1

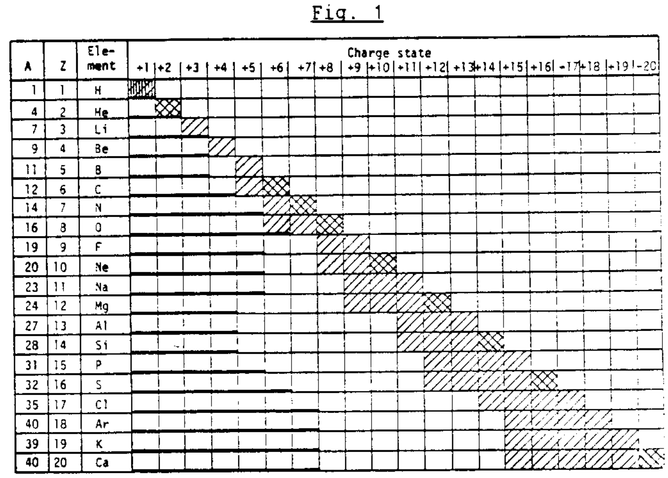
Deuterons and alphas were accelerated in the so-called 2βλ mode because, for obvious reasons, it was not possible to increase the RF field levels and the quadrupole gradients in the tanks by a factor 2. Hence

Table 1: Light Ion Beams in Linac 1 till 1980

Year	Particle	Current (mA)	Pulse-Duration (μs)	Destination
1964	d	7	10	
1976	d	12	100	PS, ISR
1976	α + d	2	100	(PS)
1977	α	0.7	100	
1979	α	2	100	
1980	α	6	100	
1980	α	10	100	PS, ISR

acceleration of ions, heavier than deuterons and alphas must be done in the same mode, provided their charge to mass ratio is the same (.5). Unfortunately, there are not too many ions with these charge to mass ratios available in sufficiently large quantities. The subsequent circular machines after the Linac need a certain minimum current for their beam control systems. Therefore, we had to look into the possibility to get higher currents from the ion source at the expense of smaller charge to mass ratios. Unfortunately, this means that the fields in the Linac have to be increased by the corresponding amount as it is not possible to run the machine in the 3βλ mode. This limits the charge to mass ratio to .38. Fig. 1 shows possible charge states for acceleration in our machine.

Fig. 1



[box] = Ionisation Energy ⩽ 138 eV, [dense hatch] = q/A = 1
[cross hatch] = q/A = .5 [hatch] = q/A ⩽ .38

Note that in this figure the limit of the ionization energy of 138 eV is taken as a rough indication of the availability of sufficiently high currents from the ion source. As can be seen, the only heavy ion species available for our purpose is O^{6+}. However, present day development in ion sources gives hope for S^{12+}.

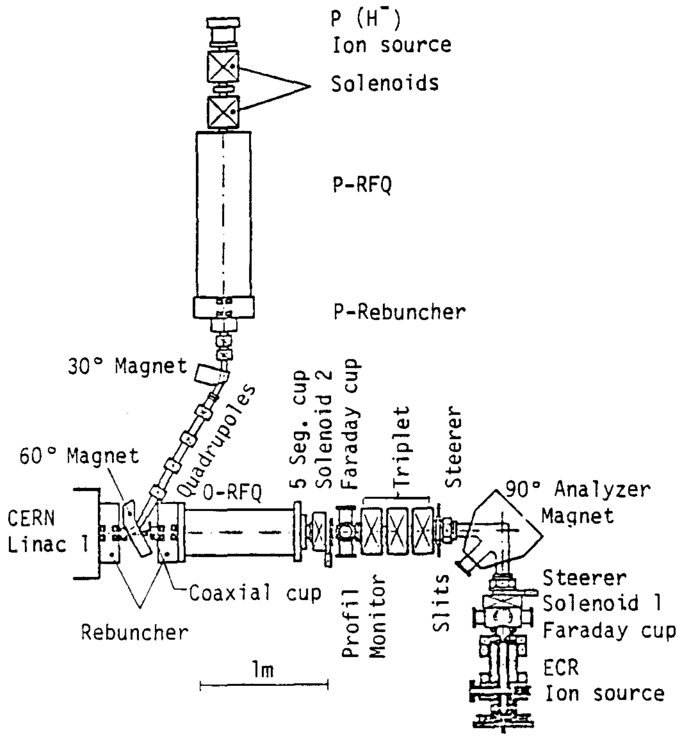
The Project to Accelerate Oxygen Ions at CERN

After the first letter of intent (aiming first for Ne^{8+}), a careful study of the possibilities with the PS machines and later on with the SPS was carried out[7,8].

finally resulted in a formal collaboration between LBL, GSI and CERN[9]. GSI was to provide the ion source (ECR-type, produced by R. Geller, CEN, Grenoble[10] for an O^{6+} beam and the low energy beam transport, LBL would build an heavy ion RFQ and CERN had to provide the infrastructure and make the necessary modifications to its machines. In general, the latter implied the adaption to these ultra low currents and, on the Linac side, the necessary increase of accelerating and effective focusing fields by 33%.

Layout

Fig.2 shows the layout of the front end of Linac 1:



Care has been taken to make the change over from oxygen to proton (H^-) injection very rapidly. First ideas involved dis- and remounting of the corresponding RFQ's and major reshuffling of larger components. The present scheme makes it (almost) possible to change over from oxygen to protons and vice versa in between subsequent pulses.

Oxygen Line: The oxygen line features 4 major items:

- the ECR ion source which is of the MINIMAFIOS type uses about 1 kW of 10 GHz power in a pulsed mode (pulse length 30 ms). It is fed with oxygen gas and helium in order to improve the O^{6+} intensity.
- A 90° analyzing magnet with a bending radius of 25 cm to select the O^{6+} beam (at 5.6 keV/n) amongst the other ion species.
- The RFQ accelerating the O^{6+} beam up to 139.5 keV/n. The mechanical design of this RFQ is similar to the heavy ion RFQ developed at LBL for use at the Bevatron. It uses vane coupling rings. The main parameters are as follows[9]:

Design ion	$^{16}O^{6+}$
Theoretical transmission	95%
Frequency	202.56 MHz
T_{in}	5.625 keV/u
T_{ou}	139.5 keV/u
Length	858 mm
No. of cells	169
Vane-vane voltage	35.6 kV
R (aperture)	2.10 mm
Peak RF power	21 kW (at Q = 5500)
Transverse acceptance	$\pi\varepsilon_n(x,y) = 0.9\pi$ mm-mrad
Output phase spread	± 23°
Output energy spread	± 4.3 keV/u

- Transverse and longitudinal matching section. This section features two rebuncher cavities of a similar design to the buncher used with the CERN proton RFQ[11]. They are essential for correct matching of the oxygen beam into the acceptance of tank 1.

Proton Line: The proton line is composed of:

- a conventional duoplasmatron source (or a multipole source for H^- production).
- The CERN RFQ1.
- The necessary matching elements which, in this case, cannot ensure an ideal matching between the output of the RFQ and the input of tank 1.

It should be pointed out that this installation was implemented after the backward displacement of Linac 1 by some 12 m. This operation was necessary to allow for the installation of a decent radiation shielding wall between the Linac and the PS ring in order to guarantee safe access to the Linac building, independent of PS operation. This change became possible because of the replacement of the Cockcroft-Walton by an RFQ. This manoeuvre turned out to be essential to allow for the conversion of Linac 1 into an oxygen accelerator.

Results

Running-in of the Injector

The running-in of the ECR source, together with the RFQ, was performed without major problems. It was eased because of the original tests already done at GSI[12].

60 to 80 μA of O^{6+} beam were obtained at the end of the RFQ.

Formation of Tanks

As mentioned above, O^{6+} acceleration in the Linac needs 33% higher fields as compared to deuteron and alpha acceleration. As the ECR source can also supply alpha particles, and the adjacent proton injection line allows for quick change-over between these different ions, care was taken as to compare the RF levels needed in the Linac tanks in either case. It turned out that the RF levels are practically the same in both cases. This did not come as a surprise, however, calculations of the transit time factors turned out to be much more surprising. Fig. 3 shows the field enhancement necessary to compensate for the low transit time factors (on axis for O^{6+}). In this context it must be noted that the transit time factors off axis are

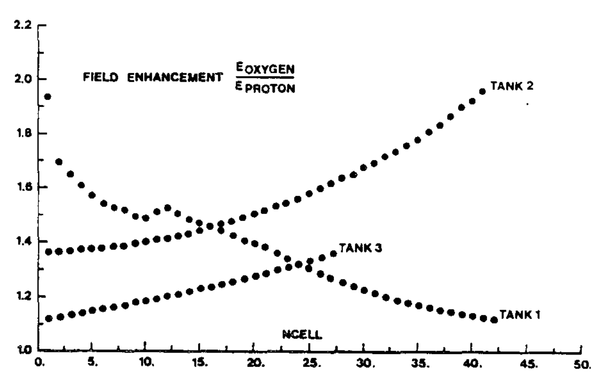


FIG. 3

considerably better. One should also remember that a stable phase angle of, say, -30° constant throughout the tank is not necessarily a condition for the successful acceleration of a beam. A simulation program showed good beam transmission through tank 2 at field levels increased by 45%.

Formation of the tanks to + 33% caused no problems on tanks 2 and 3 as soon as the necessary RF power was made available. As expected, tank 1 was more of a problem inspite of a drastic increase in pumping speed achieved by the installation of a huge cryo-pump. After some "bake-out" at moderate temperatures (55°C), the formation up to the necessary levels (using a special computer program) took some weeks. It turned out that the tank is extremely sensitive to pollution with hydro-carbons.

Acceleration of the Beam: Out of the 30 ms beam pulse coming from the source, only about 200 μs are accelerated by the RFQ (limited by the RFQ pulse length). As the pulse of the ion source is still rising during the full 30 ms, the 200 μs are obviously taken at the end. Unfortunately, a very low percentage of the low energy beam can drift through the RFQ before it is powered. It turned out that this extremely low intensity beam is sufficient to prevent the two subsequent rebunchers from operating. It was necessary to install an electrostatic deflector to stop this beam before it reaches the rebunchers.

So far, about 10 μA of O^{6+} beam were obtained at the end of tank 1, and subsequently accelerated to full energy (12.5 MeV/n) through tanks 2 and 3. Due to limitations in the available RF power, the pulse length was limited to 30 μs. Work is in progress to lengthen it to the nominal value of 100 μs. The current is certainly not yet optimized - a difficult and lengthy procedure due to the instability of the ion source.

Instrumentation: The measurement of the beam quality is, in the case of these low currents, almost more important than at the usual proton intensities. This, because the efficiency of the transmission to and through the subsequent machines is critical as one is running near the lower threshold limit as far as the RF beam control is concerned.

The conventional beam transformers turned out to be pretty useless. Some tests indicated that with special precautions readings of a few μA would be possible. Faraday cups allowed measurements well below 100 nA. TV screens proved to be valuable, but quantity readings are a problem. The SEMgrids were the most effective and sensitive instrumentation on our machine. Readings as low as 20 nA could be taken in case of O^{6+} or O^{8+} beams[13]. Fig. 4 shows a measurement of a beam profile as analyzed behind a spectrometer magnet.

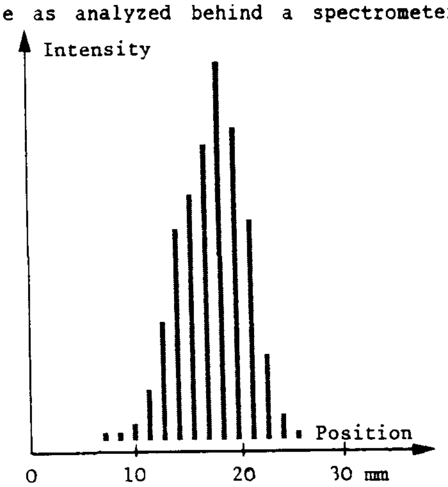


FIG. 4

Outlook

After the implementation of this project into the general CERN program, the aim is now to reach heavier masses. An upgrading of the source with the goal of reaching S^{12+} with intensities of the same order of magnitude as O^{6+} is under way. The success of this operation will ultimately depend on the transfer efficiency between the ion source and the end of the Linac.

Conclusions

After the successful acceleration of deuteron and alpha beams in the past, beams of fully stripped oxygen ions are now produced with the CERN Linac 1. Upgrading to higher masses is foreseen for the not too distant future. In this context it should be noted that after the ground had been broken by the first experimental group, a large number of additional experiments had been proposed and were finally approved.

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