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HISTORY, DEVELOPMENTS AND RECENT PERFORMANCE OF THE CERN LINAC 1

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Abstract

Early June 1992, the original CERN 50 MeV proton Linac accelerated its last beam after nearly 33 years of loyal service. Although conceived as a proton machine and commissioned in 1959 as an injector for the 26 GeV Proton Synchrotron, it finished its life as a light-ion source for the Super Proton Synchrotron (SPS) and as a cheap source of particles for tests in the Low Energy Anti-Proton Ring (LEAR). Highlights in its recent history were the installation of RFQs and the upgrading with an ECR source for O^{6+} and S^{12+} ions. The early parameters and the subsequent modifications as well as the performance will be reviewed in this paper.

Introduction

Linac 1's achievements during 33 years can be conveniently described in 3 periods. As an introduction we give in Table 1 the typical performance at 3 significant dates in the machine's history, namely, 1960, 1978 and 1992.

Table 1
Linac 1 Parameters

	1960	1978	1992	
Particle	proton	proton	S12+	
Input Energy	520.	520	139.5	keV/u
Output Energy	49.7	49.7	11.4	MeV/u
Operating Mode	$\beta\lambda$	$\beta\lambda$	$2\beta\lambda$	
Beam Current (typical)	5	70	.02	mA
Repetition Period	1.2	1.2	1.2	s
Beam Length (output)	.2	100	140.	µs
Energy Spread	±.2	<±.2*	<±.2	$\Delta W/W$ %
$\epsilon_{n,in}$ transverse (86%)	2.		3.5	π mm.mrad
$\epsilon_{n,out}$ transverse (86%)		3.5	16.	π mm.mrad

* After debunching

E. Regenstreiff [1] is the source book for Linac 1 design data. Subsequent developments of the Linac are reported in early conferences of this series. Special references are quoted where necessary.

Linac 1 as the Proton Injector for the CERN Accelerator Complex (1958 to 1978)

1958 to 1959

This period covers the initial beam commissioning, culminating with full operation at 50 MeV (with quadrupoles installed in Tank1) and regular single turn injection into PS. Figure 1 shows the layout of the linac in 1960.

The CERN Linac 1 was originally designed in the early 1950's, based on a similar accelerator built for AERE, Harwell in England. In April 1958 tank 1 produced the first 10 MeV proton beam with an intensity of 20-25 µA from an input beam, produced by an RF type ion source, of 2 mA. Later that year the input intensity was brought to 20 mA (improved steering and focusing) and the output intensity to 250-300 µA (change in RF tank level flatness and tilt).

The grid focused drift tubes of the first tank were then replaced by pulsed magnetic quadrupoles embedded in the drift tubes, resulting in an output beam of up to 4.8 mA at 50 MeV and in September 1959 the first turn at that energy went around the PS (6.7µs being required for single turn injection).

1960 to 1965.

This was a period of rapid development leading to an increase in operational peak currents from 5 mA to greater than 50 mA and pulse length up to 20 µs. There were improvements to the RF ion source, the gradient in the pre-injector increased, larger aperture quadrupoles were installed and better beam matching using two triplets in the LEBT was achieved. Important developments in the ancillary equipment were extra modulators and RF feed-forward coupling loops to compensate transient beam loading, and the start of serious investigations into beam quality, especially transverse emittances and beam brightness.

1966 to 1978.

After the installation of a duoplasmatron source and a very high gradient two-gap, re-entrant, pre-injector a peak

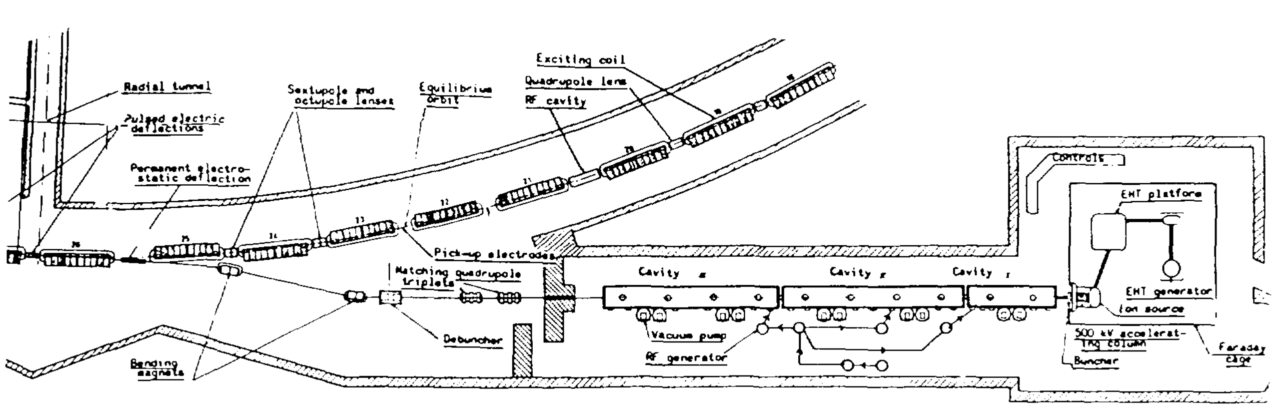

Figure 1. The Linac layout in 1960.

performance of 135 mA in 20μs was achieved [2]. However the long term aim was to meet the high quality requirements of the Proton Synchrotron Booster (PSB) input beam of 100mA, 100μs for multi-turn injection. Improvements and consolidation stages concerned firstly HT compensation (bouncer) and tests of multi-turn (3 or 4 turns) injection into PS. Later, pulse lengthening of the Tank 1 quadrupole pulsed power supplies by addition of a third harmonic and of the RF modulators met the 100 μs beam length requirements of the PSB. A double de-buncher scheme was installed to obtain PSB energy spread requirements and more detailed beam studies resulted in single pulse emittance and energy spread measurements at the hand-over point of beam. Among the changes to improve operational reliability were the replacement of mercury diffusion pumps and their refrigerated baffles by turbo-molecular pumps. The typical operational results at 50 MeV were about 70 mA for 100 μs.

Fundamental Limitations of Linac 1

It is not difficult to understand why a machine designed in 1954 had difficulty in meeting the demands made in the 1970s by the PSB.

Machine limitations were in input matching, especially in longitudinal phase-space. With a low injection energy (500 keV) only ++- - focusing was possible in Linac 1 and for high currents the poor RF field transient behaviour due to unstabilised structures was evident. The old liner in vacuum vessel design was neither suitable for modern high vacuum technology nor for stable alignment. The ancillary equipment, which lacked modern performance capabilities, included the RF system (without level or phase control), the controls system (based on the IBM1800) and the beam diagnostics, where full longitudinal emittance measurements were necessary.

The Test Bench for New Developments(1979 to 1984).

The Beginnings of the Light Ion Programme

Already in 1964 machine experiments were done accelerating deuterons [3] using an accelerating mode of $2\beta\lambda$ instead of $\beta\lambda$. During the late seventies the use of Linac 1 for accelerating deuterons was continued, encouraged by a small part of the physics community. After years of improvement (higher intensities and longer pulses), deuterons were accelerated and then stacked in the CERN Intersecting Storage Rings (ISR) for use in physics experiments.

After 1979 Linac 1 was fully available for development work. The deuteron and alpha particle currents were improved, for example with a pulsed gas-jet target at the preinjector giving a 30% stripping efficiency at 130 keV/u and an intensity of 10 mA was obtained at the end of the linac. Eventually in 1980 alphas and deuterons were collided in the ISR [4]. The success of the operation and the physics potential launched the programme for physics at SPS energies with oxygen and heavier ions .

LEAR Injection

Initially Linac 1 was considered as a (temporary) spare injection system in case there were difficulties with the newly commissioned Linac 2. However further uses were soon found for Linac 1, the first being an injector of test beams for LEAR which involved development of an H^- ion source and acceleration to 50 MeV.

RFQ 1

Another important development was of a radio frequency quadrupole (RFQ 1) designed to replace the old 500 kV Cockroft/Walton and high gradient pre-injector column. It was successfully installed in front of Linac 1 in 1984 and gave an output beam of 80 mA protons at 520 keV of which 65mA were taken to 10MeV [5].

Linac 1 as a Light Ion Accelerator(1985 to 1992)

Linac 1 Moved Back 12m

The event which started this third period in the Linac 1 life was precipitated by the risk of high radiation levels in the linac hall in the case of large beam losses in the extracted PS beam . The linac was moved back by 12 meter. This was made possible by the dismantling of the old Cockroft/Walton Faraday cage, so that a five meter thick shielding wall could be installed at its output end. This did not adversely affect the operation as using RFQ1 the full proton beam was re-established in March 1985. Access to the entire machine, even during PS operation was assured. Also the problems related to powering and controlling a source on a 500kV platform ceased to exist.

The Light Ion Programme

Already in 1977 a detailed study on the acceleration of light ions had been launched. This showed that with moderate investment, ions heavier than those utilized so far could be accelerated using the existing chain of accelerators with minor modifications to the PSB and PS (improved diagnostics) [6]. On the linac side, a new (ECR) ion source, LEBT and RFQ were envisaged. The proposed project was a collaboration between CERN (cavities for matching RFQ-Linac), GSI (ion source, which was bought from CEN, Grenoble and low energy beam transport) and LBL (RFQ). CERN also dealt with the necessary upgrading of the linac itself and the instrumentation of different accelerators [7].

In late 1985 the installation and commissioning started. An additional proton injection line was built to be able to supply LEAR with protons for machine tuning and physics experiments. Figure 2 shows the resulting layout of the machine in 1992. As the ion source could only supply O^{6+}, an increase by 33% of the accelerating and focusing fields relative to proton values was needed. For the RF this required a substantial upgrading (almost doubling the power), the cavities needed careful cleaning to try to improve the vacuum especially as far as the hydrocarbon content was concerned. On tank 1 it was necessary to install a powerful cryopump. A computer controlled RF conditioning program was used to regain the nominal acceleration field level after sparking in the tank. A more modest increase than 33% was adequate for the quadrupole fields as there was less space charge defocusing.

The first tests of acceleration throughout the whole chain of Linac 1, PSB, PS and SPS were made in September 1986. The success of the oxygen programme led to the installation of an improved ion source giving S^{12+} ions and further physics at SPS energies with sulphur ions [8]. Since 1988 the amount of time for high energy physics with sulphur ions has increased from 3 weeks per year to 9 weeks in 1992 with an increase in sulphur ion currents of about a factor 2 per run as demonstrated in figure 3.

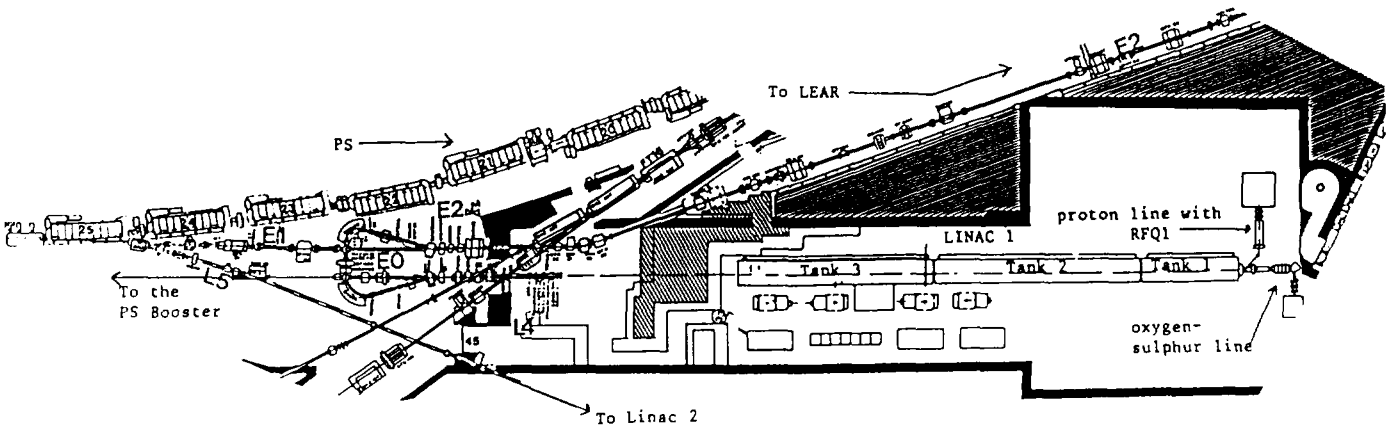

Figure 2. The Linac Layout in 1992

In parallel with the normal physics programme, test beams were injected via an additional injection line into LEAR. Protons, H^- ions and oxygen ions were provided, the latter used to demonstrate the electron cooling of ion beams for a possible LHC injection scheme.

Last Weeks of Operation

During the last operational period, which was some 11 weeks in 1992, the linac was required to furnish S^{12+}, then O^{8+} ions to SPS physics, O^{8+} and O^{6+} and then protons to LEAR. Only a vacuum pump failure during proton operation marred this achievement.

Conclusions

We have seen how Linac 1 has been adapted to the changing requirements of the physics programme. From a modest start where a 5mA proton beam for 20 µs was considered a world record performance, via continual modernisation of systems, keeping this record for most of the first period, the Linac finally achieved operational currents of 70 mA for 100µs. Its limitations as a record beating proton injector became apparent and in its second period its qualities as a test bench for new techniques (H^- source, deuteron and alpha acceleration, and the first ever use of an RFQ on an operational machine) were exploited. It is in the third period that the successful operation as a light ion injector has opened up the potentialities for very heavy ion physics e.g. lead ions at SPS energies in the near future and collision of heavy ions as a main plank of the LHC proposals. So Linac 1 has gone to make way for the future but the contributions it has made in the last 33 years have always been fundamental to the CERN physics programme.

Acknowledgments

Of course a machine cannot, in general, be better than the people who built it and who run and improved it afterwards. Hence any praise given to the "good old Linac 1" should not forget the numerous, talented and devoted people who worked on it in the past.

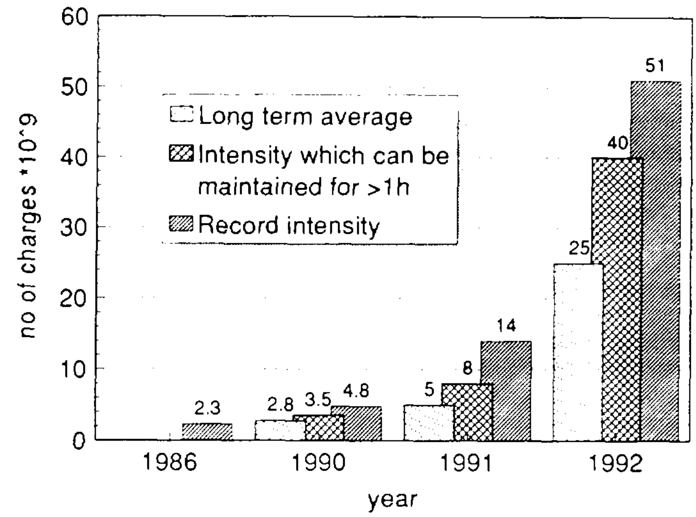

Figure 3. Progression of sulphur charges in the PS supercycle (sum of 4 pulses).

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