OPERATIONAL EXPERIENCE WITH THE CERN HADRON LINACS

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Abstract

The present CERN proton linac (Linac2) was commissioned in 1978 and since that date has been the primary source of protons to the CERN accelerator complex. During the past 18 years, the machine has had a very good reliability record in spite of the demands made upon it. Modifications have been made with the view of maintaining this reliability with reduced resources and new requirements from the users. Further demands will be made in the future for LHC operation.

In 1994, a new linac for heavy ion production was put into service replacing the original CERN proton linac. As this machine was built within an international collaboration, operation had to take into account the novelty of the techniques used and the variety of equipment supplied by outside collaborators. Even so, the new machine has also had very good reliability.

Linac1

Proton Operation

Although the original CERN proton linac (Linac1) no longer exits, from the operational point of view it is interesting to review the changes made to the machine since its construction [1,2]. Major performance improvements came about quite early with the change of the grid focusing in tank 1 with pulsed quadrupoles. Later, an easy access to these quadrupole power supplies was invaluable in tuning beam intensities for other particles. Further improvements in performance came with the addition of transient beam loading compensation for the RF systems and pre-accelerator HT systems, the installation of a high gradient HT column with a duoplasmatron ion source and improved matching in the LEBT.

Linac1 was commissioned in 1958 and was built with the technology of that age. It was very much a hands-on, manpower intensive machine with little scope for modern control technology. A considerable effort had to be expended to maintain operational availability throughout its life. The technology of the tanks, RF liner inside a vacuum envelope, made alignment unstable and the constructional methods were not of good vacuum engineering standards. The unstabilised RF structure also gave rise to instabilities that had to be dealt with on an “ad hoc” basis. These are some of the reasons the machine became unsuitable for the performance demands of the new CERN accelerators, hence the construction of Linac2.

Development Era

Following the commissioning of Linac2, the old machine became available for development work. Linac 1 had already accelerated light ions in the $2\beta\lambda$ mode and more extensive studied were carried out on the production and acceleration of alphas. The success of a gas target stripper in the LEBT enabled useful quantities of D and α particles to be accelerated and stored in the ISR.

The presence of a spare accelerator also gave rise to an interesting operation where Linac1 acted as a cheap source of particles for cooling and set-up tests for LEAR. Opportunity was also taken to replace the aging, and increasingly unreliable, SAMES high voltage generators and the pre-injector by an RFQ [3]. This exercise was successful with an improvement in injection reliability,

Light Ions

The positive experience with very light ions encouraged the users to demand other ions. Experiments demonstrated that it could be just possible to increase the accelerating fields in the tanks by 33%. Achievement of these levels on an old machine required more access for maintenance and repairs than was possible during normal PS operation. To overcome these difficulties, the linac was moved to allow the installation of a shielding wall. Surprisingly, the linac worked after this move supplying LEAR again with protons.

Installation of an O^{6+} injector [4] followed soon afterwards with the proton injection line entering at 30^{o} to the ion line. The use of the linac with these two particles was mutually exclusive but free time could be used to commission ions. This proved to be a difficult process due to sparking in tank 1. Eventually, with a computer controlled formation program reliable operation of the tanks was achieved and O^{6+} accelerated and passed to physics. Operationally, the linac proved to be much more reliable than had been hoped for. Even so much effort had to be expended in keeping all component performance at its peak but the failure rate could be held below 10% for these short experimental periods.

After beams of milliamps, beams of microamps proved much more difficult to measure and diagnostics remained a major problem. This was not helped by an inherent instability in the ion source. With the demand for S^{12+} with higher mass but lower intensity, the problem was aggravated. Linac1 finished its active life in 1992 after 33 years of service. It was a labour intensive machine which required considerable attention but which was sufficiently flexible so as to allow considerable abuse of its original components. Many more problems were experienced with modern ones.

Linac2

Reasons for a New Linac

The demands made on the old linac following the commissioning of the PSB and ISR machines proved difficult to satisfy reliably and efficiently. The input matching, low injection energy, the FFDD focusing structure and instabilities in the RF at high currents made the old machine much more difficult to handle. Thus a new machine capable of accelerating 200 μs pulses of up to 150 mA of protons was designed. Improvements built into this machine were a higher injection energy (750 instead of 500 kV), a post coupled stabilised RF structure, feedback stabilised RF amplifiers and better diagnostics. Advantage was taken of the technology of the era to simplify wherever possible and to add remote computer control [5].

Initial Experience

The linac was commissioned in stages with extensive testing between them. When in 1978, the linac was deemed ready it was used for one physics period for injection into the PSB. At this time Linac 1 was held in reserve in case of problems but not used. The improved intensity, energy stability and reproducibility gave immediate benefits to the other users. From 1979 it became the proton workhorse of the CERN accelerator complex. Reliability was high and over the next ten years a 5% downtime would give rise to concern.

Improvements

Some problems were experienced with the high voltage holding of the original 750 kV high voltage column but after a rigorous program of cleaning and electrode polishing, acceptable to good sparking rates were achieved. In the period 1983 to 1992 the sparking rate varied from 1 to 3.5 sparks per day. However, there were intensity limitations with the high gradient column and although the requirements for LHC could be just met, it was felt that more margin was needed. The success of RFQ1 on Linac1 and the promise of better injection into Linac2 from a RFQ led to the decision to replace the Cockroft-Walton system by a RFQ [6] with an injection energy of 90 kV. This was installed in 1993. Problems related to damage to vacuum pumps during HT flashovers did cause some vacuum pollution in the RFQ and a general increase in its sparking. Long term conditioning has rectified the situation.

Performance

Table 1 shows typical performance figures for 1994 both for standard operation and for high performance, LHC type, beams. For the moment, the high performance beam is used only for test purposes as some upgrading of the RF would be needed for longer beams required by some users.

For comparison, in 1995 the linac ran for 6630 hours with 98.5% availability, all sources of beam loss included.

	Operation (Typical)	LHC (50% duty)	
Current source	250	350	mA
Into Linac	155	220	mA
Linac out	140	195	mA
Into PSB	130	> 170	mA
Pulse Length	20 - 120	30 - 60	μs
Rise Time	20	30	μs
H Emittance	1.7	1.8	μm (1σ, norm)
V Emittance	1.2	1.0	μm (1σ, norm)
Energy Spread	±170	±200	keV (2σ)
Operation	6250	> 250	hours
Availability	97.6	≈99%	%

Table 1. Performance figures for 1994.

Light Ions

Although Linac2 was designed entirely for protons, it did prove possible, with little effort to accelerate deuterons in the machine. About 20 eμA of deuterons were sent to the PSB and proved invaluable in the commissioning of the early light ions in the accelerator complex in 1985. With the RFQ this facility has now been lost

Linac3

History

The Light Ion programme was initiated as a collaboration between CERN, GSI and LBNL. Following the success of this experiment and the impossibility of further upgrading the venerable Linac1 for heavier ions, a study was launched into the possibility of building a new linac dedicated to heavy ions. A cost / energy analysis based on possible source technology, restrictions from other machines and interest from physics indicated that a linac capable of accelerating Pb^{25+} to 4.2 MeV/u with stripping to Pb^{53+} was feasible in the existing hall. The project [7] came to fruition as an international collaboration between CERN (infrastructure and 200 MHz RF), GANIL Caen (source), INFN Legnaro (LEBT, RFQ and MEBT), GSI (100 MHz RF and IH linac), INFN Torino (HEBT including ion filter), IAP Frankfurt (debuncher). Additional assistance was furnished by the Czech Republic, India, Sweden and Switzerland. In spite of the variety of equipment supplied by the collaboration, the new linac was ready on time to supply beam to the next accelerators in summer 1994. Beam was supplied to physics for nine weeks of operation later that year [8].

First Operation

There had been some fears that the diversity of the equipment would lead to reliability problems as CERN staff learn to use it. Experience with ions in Linac1 had shown the importance of beam diagnostics for such low intensity beams

(80 eμA from the source, 20 eμA after stripping). Faraday cups, SEMgrids, beam transformers and phase probes proved to be invaluable during the commissioning. Also temporary 100 MHz amplifiers had to be adapted to CERN controls for two operational periods.

During the physics period, the fault rate was maintained at under 2% influenced mainly by mains instabilities. However, at the end of this period when the machine was supposed to deliver ions to LEAR for cooling experiments major problems, which are still not yet fully resolved, with the microwave generator for the source caused a considerable delay.

Consolidation

As the next physics period was not scheduled until the end of 1995, time was spent in consolidating the machine for operation. Tests were carried out on the source improving the output current to 120 eμA. However, new problems with the microwave generator arose requiring major repairs. The first of the 100 MHz amplifiers from industry was delivered and commissioned for the 1995 run but although it worked without fault during this period, the reliability has not been as good as expected. The second amplifier was delivered in 1996 to replace the equipment borrowed from GSI which had worked well, in spite of its age, until the end of 1995. The new 100 MHz amplifier is still undergoing debugging by the manufacturer.

Between the IH structures, quadrupole triplets are installed which in their initial configuration made alignment of the linac very difficult. Modifications were made by the collaborator but problems still exist in this area.

Another cause for concern, the life of the 100 $\mu g/cm^2$ stripper foils turned out to be unfounded. Although statistics are not readily available, it has been found that a foil which resists the > 100 eμA 4.2 MeV/u beam for more than a few hours, will resist for months.

The Future

Linac2 has been the supplier of protons to CERN for 18 years and during that period has showed a remarkable reliability. However, it has recently started to show signs of fatigue especially at the level of the vacuum seals. Major works are envisaged to change and improve vacuum sealing in the next years. Also during its life no re-alignment has been carried out and there are indications that due to settlement of its building this would be desirable. The demands of the LHC era will require more performance from the linac and thus some refurbishment of the machine will be needed to maintain reliability.

Ion beams will continue to be in demand. In the short term, the reliability can be maintained with manpower effort but some improvements are still needed. The use of LEAR as an intermediate ion store for LHC ion beams will require operation at 10 Hz. Most of the components are already suitable for this but the impact on reliability has yet to be assessed. Already Linac3 has shown itself to be a flexible machine capable of changing ion species at fairly short notice. When its teething problems have been overcome, it will be a very useful tool.

Acknowledgments

In the history of the CERN hadron linacs the people who built these machines should not be forgotten. Service groups provide us with the equipment and the repair service that keeps the machines running with high reliability. The authors would like to thank them all.

This paper is also dedicated to Pierre Tetu, who left us with linacs that work and who’s knowledge of them is sorely missed

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