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PERFORMANCE OF THE NEW CERN 50 MeV LINAC

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The new 50 MeV proton linac injector for the CERN accelerator complex has just commenced routine operation. In this paper the design characteristics and commissioning of the machine as well as some results of the study programmes at 750 keV and 10 MeV are briefly described, to put into perspective the present 50 MeV performance. It has already been demonstrated that the improved beam brightness and stability at 50 MeV lead to higher intensities in the subsequent accelerators and it is expected that further development of this linac's potential will be made during 1979.

PARAMETERS

The project study (1973)[1] gave a preliminary definition of the parameters and these needed only slight updating for the 1976 Linac Conference[2,3]. The specified beam quality refers to the debunched beam at 150 m from the linac output viz. :

current	50 mA to 150 mA
pulse duration	200 µs to 70 µs
repetition rate	2 pps
normalised emittance	< 8πmm mrad (90% of beam)
energy spread	<±150 keV (90% of beam)

SUMMARY DESCRIPTION

The source is a duoplasmatron similar to the one on the old linac[4] with its diameter reduced to keep reasonable voltage gradients around the column anode. Nickel plating has been applied to protect all surfaces of the soft-iron magnetic elements. This and pulsing the hot cathode from a delay-line, capable of supplying up to 2 kV to strike the arc, pushed up the lifetime of the cathode to years, even when frequently letting up the system to air. Extraction of the protons from the expansion cup is directly into the column gap.

The accelerating column was built to CERN specifications by H.V.E. with the technology developed at CERN[5]. The double gap configuration has a total gap of 12.9 cm. A non-araldite construction using ceramic rings and viton was applied to the bottom end of the column ("sandwich"). To avoid problems with secondary electrons the re-entrant cathode is biased at -4kV. The column is cantilevered with a counterweight to minimise the bending moment.

The high voltage generator (750 kV) is a Cockroft-Walton cascade (Haefely). A compensated resistive divider serves for regulating the HV generator 5 KHz supply as well as for the error signal derived for the HB stabilisation. In this (usual) 2 tube "bouncer" system, one tube is used for beam loading compensation and both are used to reduce the ripple.

The low energy beam transport[6] (LEBT), Fig. 1, is designed to accept preinjector beams up to 300 mA and then to limit, transport and match (in six dimensions) to the linac a range of currents (50 mA to 250 mA). It consists essentially of an unbunched beam section with four triplets and four steering magnets, which transfers the beam to the first two bunchers, and a bunching section with six quadrupoles to match the beam to the linac. For longitudinal matching there are 3 bunchers, a double drift harmonic buncher (DDHB) at 202.56 and 405.12 MHz and an energy spread corrector at 202.56 MHz. There are five beam transformers, two emittance measuring stations, a transverse profile measurement device before the DDHB and a fast probe for longitudinal profile measurements.

The drift tube accelerator[3] consists of 128 unit cells contained in three copper clad tanks operating at 202.56 MHz forming a single unit for vacuum purposes. They accelerate to 10.4 MeV, 30.5 MeV and 50.0 MeV respectively. The tanks are made up from sections 3 to 4m long and the drift-tubes in each section are suspended from a demountable rigid girder. Total pulsed RF power requirements are 2.9 MW for structure alone plus 7.4 MW to accelerate 150 mA. Focusing is by pulsed quadrupoles in +- configuration.

The high energy beam transport (HEBT) is shown on Fig. 2. Operation is transferred from old to new linac via BH3. The 50 MeV beam can be measured in the three phase planes using single pulse measuring systems[9] at the output of the linac or at the end of the HEBT.

The RF system consists of ten independent RF chains fed individually from a phase-stable reference line. Each chain comprises fast amplitude and phase servomechanisms and a slow tuning loop. The control elements for phase (a hybrid with varicaps) and for amplitude (a PIN modulator) act on the low-level side of each chain; no high power modulators are used. Thus one uses modular elements throughout the RF system, and avoids high-voltage decks in the plate supply for the 2.5 MW stages; simple and reliable PFN circuits with an efficient charging circuit based on low-loss current limiting chokes are used. FTH 170 tubes, a new water-cooled version of the FTH 470 are used in all 2.5 MW power stages.

The control system[7,8] is based on two DEC PDP 11/45 computers in a back-up scheme. Normally one computer does process I/O, the other measurement, computations and display plus program development work. In abnormal situations, one computer can do all at reduced response time. The console consists of two parallel sets of three segments each set providing all the control facilities. Access is via touch panels, knobs, keyboards, and video terminals. A List Processor permits the setting of a group of parameters by a single touch panel button. User programmes are written in FORTRAN or BASIC. The console segments and two 2.5 MHz serial CAMAC loops are driven from a parallel CAMAC branch. Through a branch mixer each computer has access to the parallel branch and to a common Data Base of 64 k core memory which contains status and description of each parameter. One serial loop crosses the 750 kV via infrared optical links to control ion source parameters, the other links 12 CAMAC crates in the equipment gallery.

The vacuum system is based on turbomolecular pumps and ion pumps. Al-wire seals are used throughout.

CONSTRUCTION AND COMMISSIONING

The project was authorized in October 1973 and milestones during construction were passed as follows :

a) 750 keV beam	Dec 1975
b) 10 MeV beam	May 1977
c) 50 MeV beam	Sep 1978
d) Operation with PS/SPS	Dec 1978

Within this construction schedule measuring programmes at 750 keV and 10 MeV alternated with commissioning of ancillary systems. In particular tank 2 was installed last, to allow operation of the 10 MeV measuring line until July 1978.

With the experience gained in setting up the linac and the extended test of some systems it was possible to eliminate some weaker components. This experience was an indispensable factor in the short interval between obtaining 50 MeV and the first scheduled operation when beam currents between 90 mA and 120 mA were provided provided and new intensity records were

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achieved with the other CERN accelerators.

RESULTS AND EXPERIENCE

a) 750 keV

The formation of the accelerating column which is done by the computer referring to the X-ray level is quiet without many breakdowns. Breakdowns rates <1/day were observed during the operation period.

The beam currents in the LEBT are limited by the 4-jaw apertures (AP1 and AP2) to about 1.3x (beam current after acceleration). Presently the first two triplets and apertures are set to minimise the beam noise (Fig. 3) which seems unavoidable with the source adjusted for small near-elliptical emittances.

Emittance measurements are analysed in terms of E_{rms} (as function of current contained), this being the significant matching parameter for the linac[10]. Typically at EM3 (after DDHB) the normalised E_{rms} for 90% of a 200 mA beam is 0.34πmm mrad compared to E(90%)=2πmm mrad (see Fig. 4).

Transverse matching after the apertures uses two triplets to ensure a beam diameter ≤10mm at DDHB, a necessary condition for control of emittance growth and bunching. Using emittance results from EM3 as input data, one derives quadrupole settings necessary to fulfil the linac matching conditions (α, β in both planes) by using a program[11] on the PDP 11/45.

Longitudinal matching : the bunching system has been designed so as to operate with an approximately constant setting of the DDHB (for a given linac operating condition) and to vary merely the third buncher as function of beam intensity.

Matching parameters at the linac input and the linac quadrupole settings for various accelerated currents are determined by a program on the CDC 7600[12]. For modifying all the quadrupole settings to account for changes in accelerated current, an on-line program is used via a touch button.

b) 10 MeV

Trapping : for accelerated currents between 10 mA and 150 mA it was possible to accelerate 80% or more of the injected beam (as measured on IM6) when using the DDHB (cf. 65% for single buncher and 30% for no bunchers). The output current was relatively insensitive to adjustments of RF, focusing, and steering about nominal settings, confirming that beam emittances are much less than available acceptances.

Transverse emittance and emittance growth: our very dense beams combined with the high observed trapping efficiency lead to larger emittance increase than originally calculated (for less dense input beams[10]).

Current (I)	E_{out}(90% I)	E_{out}/E_{in}
25 mA	1.4πmm mrad	2.5
75 mA	2.4πmm mrad	1.8
150 mA	3.0πmm mrad	1.7

Varying the matching conditions around the nominal settings did not have a marked effect on output emittances. This may indicate that a "perfect" match has not yet been achieved.

Longitudinal phase space: in the interpretation of results from the 53° spectrometer at 10 MeV, effects of emittance, matching, space charge and sampling were considered. To simplify the study of phase acceptance limits and accelerating threshold a low current (<20mA) paraxial beam was used. At 150 mA the energy spread is ±85 keV which is consistent with a longitudinal emittance increase of x3.

c) 50 MeV

First attempts at 50 MeV acceleration required a reliable 10 MeV beam, nominal RF levels and precomputed drift tube quadrupole currents (available via touch panel control). Then a 50 MeV, 50 mA beam was quickly established by adjusting RF levels and phases and observing the acceleration threshold and phase acceptance on beam transformers with energy discrimination. After the spectrometer had been set up, measurements of output energy versus input beam phase (varying RF level) were compared with computed values to fix the operating phases and levels precisely.

One effect, emphasized by the high trapping (>80% between 0.75 and 50 MeV), is that noise in the injected beam can persist at 50 MeV but the present LEBT settings give satisfactory results for a range of currents between 20 mA and 150 mA.

On Fig. 4 a comparison of the normalised transverse emittance versus current at 0.75 and 50 MeV is shown for the 150 mA case. The emittance increase, x2.3, is greater than computed for this input beam density while the actual output emittance, 5.1πmm mrad, is well within the specification.

Fig. 5 compares results with and without a beam sieve (22% transparency) which reduces the space charge effect between linac and spectrometer. Although the longitudinal emittance is larger than expected one needs only one of the three debunchers to meet the Booster energy spread requirements. Stability of the emittance during the beam pulse is shown on Fig. 6.

To transfer the beam to the Booster, the HEBT quadrupoles are set to nominal values predicted by TRANSPORT, respecting, in particular, the achromatic conditions between BH2 and BH3 and adjusting the beam steering systematically by reference to position monitors and current transformers. Between the output of the Linac and the end of HEBT one has <5% beam loss and the transverse beam quality is essentially unchanged. So far a limited time (10 hours) has been available to study this beam transfer region where, in particular, the benefits of using 3 debunchers have not yet been explored.

While there has been insufficient running time for a complete evaluation, the linac performance can be summarized thus:

1) It was commissioned rapidly, and specified performance was soon attained.
2) The parameter settings derived on the basis of rms beam emittances have been confirmed experimentally.
3) The design options taken in respect of the various sub-systems (control, mechanical, RF, vacuum) have resulted in a machine which is mechanically stable, and which produces a beam stable both during the pulse and pulse-to-pulse. By the use of stored data, the computer control system can set the operating conditions quickly and reproducibly.
4) The down-time during the 2 weeks' operation period in December 1978 was only 2%, and this was mainly due to inexperience with the new systems.

We hope to present more quantitative results at the September 1979 Linac Conference.

ACKNOWLEDGEMENTS

This project has actively involved the whole linac group with essential support in the PS Division, in particular on mechanical design, vacuum technology, magnetic measurements and mechanical and electronic fabrication. Additional help was provided within CERN on surveying and generally by SB Division. We have also profited from the traditional friendly collaboration with other labs and from the presence of many short and long term visitors. All the above have contributed significantly to the success of the project.

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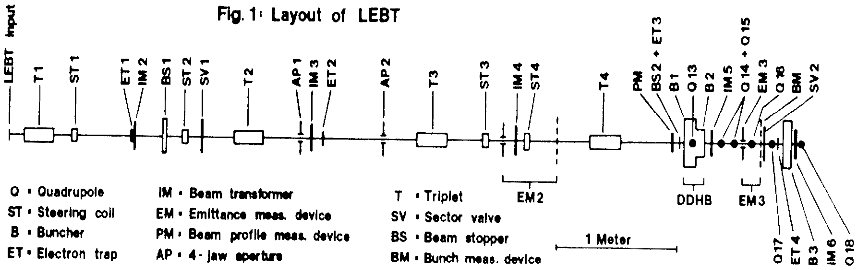
Fig. 1: Layout of LEBT

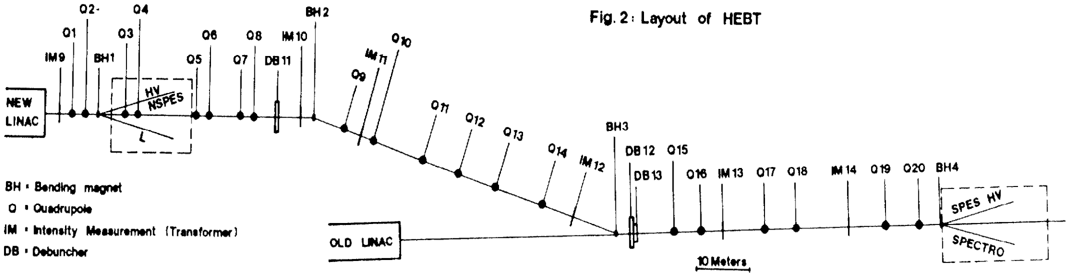
Fig. 2: Layout of HEBT

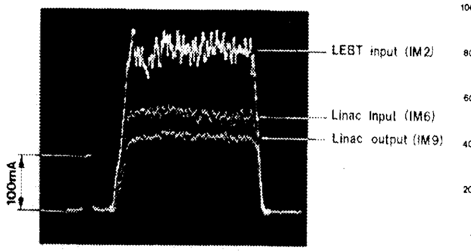
Fig. 3: Beam pulses

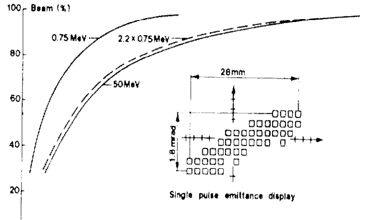
Fig. 4: Transverse emittances at I (50MeV) = 150mA (H,V coincide)

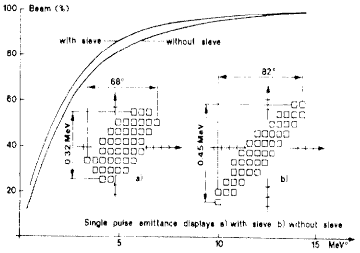
Fig. 5: Longitudinal emittance at I (50 MeV) = 150mA

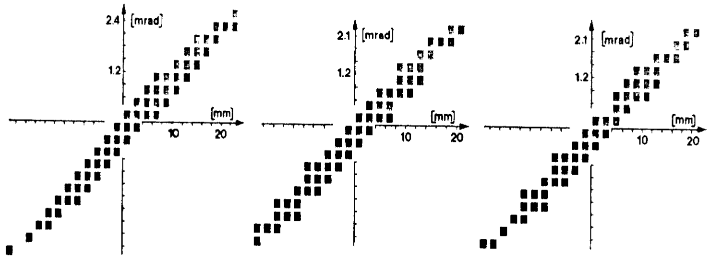
Fig. 6: Emittance (vertical) at beginning, middle and end of beam pulse of 100μs