FIRST ELECTRON BEAMS FROM THE LEP INJECTOR LINACS

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Summary

The commissioning of the LEP Injector Linacs (LIL) with beam is now taking place at CERN. Acceleration of electrons to 265 MeV has been achieved by 6 sections of the 600 MeV linac (LIL W) and the beam transported to the electron injection line of the Electron Positron Accumulator (EPA). Preliminary measurements of energy, energy spread and emittance can be reported for the maximum energy, with more details of measurements at intermediate energies, nominally 4 MeV and 100 MeV, and of experience gained in commissioning the r.f. systems including LIPS, and the beam instrumentation. It is too early to claim comprehensive agreement of measurements with design parameters but no fundamental limitations have been found.

LIL-W Parameters

Previous papers[1,2] treat the design of the two linacs of LIL, one at 200 MeV (V) with high currents for production of positrons, followed by an electron/positron linac at 600 MeV (W) accelerating more modest currents. A status report[3] and papers describing systems were presented at LINAC 84 at a stage when parameters had been frozen and some items delivered.

This paper concerns the first acceleration with LIL W so that a brief summary of the systems and parameters concerning the beam commissioning is given (see Table I). Figure 1 shows the layout of LIL and EPA with the three places in which measurements have been made i.e. the 4 MeV region, the TW acceleration part (4 MeV to 600 MeV) and the electron injection line to EPA, which is used for beam measurements. More detailed diagrams (figures 2, 3, 4) show the hardware layout and nomenclature, emphasing beam transport elements, and beam measuring instruments which are briefly described below.

Table I, Required Electron Beam Parameters (LIL W)

Gun	Energy	60 keV
	Current	250 mA
	Pulse Length	8 to 25 nsec
	Repetition Rate	100 Hz
Buncher W		
	Energy	4 MeV
	Current	150 mA
TW Sections		
	Energy	600 MeV
	Current (I)	60 mA
	Emittance (80% of I)	<<1 π mm mrad
	Energy Spread (80% of I)	< 1 %

Beam Instrumentation

WCM: The broadband (1 GHz) wall current monitor is used to observe detailed pulse forms.

UMA: The magnetic position monitor (BW 150 MHz) gives signals proportional to current and proportional to the beam vertical and horizontal positions. Precise charge and position results are computed on-line.

WBS: In the wire beam scanner two beryllium wires (0.30 mm) mounted at right angles are swept across the beam at 45° to horizontal and give signals proportional to the density profile. A computer analysis and display are made after each beam traversal.

MSH: The secondary emission grid consists of titanium bands, 5 µm thick, pitch 2 mm. Beam profile signals corresponding to individual pulses are analysed and displayed.

MTV: A fluorescent screen which is observed by a TV camera to enable quick estimates of beam size and position.

The 60 keV to 4 MeV Measurement Programme

The tri-periodic standing wave buncher, though similar to a tried design had not been previously tested. A special measurement programme was thus implemented at the beginning of 1986 to study the quality of the 4 MeV beam. In addition the 60 keV off-axis gun, the 60 keV transport, the extended r.f. system, the prebuncher W and several beam monitors, could be tested under realistic conditions.

Equipment Layout

The first TW section of LIL W (ACS25) was not installed leaving sufficient space for a 45° spectrometer beyond the converter (see fig. 2) and for isolating this region by concrete shielding walls. Additional measurement facilities were a wall current monitor (WCM25.S) and a 45° bending magnet with beam pipe to a secondary emission monitor (MSH25.S) forming a spectrometer. The converter was a beam stop when the target was "in" and provided beam size definition via the 2 mm and 5 mm aperture positions. More details are given in an internal report[4].

Provisional controls were available in the klystron gallery (r.f. equipment and signal observation) and in the local control room EB1) where three Macin-

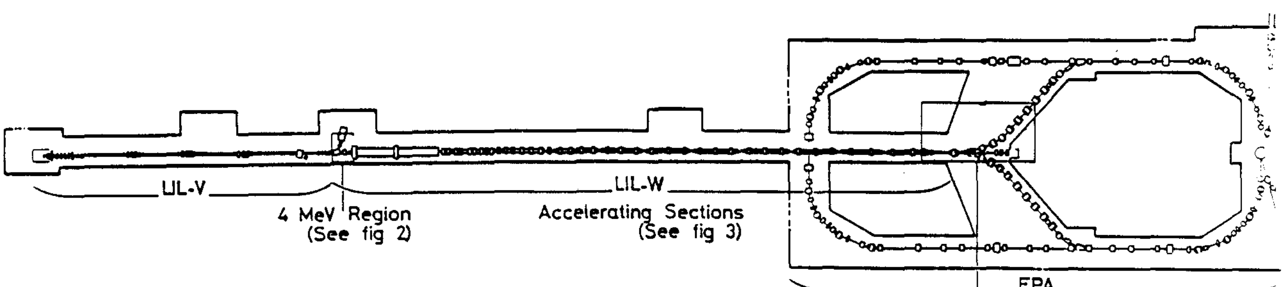

Fig 1 : LAYOUT OF LIL/EPA
Showing Beam Measurement Regions

tosh computers controlled magnet power supplies, beam measuring programs for WBS25 and the spectrometer SEM grid, and some timing triggers. Also in EB1 were manual controls (gun) and analogue signals, e.g. buncher r.f. envelope and beam monitor signals.

60 keV Beam Transport

The specification of the 60 keV gun asked for a 250 mA beam with beam diameter less than 5 mm at the output of the anode. However, the beam had a large angular deviation so with the first solenoid at 0.27 m from the gun anode only 100 mA was measured at WCM221. Measurements made at 65 keV with a nominally 25 nsec pulse length, a 5 mm diameter defining aperture in front of the α-magnet and the aperture restrictions in the α-magnet led to a further reduction of current measured on UMA22 and on UMA25 with unpowered buncher (typically 40% and 35% of WCM221 values respectively). Some improvement has been obtained using a 10 mm aperture and a further gain is expected with a solenoid closer to the gun.

Current Transmission at 4 MeV

These measurements depended critically on the adjustments of solenoids (before, on and after the buncher) and on the steering, especially when the current was being optimised on WCM25.S. Other important parameters were the prebuncher r.f. level and phase which, when optimised, gave about the same transmission to UMA25 as for 65 keV with unpowered buncher. Typically only 20 mA could be obtained beyond the 5 mm converter aperture compared to 60 mA needed.

R.F. Measurements and Beam Energy

In the experiments to correlate r.f. measurements, beam energy measurements at the nominal 4 MeV and beam dynamics calculations it was found that errors, could be up to ±20% in power relative to the mean 4 MeV energy gain for 1.2 MW power in the buncher. This discrepancy was ascribed mainly to the r.f. power measurements. Errors in the momentum arising from the summary magnet calibration could be 2%.

Energy Spread

The typical energy spectrum shown in Fig. 2a has a characteristic steep flank and a low energy tail. Due to amplitude and base line position instability it was difficult to optimise energy spread as function of r.f. level and phase in the prebuncher. However, the measured energy spreads (< 1% fwhh) were rather less than those calculated (2 % fwhh) and the optimum phase setting between prebuncher and buncher was critical. to < ±10°. The r.f. levels in the prebuncher were generally higher than small signal bunching would require as this gave a better transmission.

Emittance Estimates

Using the solenoid SNT25 as a variable element and measuring a) the beam size with WBS25 and b) the beam transmitted by the 5 mm aperture, it was possible to deduce that at 4 MeV the emittance is between 4 and 12 π mm mrad which is consistent with the required emittance at 600 MeV.

100 MeV Tests

After installation of ACS25 and the commissioning of the modulator/klystron ensemble MDK25 including the r.f. conditioning, 100 MeV operation could be tried. By then improved control facilities were available from a PS standard console allowing control of all power supplies and access to analogue signals (e.g. RF envelopes); some general programs were installed e.g. for display, listing and logging parameters, and cycling magnets. Necessary timing signals were available (via Macintosh) and there was a digital display of beam currents and positions.

Finding the Beam on UMA27

To help centre the beam on the 5 mm aperture, a pair of dipoles was installed after the buncher and the beam position measured at WBS25. Then by observing the induced r.f. signal at the section output coupler, it was possible with the long solenoids at 0.10 T, to adjust the dipoles on the sections successively so that the 4 MeV beam passed through. The induced r.f. envelope length indicated how far the beam had progressed e.g. a pulse length of 1.2 µs, (the filling time) corresponds to the beam passing completely. These steering settings could be retained when the sections were powered with r.f.

Setting the R.F. phase

It was noted that the transmitted beam was quite insensitive to the relative r.f. phase between buncher W and sections ACS25 and 26. As it was not possible to transport the beam to the spectrometer in the electron injection line of EPA, maximum energy gain could not be measured with high resolution. However, by using the steering dipole directly after ACS26 and observing the beam deflection on UMA27, the beam momentum was determined with a resolution of about 2% and it was thus possible to optimise the phase setting to give about 95 MeV/c maximum.

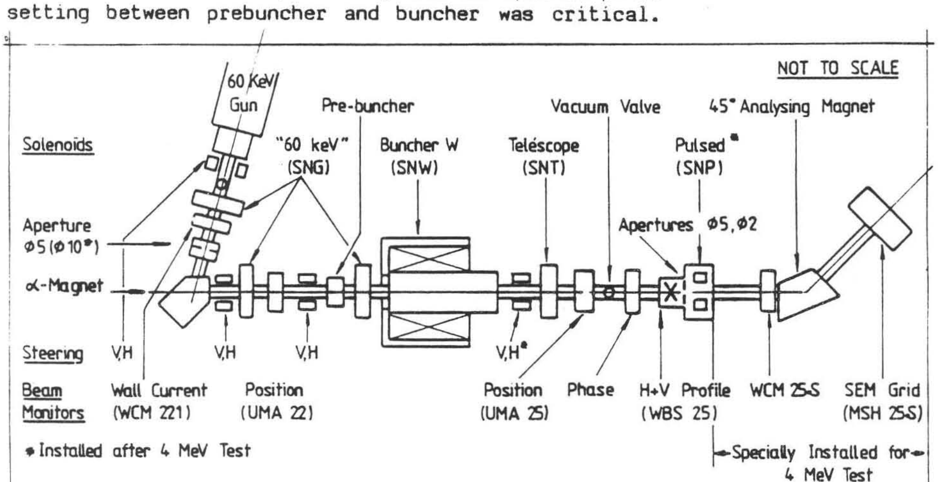

Fig 2 : Schematic Layout of 4 MeV Test Region

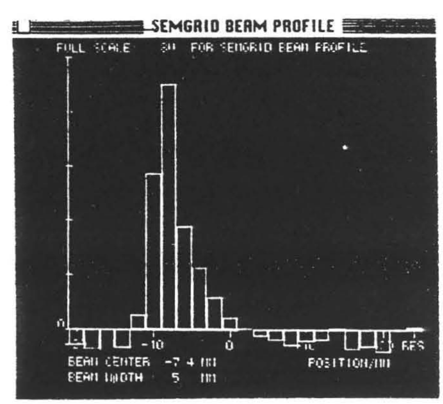

Fig. 2a: 4 MeV energy spectrum at MSH25.S. Energy increases from right to left. Resolution 0.16%/channel.

Beam Steering

When steering the beam through ACS25 and 26 an anomalously high horizontal field correction of 0.2 mT was required at 0.10 T longitudinal field, and this correction increased linearly with the longitudinal field in SNL25/26. First tests simulating the effect of partially magnetic materials near the solenoids were inconclusive.

Experiments to calibrate and optimise the 100 MeV beam steering in sections ACS27 and 28, with the focusing off to simplify the interpretation, became insensitive as the natural transverse growth caused beam loss. With the matching quadrupoles and FODO system (QNFA) set to standard values, the 100 MeV beam beam was easily centred on WBS28 but as predicted by computations, it was strongly mismatched.

Pulsed Converter Solenoid (SNP25)

Though mainly designed for use at 1.8T (semi-sinusoid, 10 µs with peak current 6000A) for positron focusing, SNP25 will also be used at about 0.2T for matching the 4 MeV electon beam. First tests with SNP25 showed that the beam match (at WBS28) noticeably changed above 0.1 T, that no apparent mis-steering occurred but that spurious e.m. noise affected UMA25.

300 MeV Tests

Setting the Operating Parameters

A nominal energy gain of 200 MeV should be obtained with four sections powered via the LIPS pulse compression scheme (analogous to the SLAC SLED system), with the klystron at about 30 MW. Problems with severe outgassing, thought to be due to r.f. leakage into the vacuum pumps, limited operation to about 21 MW into LIPS (125 MW peak transient power out) so that the first measurements gave about 170 MeV gain i.e. 265 MeV total energy. The quadrupoles were set to the nominal gradients for 600 MeV operation and there was little difficulty in transporting the 265 MeV beam to the measurement lines with negligible beam loss after UMA27 (see fig. 3) after adjusting the steering dipoles empirically. A more systematic trajectory control will be necessary for positron operation[5].

First quantitative confirmation of acceleration above 100 MeV was obtained (on 8 May 1986) by adjusting the splitter magnet current (HI.BSHM00) and observing the screen, HIE.MTV00. Optimisation of both energy and energy spread could be made by adjusting the phase of klystron 27 in manual mode. For stable reproducible operation in the following runs the phasing system was operated in servo mode though, provisionally, the buncher W phase was set with respect to the cavity phase signal instead of the 4 MeV beam induced signal. The timing of the beam relative to the LIPS 180° phase switching is considered critical but in fact the initial setting via oscilloscope signals gave nearly optimum beam energy.

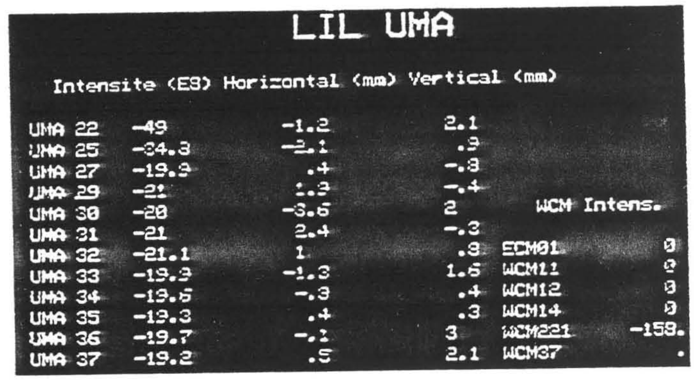

Fig. 3a: Beam currents, horizontal and vertical position from gun to end of linac (265 MeV). Units: $-1 = 10^8$ electrons/pulse, so: -20 = 13 mA for 25 ns pulse

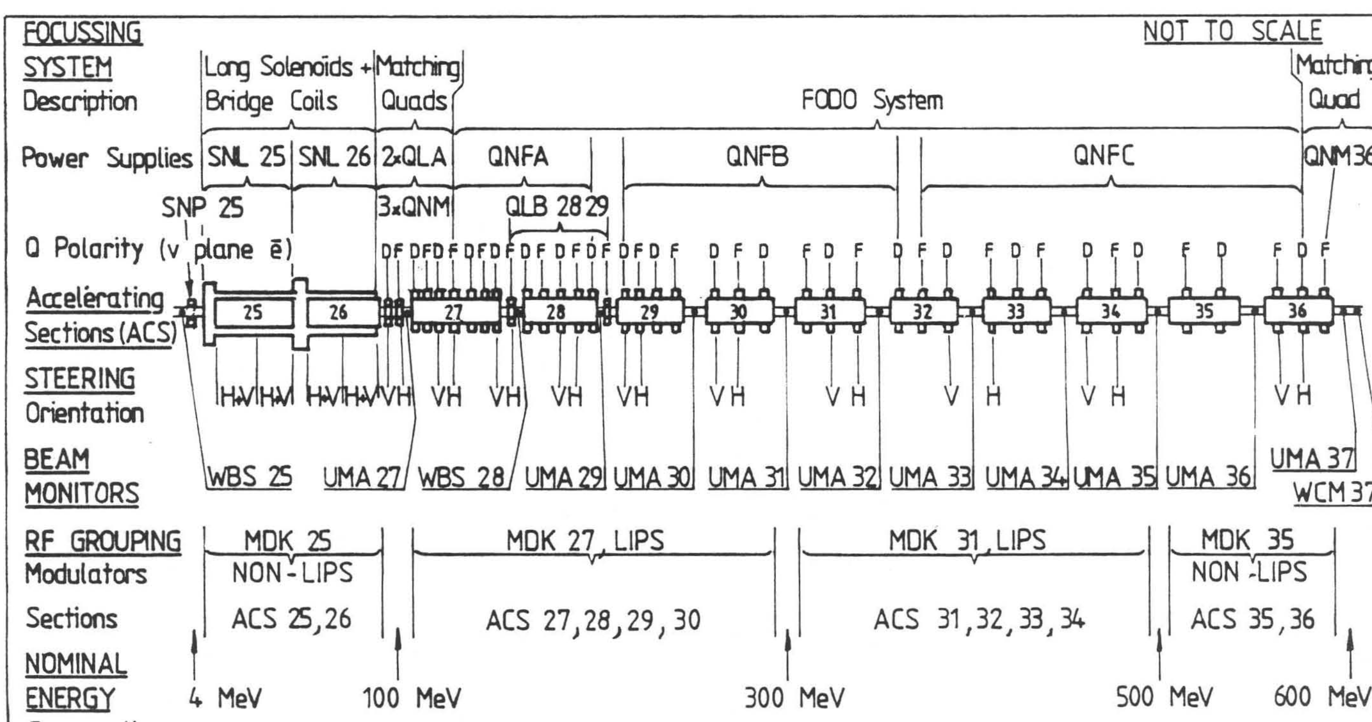

Fig 3: Schematic Layout of LIL-W Accelerating Sections

Energy and Energy Spread Measurements

With the three horizontal dipoles and the quadrupole HIE.QFW11 set to nominal values corresponding to the energy, the beam was centred on the SEM grid HIE.MSH20 and the corresponding sensitivity for beam energy measurements was 0.29%/channel. Thus fig. 4a shows a 265 MeV beam with a full width at half height of about 1% and a characteristic low energy tail.

Emittance measurements

The variation of the beam profile on HIM.WBS00 with the strength of quadrupole QNM36 is a function of the beam emittance, which can thus be determined. First results are much higher than the expected value (< 0.2 π mm mrad) but real operating experience is still lacking.

Experience Gained with RF Systems

The rate at which LIL has been commissioned with beam has been largely determined by the availability of the modulator/klystron assemblies and the r.f. conditioning of LIPS, waveguide networks and accelerating sections.

In particular the waveguide network on MDK25 was brought to 31 MW with 4 µs pulses at 100 Hz in ten hours and the conditioning of the associated sections ACS25 and 26, took much less time than waveguides. With LIPS27, the first r.f. conditioning to about 30 MW input power required less than 20 hours spread over several sessions. LIPS31 has proven much more difficult with input power limited to about 20 MW apparently due to r.f. leakage into the LIPS vacuum pumps causing overheating and breakdown near the network SF6-to-vacuum windows. Subsequently LIPS27 had the same overheating problems but recent installation of r.f. filter baffles in the pump ports has reduced the r.f. leakage for both systems. LIPS27 is still limited by vacuum, however.

There are other potentially weak points in the r.f. systems, e.g. the pin switches at the klystron input barely handle the necessary power, and there was voltage breakdown on an insulating plate in the klystron tank. The r.f. systems will only be brought gradually to their maximum potential performance as replacement spares become available.

It was found that calibrated peak power instruments with low pass filters (f_c = 4.8 GHz) are important for a proper investigation of the teething troubles of the r.f. systems. In particular there will eventually be 65 measurements couplers for incident and reflected power at inputs and outputs of klystrons, LIPS cavities and sections, each requiring attenuators, filters and cables to prepare the r.f. signals for the calibrated demodulation units.

Immediate Programme

Recently, during several hours the beam energy was increased to 385 MeV from 10 accelerating sections, using LIPS31 at a safe input r.f. level, but without optimising phase.

Thus although the two LIPS systems are run below their nominal performance and the last two sections not yet fed by r.f., a beam with an energy between 400 and 500 MeV should be delivered on schedule to the EPA early June. The debugging of the EPA systems can thus start in time and it seems feasible to have the LIL and EPA ready by the end of the year to deliver electrons to the CERN-PS.

Acknowledgements

A large collaborative effort by many CERN and LAL staff has been necessary to bring the LEP Injector Linacs to their present, pre-operational, state. This help is greatly appreciated.

References

1. R. Belbeoch et al. "Rapport d'Etudes sur le Projet des linacs de LEP (LIL)", LAL-PI 82-01/T (1982).
2. The LEP Injector Study Group "The LEP Injector Chain", CERN/PS/DL/83-31 and LAL/RT/83-09 (June 1983, Ch. 3).
3. F. Dupont, CERN-LAL Collaboration, "Status of the LEP e$^{\pm}$ Injector Linacs", Proceedings of the 1984 Linear Accelerator Conference pp 288-292.
4. J.C. Bourdon et al., K. Hübner (Ed.), "Report on the Running-IN of the Electron Injection System of LIL-W", CERN/PS/LPI Note 86-15, to be published.
5. R. Chehab et al., "Simulation of Trajectory Control in LIL", these proceedings.

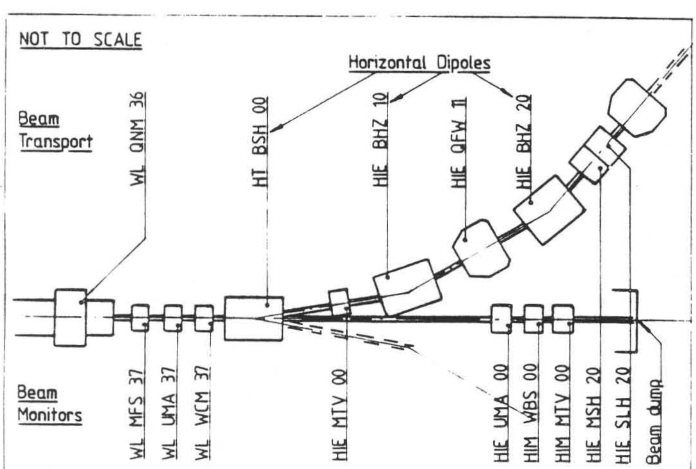

Fig 4 : Schematic Layout of Injection and Measurement Lines

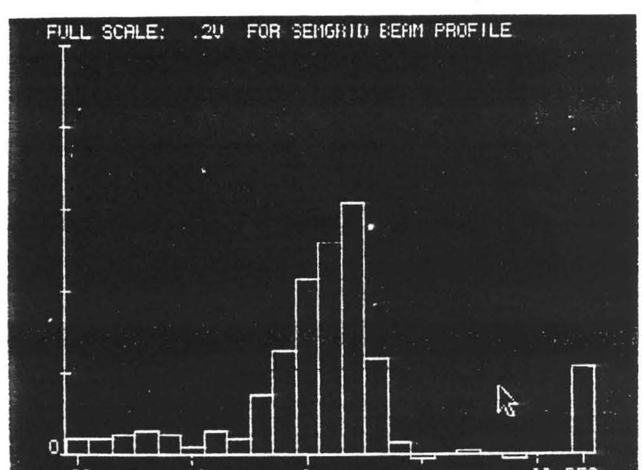

Fig. 4a: 265 MeV energy spectrum at HIE.MSH20
Energy decreases from right-to-left.
Resolution 0.29%/channel