

## FIRST EXPERIENCE WITH THE LEP PRE-INJECTOR (LPI)

BY THE LPI BEAM COMMISSIONING TEAM

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### 1. Summary

The LEP Pre-Injector (LPI) consists of two linacs and an accumulator ring. A high current electron linac of 200 MeV, used for positron production is followed by a lower current linac accelerating either electrons or positrons to 600 MeV. An accumulation ring (EPA) serves to match the linac repetition frequency of 100 Hz to the slower cycling Proton Synchrotron (PS), the next machine in the LEP injector chain.

In 1986 the installation of LPI was completed in stages and each stage was followed by beam tests. The aim to have LPI ready in September as an electron injector for the PS was achieved. The design values for  $e^-$  operation are attained and even surpassed. The commissioning of the machines with positrons will be done this year.

### 2. Description of the LPI

LPI is the purpose-built pre-injector of the LEP injector chain which consists of LPI, PS and SPS. The beam parameters for LPI were derived from the required almost simultaneous accumulation in both LEP beams with interleaved operation mode of  $e^+, e^-$  and  $p$  in the PS and SPS and by considering the expected intensity limitations in the synchrotrons [1,2]. During one supercycle, lasting 14.4 s, the PS and SPS will produce in sequence two  $e^+$  followed by two  $e^-$  cycles (duration each cycle 1.2 s). The production rate of LIL for  $e^+$  is about five times lower than for  $e^-$ , and EPA is accumulating  $e^+$  during 10.8 s followed by an extraction of half of the accumulated intensity in two batches separated by 1.2 s. Two accumulation cycles of 1.2 s each are used in EPA for the  $e^-$ . The nominal number of  $e^+$  which has to be accumulated in the EPA is  $2.5 \cdot 10^{10}$  particles per bunch in the 8 bunch mode and half of this for  $e^-$ .

The 200 MeV electron linac (LIL-V) is used only for  $e^+$  production. It consists of a high intensity gun [3], a standing-wave buncher [3] and four travelling-wave S-band sections [4]. The 200 MeV  $e^-$  beam, nominal current 2.5 A in a 12 ns pulse with repetition frequency of 100 Hz, produces the  $e^+$  in the converter target, just upstream of the 600 MeV linac (LIL-W). The four sections of LIL-V receive their r.f. power from one 35 MW klystron amplifier with LIPS [5] (an energy storage configuration based on the SLAC-SLED arrangement).

LIL-W has its own injection system to enable the fast switching required between  $e^+$  and  $e^-$  cycles. The  $e^-$  beam from the off-axis gun is bunched and accelerated to 600 MeV in twelve sections which are nearly identical to the sections of the first linac. The nominal output current is 60 mA for  $e^-$  and 12 mA for  $e^+$ . For more references on LIL cf. [6, 7]. The design [8, 9] of the Electron Positron Accumulator (EPA) is aimed at an efficient and economical injection/accumulation and extraction/transfer process. To achieve these targets it was found that particular care had to be devoted to the optics in the short bending magnets [10]. Thorough attention had to be paid to possible beam-equipment interactions resulting in instabilities and beam blow-up [11]. The energy of the EPA is constant during an operational period. The nominal energy is 600 MeV but during the design the parameters for operating at a lower and higher energy, 500 MeV and 650 MeV were explored and found feasible.

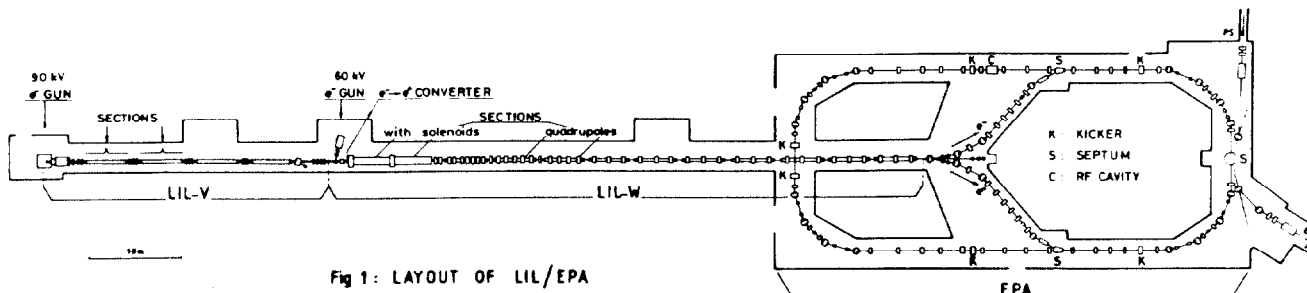
The r.f. frequency is 19.1 MHz and the peak voltage is 50 kV. The strongly capacitive loaded cavity is relatively small and has material in it damping the higher order modes efficiently [12].

The accumulation of the linac pulses takes place in the betatron phase plane close to the stored bunch and is in the nominal scheme done at an equal rate in each of the eight equidistant circulating bunches. The distance between the bunch centers is 52.4 ns and the bunch length at max. 25 ns. Short rise time kickers operating at 100 Hz were constructed. Another kicker system was built to extract all eight bunches within one PS turn, requiring kicker shots spaced by 262 ns.

### 3. Beam Commissioning

#### 3.1 General

At the end of 1985 a 4 MeV  $e^-$  beam was obtained in the injection system of LIL-W [13]. In 1986 work continued on the installation and commissioning of the modulator/klystron assemblies and the low and high-power r.f. distribution systems. Beam tests were made as soon as another modulator/klystron system was available. During LIL-W r.f. and beam tests the tunnel housing LIL and EPA is not accessible; consequently the EPA installation had to be scheduled interleaved with the LIL commissioning during the first months of 1986. In spite of this limitation,



the installation of EPA could be finished in May for e<sup>-</sup> operation. By then, the energy of the LIL-W beam had attained 410 MeV. Although this energy is far below the nominal 600 MeV, injection and accumulation tests were successful. The on-line computer program representing the optical model [14] and derived from magnetic measurements of the elements of EPA was very useful during the trials as well as afterwards.

The LPI controls forms part of the PS controls system but will contain new features such as stand-alone capacity with local interaction [15]. Not all facilities being ready, during the first phases of commissioning personal computers were used to access via CAMAC process equipment [16]. It was found that this multiple access system has certain advantages over the standard one-console for machine commissioning.

Pulse to pulse changes in operating conditions are achieved via a local sequencing unit [17] which drives the timing or setting of different equipment. The sequencing system provides great flexibility. A large variety of accumulation schemes (number of bunches filled, order of bunch filling, number of linac pulses to accumulate etc.) can be composed through a local terminal.

Beam commissioning benefited from the beginning by the availability of the instrumentation [18, 19, 20]. Observation of analog signals was very helpful as the software for signal processing and display required a certain debugging time. Once more we found that beam observation with screen and TV camera is indispensable. The beam observation with the synchrotron light monitor in the EPA gave a powerful support to the running-in from the start.

### 3.2 LIL-W

The previous paper [21] reported about the experience with the commissioning of the 600 MeV linac up to mid May 1986.

With all the twelve accelerating sections fed by r.f. a beam energy of 500 MeV was readily available. A number of weak points in the modulator/klystron assemblies which are voltage related could not be solved in a short time and it was preferred to continue running as injector for EPA at 500 MeV. Studies concentrated on improving energy resettability and stability by working on r.f. set points (levels and phases), temperatures of accelerating sections and timing of LIPS. During a test run a stable 615 MeV beam was achieved. The energy gain from the accelerating sections is close to the theoretical predictions. The beam focusing and beam steering possibilities proved to be good with the exception of the dipole correction on the solenoids of the first sections which had to be made stronger. A lossless beam transmission is measured from the second section up to the end of the linac.

Performance ----- LIL-W	nominal at 600 MeV	measured at 500 MeV	comments
Pulse repetition rate (Hz)	100	100	
Beam pulse length (ns)	12	25	shorter available
Beam pulse rise time (ns)	3	6	
Pulse current (mA)	60	64 30	maximum typical
Hor. and Vertical emittance/ $\pi$ (mm.mrad)	$\ll 1$	$< 0.3$	
Relative energy spread (%)	$< 1$	0.5	FWHH

### 3.3 LIL-V

A first 200 MeV beam could be produced and passed through a spectrometer by the end of last year. After a shutdown, the beam tests were resumed in mid February and soon after directing the beam on the e<sup>-</sup> → e<sup>+</sup> target the first e<sup>+</sup>'s could be measured in LIL-W.

Performance -----	nominal	measured at 200 MeV	comments
Pulse rep. rate (Hz)	100	100	tests at 12.5 Hz
Beam pulse length (ns)	12	10	
Beam pulse rise time (ns)	3	3	
Pulse current (A)	2.5	2.6	
Hor. and Ver. emittance/ $\pi$ (mm.mrad)	$< 1.3$	not yet measured	
Energy spread (%)	$< 10$	14	

### 3.4 EPA

The start-up with e<sup>-</sup> of the EPA tuned to the settings calculated by the on-line model [14] has been rapid and soon the nominal intensity was accumulated in four or eight bunches with an accumulation efficiency of 80%.

The main optics functions (Beta, Dispersion, Tunes and Chromaticity) are in very good agreement with the calculated ones except for the vertical chromaticities being 20% higher. The measured chromaticity are consistent with a somewhat higher sextupole strength in the bending magnet. In fact, the calculated sextupole strength of a 0.3 T/m is very small and is at the limit of the resolution of the magnetic field measurement and analysis.

The natural closed orbit distortions are small (-4/+6 mm in horizontal and -5/+7 in vertical plane) and slightly lower than the maximum expected from PETROC simulations. They justify the decision, taken during the design, of not equipping the machine with an active closed orbit correction system.

Basic studies of injection, accumulation and extraction consisted mainly in setting-up the different elements and trajectory measurements. Optimisations provided excellent beam transmission between LIL and PS practically independent of the number of bunches.

No coupled bunch instabilities were observed at the nominal intensities and the RF cavity seems to be in this respect "monochromatic" as designed [12]. This blow-up has been attributed to interactions between the beam and ions created by ionisation of the residual gas. With beam, the average pressure is about 10<sup>-8</sup> mbar [22]. At each pumping position, ion clearing electrodes are installed but improvements on this system are needed to suppress the ion effect. Bunch lengthening by potential well and turbulence were measured and compared with the prediction based on the longitudinal impedance derived from measurements of the different equipment [11].

Performance at 500 MeV and V <sub>RF</sub> = 30 kV -----	nominal	measured
Betatron tune Q <sub>x</sub> , Q <sub>y</sub>	4.46, 4.38	4.43, 4.39
Natural chrom.	- 1.32, -1.77	-1.16, -2.23
Dispersion, max. Dx	2,301 m	2,485 m
min. Dx	0 m	0 ± 0.011 m

	nominal	measured	
Damping time constants $\tau_x, \tau_y, \tau_z$ (ms)	59,120,127	62,119,130	
Horizontal equilibrium emittance, $\epsilon_{x0}$ (radm)	$8.9 \cdot 10^{-8}$	$9.1 \pm 1 \cdot 10^{-8}$	( $\pm 5$ ms)
Transverse coupling (%)	< 25	11	
Bunch length $\sigma_s$ (cm)	21	24	
Accumulation rate (mA/s)	38	140	8 bunches
Nominal intensity (mA)	38		8 bunches
Intensity, max. achieved (mA)		81	1 bunch
		230	4 bunches
		230	8 bunches (but with blow-up)

#### 4. Recent Results and Future Work

The beam commissioning of LIL with positrons has started. In the design it has been assumed that with a 200 MeV, 2.5 A beam on the converter a 12 mA 600 MeV,  $e^+$  can be obtained. After a few runs, we measured with a 200 MeV, 1.2 A beam, 3.1 mA of  $e^+$  in the EPA injection line.

The matching of the  $e^+$  from the converter into the acceptances of the accelerating sections will be studied and possible simplification in the crowded converter area will be sought. Studying beam properties of a high current in LIL-V is one of our aims for this year as well. The EPA studies will focus on the beam performance limitations due to the ion and impedance effects. But above all, we will concentrate on making LPI an operational and reliable link in the LEP injector chain.

#### Acknowledgements

The LIL has been designed and constructed in a collaboration between CERN and LAL (Orsay, Paris). Valuable support was given by LAL during the initial tests of LIL. The success of EPA is to a large extent due to the competence and hard work of the different teams of the PS Division who were in charge of the equipment, design and construction.

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