THE LEP INJECTION MONITORS : DESIGN AND FIRST RESULTS WITH BEAM

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Abstract: The LEP injection monitors comprise of split foil monitors, luminescent screens and beam stoppers. The monitors are described with particular emphasis on their special features. These include: their low loss factors, their protection against synchrotron radiation and the screen read-out with a CCD chip. The results obtained during the positron injection tests in LEP in July 1988 are reported.

1. INTRODUCTION

Electrons and positrons are injected from SPS into LEP at two points located 500 m on each side of crossing point 1. These locations are at the beginning of the regular arc lattice: Fig. 1.

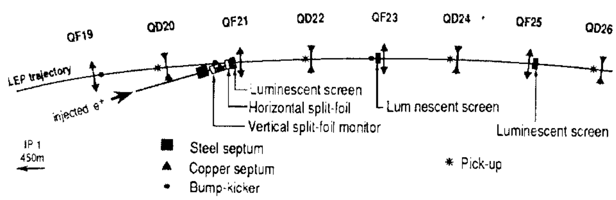

Fig. 1 : LEP Injection layout

The first luminescent screen (LS) and the two split foil monitors (SF) are installed on the injection channel, just before QF21, to provide the position and the transverse size of the injected beam. Two other LS's are located at the next focusing quadrupoles (QF23 and QF25). The first LS is in a region with an enlarged vacuum chamber which includes the injection and LEP trajectories. The injected beam oscillations will be controlled by tuning the beam at these high β_H locations with the septa and kickers so that the Pick-Up stations, located at QD's, can provide the beam trajectory. The first SF monitors the vertical plane and is located immediately downstream of the steel septum which is used to kick the beam vertically and to put it in the LEP median plane. The second SF gives the horizontal beam position at the fast copper septum which defines the horizontal injection trajectory. The injection stability during filling is monitored by the two SF's. The SF is placed in a fixed position and the ratio of the charges collected on the two foils is monitored. The SF can also be moved to scan the complete aperture and the beam profile can then be derived.

2. COMMON DESIGN FEATURES

The critical energies of the synchrotron radiation (SR) are 170 keV from the steel septum, 37 keV from the copper septum and 6 keV from the LEP bending magnets for a beam energy of 20 GeV. The SR generated in the septa falls on the SF's. It could induce parasitic signals of up to 14 % and 8 % at the vertical and horizontal SF's. In the worst case this would give an error of 0.3 mm in the detected vertical position. SR also falls on the LS's which have therefore been protected on both sides by metal screens.

All the monitors, except the first SF, are "seen" by the beam circulating in LEP. It is therefore important to reduce the RF loss factor of these devices by providing a smooth enclosure for the beam. The most efficient and least expensive way to achieve this is to separate the vacuum and the "RF" functions of the enclosures. This is done by using a "dummy" or "RF" chamber to enclose the beam when the monitor is not being used: Fig. 2. From computations made for the LEP collimators, it can be inferred that the loss factor of the monitors will be well below 0.1 V/pC. All the monitors have to be short longitudinally.

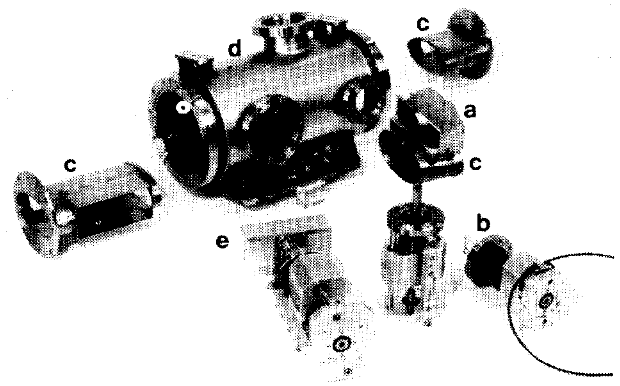

Fig. 2 : Luminescent screen (a) and split-foil (b). Also shown are the "RF" chambers (c), the vacuum tank (d) and the beam scraper (e).

The control and monitoring electronics are in the VME standard.

3. SPLIT FOIL MONITORS

Each of the SF's is made of two adjacent foils in which a charge depletion occurs when they are traversed by a beam. The quantum efficiency of this process is in the order of 5 %. The monitor position is defined by the slot (40 µm wide) between the foils and the charge ratio from the two foils gives the relative beam position. For a nominal current per injected bunch of 10^{10} particles, a total charge of 80 pC is expected when the two foils see the full beam. With a detection sensitivity of 1 pC, a resolution of about two orders of magnitude is achieved. Each foil should have a width larger than 2.5 times the beam rms size which is between 2 and 3 mm. A stroke of 10 mm around the nominal position is needed to be able to scan properly through the distribution, assuming a trajectory distortion of 5 mm. The thickness and material of the foil has been selected to minimize the disturbance on the beam. Titanium foils of 7 µm thickness have been chosen. The resulting effects on the injected beam are a relative energy loss of 2×10^{-4} through Bremsstrahlung and an emittance blow-up of less than 10 %.

The vertical SF sees a beam height of 2 mm rms. The foils are 15 mm high and the slot can be moved vertically from -17 to +38 mm. The horizontal monitor is situated where it could see both the injected and the LEP circulating beam; it must therefore always stay within the shadow of the copper septum. A compromise had to be adopted for the foils resulting in a foil width of 7 mm and a movement from +7 mm to -31 mm wrt the injection beam centre of -73 mm from the LEP central orbit. The foils are displaced by stepping motors with a resolution of 5 µm. They can be polarized with respect to the surrounding chamber with a voltage of either polarity.

Local electronics are used to amplify and shape the signals and to give low impedance outputs suitable for driving cables over distances of 600 m to the processing equipment. Twelve bit ADC's are used to digitize the foil signals.

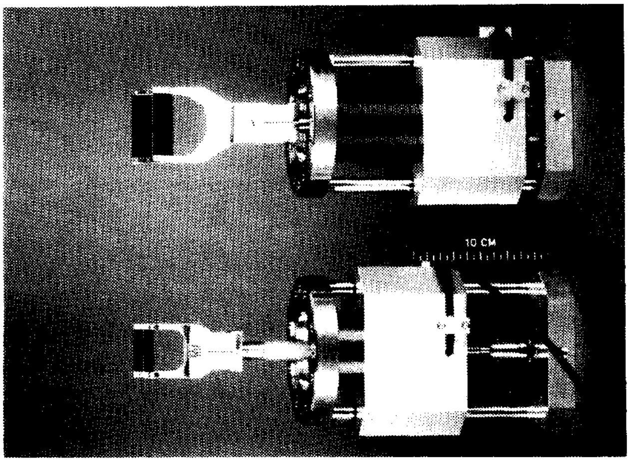

Fig. 3 : Vertical and horizontal split-foils.

4. LUMINESCENT SCREENS

There are six independant screens mounted on "RF" chambers as mentioned previously, and eighteen screens mounted on either side of the nine beam stoppers.

The screens have to be bakeable to at least 150°C and be UHV compatible. Chromium doped Al_2O_3 screens of 1 mm thickness are used. They scintillate at about 700 nm and are viewed with a CCD (Charged Coupled Device) camera, the maximum sensitivity of which occurs around 780 nm. The sensitivity of the monitor is a function of the doping level and of the thickness of the screen. Tests have been made to determine the optimum doping level for this application. Three levels have been tested: 0.5 %, 0.2 % and 0.1 %. The 0.5 % screens are too sensitive and their afterglow is too long for this application. No appreciable difference has been noticed between the 0.1 and 0.2 % screens. The 0.1 % screens appeared to be less homogeneous so they were eliminated. Tests were also made on other scintillators. They were found to be unsuitable for this application. The predicted sensitivity of the monitors is 4×10^6 e^+/mm^2. The upper limit of the dynamic range can be extended by using the long (10 s) afterglow of the screens. Pulses of at least 3×10^9 e^+/mm^2 should be practicable. The screens are perpendicular to the beam and the light spot is observed via a stainless steel mirror placed in front of them at 45° wrt the beam. A copper plate 2 mm thick is added to the back of the luminescent screen (Fig. 2). This plate and the mirror shield the LS from SR.

CCD devices are for the moment rather new in the field and they are suspected to be more prone to radiation damage. However, because they are small, they can be protected quite efficiently without excessive amounts of shielding: Fig. 4. The monitors are located at distances up to 750 m from the accessible underground caverns where most of the processing electronics is located.

The simplest use of these monitors is to observe them on a TV monitor. A reference grid is deposited on the screen to give a precise spatial and dimensional reference. Digitally generated information is added to the TV picture to identify the screen and to give the results of the picture analysis. The well defined matrix structure (384 x 288) of the CCD is ideal for digitization. Each picture element (pixel) is digitized separately thereby obtaining the best geometrical resolution.

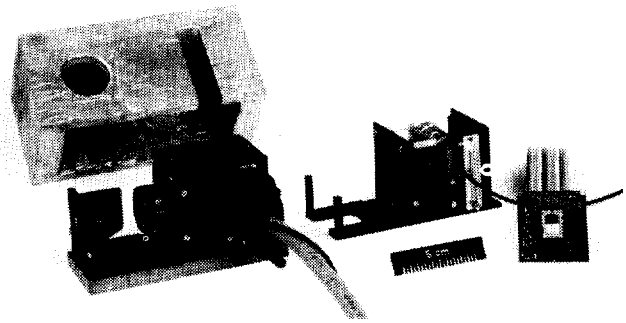

Fig. 4 : CCD camera head with its lead shield and, at the right, an exploded view of the camera head with the CCD chip.

The CCD's dynamic range, of the order of 1:700 in single shot operation, makes it possible to use the monitor to measure beam profiles. It is foreseen to digitize one frame per injection cycle to calculate the centre of charge and the rms size of the injected pulses and to add this information to the TV picture. The digitization is performed with a 12 bit ADC converting at a rate of 500 kHz and feeding a 128 kword buffer memory. The digitized profiles can be used to generate various displays of the beam density. This digital processing is foreseen on the six injection monitors.

5. BEAM STOPPERS

Nine beam stoppers are installed around the circumference of LEP. Eight of these stoppers are located on either side of the four experimental areas. Their function is to protect the experiments during the tune-up periods. EGS simulations have shown that with a length of 44 cm of copper less than 0.1 % of the incoming energy escapes through the rear of the block. A ninth stopper is located between the two injection points, close to crossing point 1, and is used in the safety chain of LEP. The blocks are water-cooled to allow continuous use of the stoppers. They are fitted with "RF" chambers of elliptical or circular cross-section, depending on their adjoining vacuum chambers in the machine: Fig. 5.

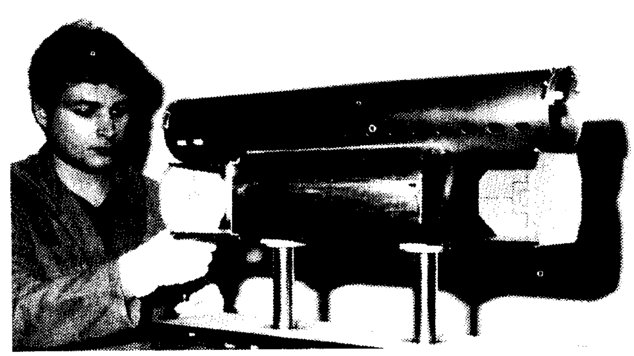

Fig. 5 : Beam stopper block with a circular "RF" chamber. The block is supported on the cooling circuits. On each side of the block is a luminescent screen, which is viewed via a stainless steel mirror.

The pumping holes in the RF chamber seen in Fig. 5 were reduced in size on the succeeding models. The RF chamber of the safety stopper has a slot milled in it so that the stored beam which traverses it will not encounter more than two radiation lengths of material and will therefore not overheat it. The slot is covered by a 0.5 mm copper sheet which ensures RF continuity but is thin enough so that a shower cannot develop. The chamber acts as a beam scraper.

The stoppers are controlled pneumatically by the dry nitrogen line supplying the LEP sector valves. A local reservoir compensates temporary pressure fluctuations. The safety stopper is driven to the "out of beam" position by its piston. A spring and cam provides a constant force which drives the block to the "in beam" position under fault conditions. The other stoppers are driven in both directions and stay "out of beam" under fault conditions.

The two luminescent screens are observed by a single CCD camera which is displaced from one screen to the other by a piston coupled magnetically to the camera support.

6. RESULTS FROM THE LEP INJECTION TESTS

The sensitivity of the luminescent screens was checked by using a blown-up beam. The expected sensitivity of less than 10^7 particles per mm^2 was confirmed. No SR background was noticed.

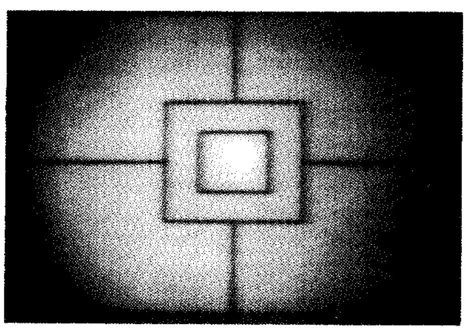

Fig. 6 : One of the first injected pulses into LEP (4×10^{10} e^+) monitored at the beam stopper in front of crossing point 2.

The four bunches injected on each cycle were analysed separately with the two split foil monitors. No noticeable effect was observed on the beam after traversal of the monitors as far as beam current, energy loss (checked with the trajectory) and beam size (as seen from the luminescent screens) are concerned. Without beam, a noise level of 0.5 to 1 pC was measured. Parasitic signals of 2 to 5 pC were noticed with beam. Various interpretations are possible related either to beam-gas interactions or synchrotron radiation background. They could not be fully investigated during this short test. The linearity of the vertical monitor was checked using beams of 10^9 to 10^{10} particles per bunch. Various bias voltages were applied to the foils and their influence on the signal observed. The shortest signals were obtained for a positive bias of 100 V, indicating that the ions were the main source of parasitic signal. The sum signal of the foils is reduced by a factor of 3 for the vertical monitor when a voltage of 100 V is applied whereas in the case of the horizontal one the effect is only 25 %.

Beam scans were also performed. The curves in Fig. 7 show the percentage of sum signal seen by the Inner foil versus monitor position for bias voltages of 0 V and 100 V. The centre of charge of the beam is where each foil detects 50 % of the total charge; both curves give the same result within 0.5 mm. The signal is truncated at the outside due to the limited stroke and aperture.

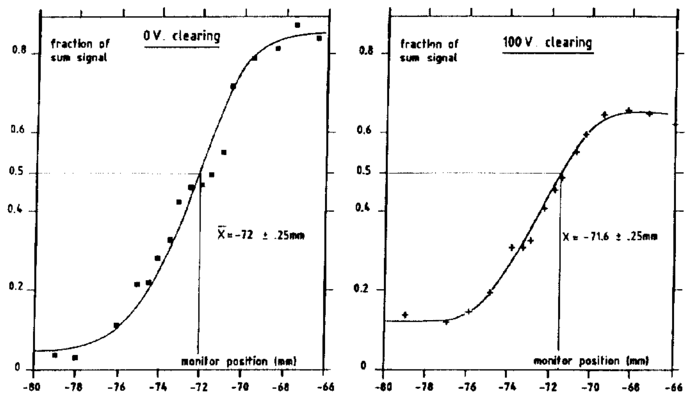

Fig. 7 : Percentage of signal seen by the INNER foil (H monitor) versus monitor position.

In the vertical plane, where the foils are wide wrt the beam, the sum signal corresponds to the full beam signal in the useful range of the scan. The fraction of signal seen by each foil gives then the beam repartition function and its derivative gives the distribution. The beam rms size can be evaluated from these curves.

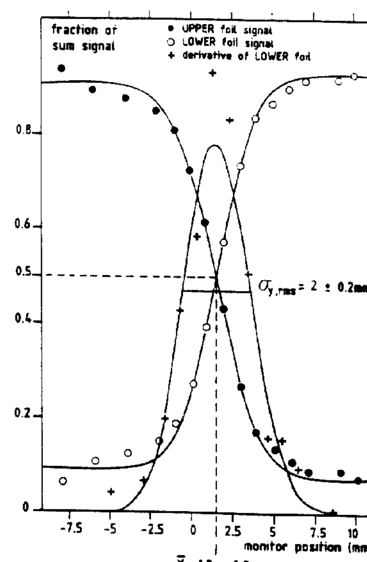

Fig. 8 : Percentage of sum signal seen by the UPPER and LOWER foils for 0 V clearing. The vertical beam position is at the crossing point of the two curves (50 %). The gaussian fit of the derivative of the curve of the LOWER foil is also included and shows good agreement for the beam position and rms distribution.

7. ACKNOWLEDGEMENTS

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