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DEVELOPMENT OF BEAM PROFILE AND FAST POSITION MONITORS
FOR THE LEP INJECTOR LINACS

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Abstract

The beam profile monitor is a wire scanner comprising of an isolated L-shaped tungsten wire driven at 45° through the beam by a stepping motor controlled by a microprocessor system. Three measuring methods have been investigated: the secondary emission, the change of resistance of the wire, and the observation with a scintillator of the interactions taking place in the wire. Profiles of beams with 6×10^7 to 3×10^{11} e^- have been measured, some of them in the vicinity of the e^-/e^+ converter at the LAL ORSAY linac.

An economical S-band waveguide monitor has been designed to follow the beam position changes during the 12 ns pulse of LIL. It consists of a waveguide pick-up with a 2-4 GHz bandpass, of a voltage controlled phase shifter and of a double-balanced mixer used as a phase detector. The S-band components are located close to the pick-up and are small enough to be easily shielded.

1. Introduction

The LEP Injector Linacs (LIL) comprise of a high intensity linac (V) accelerating e^- pulses of 2.5 A peak current to 200 MeV which impinge on a tungsten target of 2 radiation lengths thickness to produce positrons, and of a low intensity linac (W) for accelerating low intensity e^+ pulses of 12 mA peak current and medium intensity e^- pulses of 60 mA peak current. The beam pulses are typically 12 ns long and have a repetition rate of 100 Hz. The RF frequency is close to 3 GHz.

For the instrumentation described here, LIL can be divided in three areas: Linac V with a beam of small transverse dimension and high intensity, the converter area with the previous beam and the problems inherent to the converter neighbourhood, and linac W with a positron beam of large transverse dimension and low intensity. The monitors described hereafter were tested at ORSAY on the LIL front-end [1] and on the LAL linac for the problems specific to the converter area.

2. Beam profile monitor

The monitor was designed to be used in front of the e^-/e^+ converter and in linac W and to use as little longitudinal space as possible. The measuring head consists of a fork with an L-shaped wire. The fork is driven at 45° through the beam, taking successively the vertical and the horizontal profiles. The dimensions are chosen so that there is no ambiguity in the measured profiles.

The fork is driven by a stepping motor giving a resolution of 10 μm per step. The stroke is 70 mm. The maximum translation speed is 23 mm/s. In order to be able to test all measuring methods, a tungsten wire was used. Most of the results were taken with a 300 μm wire, but some were also taken with a 75 μm wire. Both ends of the wire are brought out of the vacuum which allows one to measure the wire resistance and hence its continuity. The longitudinal dimension of the monitor is 11 cm.

2.1 Secondary emission profile

The secondary emission yield is a few percent (5 to 7 %) of the intercepted charge, irrespective of the wire material. This is adequate in linac V and results in very clean profiles as have been experienced previously [2]. This measurement becomes more critical close to the converter, where there is a non negligible backscattering which pollutes the measured profile of the incident beam. To suppress the low energy background profiles, the wire has to be polarized by 400 to 600 V. This measurement is more difficult in linac W because of the low beam density. In both cases best results are obtained with a local shaper and line driver.

When it is intended to use only this method, a low density material, for example beryllium, can be used for the wire.

2.2 Scintillator profile

This method makes use of the particles coming from the interaction of the beam with the wire. A proper collimation will restrict the received particles to the ones only originating in the wire. One profits from the amplification of the photomultiplier and of its low output impedance. These properties are most useful in the converter area and in linac W. In order to minimize the volume of the collimator, a small 6 stage photomultiplier (Philips XP 1920) together with a scintillator of $85 \times 30 \times 10 \text{ mm}^3$ have been chosen. They have been incorporated with the high voltage divider chain, into a $20 \times 10 \times 5 \text{ cm}^3$ lead brick which is the minimum protection foreseen. This assembly is sufficient in an area where there are not too many beam losses. For the converter area EGS simulations have been made to determine the best position of the scintillator and the minimum shielding required. An additional row of 20 cm length and 5 cm width of lead has to be added on each side of the scintillator window. The scintillator has to be placed at 85° and at a distance of 40 cm with respect to the beam. The results obtained for a beam of 1×10^{11} e^- of 200 MeV and having a gaussian distribution with a sigma of 0.5 mm are given in the Table below.

Wire material	50 μm	W 300 μm	Be 300 μm
Wire diameter			
Intercepted beam	5×10^9	3×10^{10}	3×10^{10}
Wire heating °C/pulse	8.2	8.6	.8
Energy deposited in scintillator MeV/pulse	82.7	3×10^3	83.5

The energy deposited in the scintillator and coming from the converter is 7×10^5 MeV per pulse without additional shielding and practically zero with the shielding. The dynamic range is given by the photomultiplier whose gain can be adjusted over 3 decades.

2.3 Thermal profile

It was realised that the local temperature increase of the wire could be used to measure a beam profile by putting the wire in one arm of a resistor bridge. This gives a low resistance signal source which is not susceptible to the usual high electric noise generated in a linac. This method doesn't need any local electronics. It requires a low wire speed of around 1 mm/s. It is a helpful method for setting-up the monitor in difficult situations.

2.4 Control system

The system is built around the G 64 microprocessor bus which has been recommended at CERN, so most of the elements were available from other projects or from industry. Only the stepping motor card had to be developed for this application and is built around an intelligent stepping motor driver chip (CY 512 from Cybernetic). The diagram of the system is given below. The measured profiles were memorized on floppy discs to allow further analysis at CERN.

The program is written in PASCAL and the data-acquisition is interrupt driven from the linac timing. The program drives the wire through the aperture at an operator defined speed (5 to 23 mm/s), memorizes for each pulse the wire position (10 μ m resolution) and the output of the PM integrator and treats the acquired data once the end-switch has been reached.

The position of the maxima and the half-height widths of the profiles are then calculated. The results are presented on an X-Y display and on a semi-graphics TV monitor.

2.5 Beam tests

Six tests were carried out at ORSAY, both at the LIL front-end and in front of the e^-/e^+ converter of LAL, 40 cm upstream of the converter target. The lowest density beams were obtained on LIL with a beam of 6×10^7 e^- having a FWHM of 1 mm. This measurement was done with a less than optimum shielding of the scintillator. This limit can probably be lowered under the conditions prevailing in linac W. It is mainly a signal to noise limit. Higher beam densities were obtained in LAL with beams of 2×10^{11} and a FWHM of 1 mm. The highest density has been obtained in [2] with 3×10^{11} e^- beams having a FWHM of 350 μ m and a wire of 75 μ m. Given below are an X-Y monitor output and a TV display of a measured pulse. Given also are manual scans using the thermal and PM methods for comparison. As can be

seen, the center and the width of the profiles can be easily deduced from two thermal scans taken in opposite directions.

3. Fast beam position monitor

The ideal monitor to measure the beam position evolution along the 12 ns pulse is the travelling wave monitor [3], but the available designs were not suitable for the LIL short pulses. We therefore developed a broadband monitor covering the range 2-4 GHz, which doesn't need any RF tuning of the waveguide pick-up during construction, and a small volume RF processing electronics which can be easily shielded against beam radiation damage and hence be placed close to the pick-up which minimizes the lengths of high quality RF cables. The block diagram of the monitor is given below.

As a bunch passes through the hole in the broad side of the waveguide pick-up an electromagnetic field is induced on both sides. Some of the energy is extracted at both ends through matched waveguide to coaxial transitions. These band limited signals are fed via short cables and a phase shifter on one side, to a double balanced mixer. The mixer works as a phase detector whose output is a DC signal which varies as the cosine of the phase difference of the input signals. The mixer was a Watkins-Johnson M 63-C having an output IF bandwidth of DC to 1 GHz. The higher order mixing terms are above the bandwidth of the mixer output. If the input signal paths differ by 90°, then the output of the mixer will be zero when the beam passes through the center of the pick-up, irrespective of the signal amplitudes. Hence the basic

mode of operation of the monitor is to null the mixer output and to read the beam position from the phase shifter. This operation could be incorporated in a feedback loop. If the beam position changes during the beam pulse, the variation can be obtained by reading the phase shifts needed to null the mixer output along the beam pulse or by estimating the position with respect to the one given by the shifter by measuring the mixer output. In the latter case a normalization by the instantaneous beam current has to be performed. In order to maintain the high system bandwidth, no attempt was made to suppress the amplitude information for this mode. The various parameters of the monitor were studied with the help of a simulation program run on an HP9816 desktop computer.

3.1 Waveguide pick-up

A beam hole of 40 mm was imposed for vacuum reasons. This led to the use of the standard S-band waveguide WR 284 having a broad wall of 72 mm. Assuming a pure TE₁₀ propagation at a center frequency of 3 GHz, the waveguide to coaxial transition was optimized using the procedure outlined in [4]. The transition was made using a ceramic N-type vacuum feed-through. The result is a broadband transition [5] covering the range 2-4 GHz.

To estimate the sensitivity of the monitor we have assumed a pure TE₁₀ propagation and gaussian bunch length and waveguide to coaxial transmission bandwidth. The power output is then given by $P = k \times I^2 \mu W$ with $k = 16 \mu W/MA^2$, I being the peak current expressed in mA. With these hypotheses, the phase difference of the two pick-up outputs is 5.19 °/mm beam displacement. Tests in the laboratory have shown that there is less than 1 % coupling between planes.

3.2 Electronically controlled phase shifter

The phase shifter was built for the frequency range 2-4 GHz in a similar way to [6]. It is incorporated in an RF-proof box of $7.5 \times 5 \times 2.5 \text{ cm}^3$ and is built on a microstrip card using a commercial 90° hybrid [7]. The phase can be varied continuously from 0 to 180° (equivalent to a 35 mm beam position change) by changing the bias voltage of the two varactor diodes terminating the 0 and 90° ports of the hybrid. The phase shift is linear from 0 to 140°. The insertion loss of the phase shifter varies from 1.5 to 3.5 dB and the VSWR from 1.1 to 1.2 depending on the phase shift. The rise time of the phase shift in response to a step function of the control voltage was measured to be 1.2 μs. The estimated maximum peak power is 2.4 W. The sensitivity of the complete monitor as given in 3. is predicted to be .7 mV/mm x MA.

3.3 Beam tests

Two beam tests have been carried out at the LIL front-end. The pick-up was mounted horizontally. The power output versus peak current was measured and found to follow the law $P = 20 \times I^2 \mu W/MA^2$ which is close to our expectations. The current could be varied between 10 and 500 mA, i.e. 2×10^7 to $1 \times 10^9 \text{ e}^-$ per bunch.

The position linearity of the monitor was then checked by defining the beam position with the horizontal collimators. They were used with apertures of .3 to 5 mm. The beam was also steered to obtain a flat current shape. The beam position plot deduced from the phase shifter setting for zero mixer output, versus collimator position is perfectly linear over the center portion of $\pm 7 \text{ mm}$. The position is the average over the pulse length as observed on an oscilloscope. The position change along the beam pulse was measured using the two methods mentioned previously. Both methods gave results compatible with the collimator setting. Given below are two examples of oscilloscope outputs, the first of them taken with a sampling plug-in. The current is taken from an adjacent fast current transformer. The fastest observed

beam position change was 1 mm/ns. Faster changes couldn't be provoked. The measured rise time of the monitor signal is 1 ns. This is the result of the beam intensity, oscilloscope plug-in and monitor rise-times and is compatible with the expected monitor rise time of 400 ps.

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