

## Beam Diagnostics of the ELETTRA Injector

J.-C. Denard, C. Bocchetta, A. Carniel, T. Monaci, P. Sereni, S. Sierra<sup>o</sup>, R. Ursic<sup>†</sup>  
 Sincrotrone Trieste, Padriciano 99, I-34012 Trieste  
<sup>o</sup> General Electric CGR MeV, F-78530 Buc

### Abstract

A 1.5 GeV Linac will inject electrons into ELETTRA via a transfer Line. We describe here the beam diagnostics that will equip the Linac and the Transfer Line. Most of them have been partially tested on the first part at 100 MeV of the Linac that is presently under commissioning. Of these diagnostics, the beam position monitor system can be noted for its simplicity, good performance, and its wide use of commercialized hardware. The fluorescent screen monitors use a CCD (charge coupled device) videocamera connected to a frame grabber linked to an "intelligent" board; although the hardware and software development has not been negligible, we were pleased to see the automatic measurement of the Linac emittance successfully tested.

### 1. INTRODUCTION

A 1.5 GeV Linac built by CGR-MeV [1] will inject electrons into the ELETTRA storage ring via a transfer line. We will describe the beam diagnostics that have been built for the Linac (11 assemblies of a toroid and a wall current monitor, 9 beam position monitors or BPMs) and those in construction for the Transfer Line (2 toroids, 6 BPMs, 11 fluorescent screens, 1 scraper, 1 faraday cup). Most of them have been tested on the first part of the Linac termed as pre-injector where a provisional diagnostic line has been installed for the acceptance tests [2].

The scope of the diagnostics is mainly to run routine tests that show at a glance that the Linac is ready for injection; the task requires all measurements to be accessed by the control system. Another design priority has been to use equipment commercially available or already developed in the laboratory.

### 2. LINAC DIAGNOSTICS

#### Toroids

The so called toroids, working as current transformers [3], measure the peak current of the macropulses. Ten of them, connected to a ten-to-one-channel multiplexer, will measure the intensity along the machine in order to check possible intermediate losses. On the block diagram shown in figure 1, we see that the actual measurement is performed by a digitizer, GPIB controlled; this choice has the following advantages with respect to an especially built electronics:

- it avoids the development of a special detector.
- the signal can be viewed on an oscilloscope with all the settings and readings that are accessible to the control system.

- thanks to the various processing and triggering options (peak value, average, peak to peak), there is a reduction of the amount of software development and we benefit from a flexibility in use that will be valuable when the system will have to be put quickly into operation.

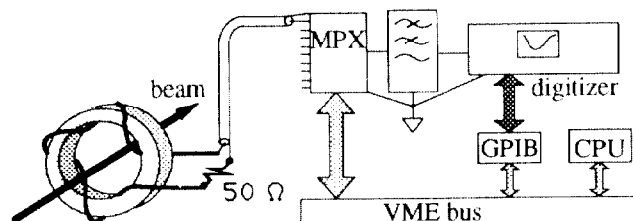


Figure 1. Toroids block diagram

Presently, the toroids are routinely used during the pre-injector commissioning; however, a spurious signal is induced by the klystron modulator and it is not clear yet if in all Linac operational modes, the digitizer can measure properly the current in its whole range with a unique and well defined setting. This condition must be fulfilled to send reliable measurements to the control room.

#### Wall Current Monitors

For the sake of standardization and flexibility of use, each toroid is followed by a wall current monitor (WCM) [4]. Although both items have their own ceramic gap and could in principle be used simultaneously, the WCM shows a better response when its neighboring toroid gap is short circuited. Only two WCM have been equipped with a set of 24 resistors that, connected in parallel, present a 1  $\Omega$  resistance to the beam image current. A good quality coaxial cable, about 20 m long, brings to the klystron gallery a signal representative of the beam longitudinal distribution. We presently display the wide spectrum signal on a 1 GHz bandwidth analog oscilloscope (Tektronix 7904) that shows well the effect of the 500 MHz buncher and/or chopper. A short test, done with a 4.5 GHz, single shot, digitizer (Tektronix SCD 5000) clearly revealed the structure of a 3 GHz bunched beam. We are planning to use this kind of instrument with 11 bit resolution for detecting unwanted satellite bunches when the Linac runs in single bunch mode. Most importantly, it will make the longitudinal profile available in the storage ring control room via a GPIB bus interface linked to the control system.

#### Gun Current Monitor

A special monitor [5] mounted right after the gun observes the beam shape and current the gun produces. A thin layer ( $\approx 0.3$  mm) of Zirconium oxide, deposited by sputtering, insulates a copper electrode from an external aluminum tube

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inserted into the vacuum chamber (figure 2). The wave in the insulator propagates at a smaller speed than that of the beam and reflections take place at both ends. A short connection between the vacuum feedthrough and the middle of the electrode provides the best impulse response ( $\leq 1$  ns). Unfortunately, because of the presence of the first focussing coil around the electrode, a 6 cm long wire is actually connected to the end of the electrode.

The monitor exhibits a long time constant (tens of  $\mu$ s) when the cable following the feedthrough is terminated by the 1 M $\Omega$  input impedance of an oscilloscope. With this impedance set to 50  $\Omega$ , the sensitivity is about 140 mV/A for 100 KeV electrons. The electrode capacitance is 2000 pF.

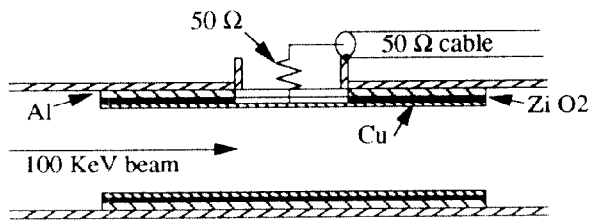


Figure 2. Section of the gun current monitor.

#### Beam Position Monitors (BPM)

A more complete description of the BPM system is found in reference [6]. We chose stripline type electrodes, 15 cm long, for their good sensitivity [7]. Two opposite electrodes are mounted on the x transverse axis and two others on the y axis; two pairs of coaxial cables bring their signals to the klystron gallery where all the electronics resides.

A simplified block diagram of the system is shown in figure 3. Two opposite electrodes are processed together. A 180° hybrid junction, by supplying the sum and difference signals, gives the measurement a good resolution although the digitizer performs only a 8 bit conversion. A group of analog multiplexers, scans successively the x and y positions of all BPMs.

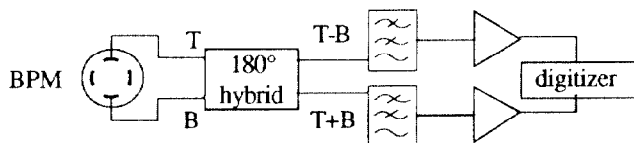


Figure 3. Simplified block diagram of the BPM electronics.

During a test done in the laboratory where we applied to the electronics four electrode signals corresponding to a 20 mA centered beam, we measured the equivalent of a 40  $\mu$ m resolution (rms fluctuation over 10 pulses) for the Linac, which corresponds to 100  $\mu$ m for the transfer line. If necessary, the expected speed of one trajectory every 18 s could be improved by an order of magnitude by optimizing the communication software that controls the digitizer.

During an early test done on the pre-injector, the modulator was generating a spurious signal that is larger than that of a 25 mA beam. Like for the toroids, triggering the

beam more than 4  $\mu$ s after the modulator had fired makes a good time separation; then the delayed time base of the digitizer previously triggered on the unwanted burst, triggers on the BPM signal. It is not clear yet if this scheme works properly for all modes of operation (single bunch, multibunch, FEL) in the appropriate current range.

The BPM system required very little development effort (mostly software) and it exhibits very good performances. Its flexibility should greatly help overcome the electromagnetic and/or ground problems.

### 3. TRANSFER LINE DIAGNOSTICS

The Linac-to-Ring transfer line [8] will be equipped with the following beam diagnostics:

- Eleven fluorescent screens that help to quickly prepare the transfer line for injection; some of them will measure the Linac emittance, energy, and energy spread.
- Six BPMs that are similar to the Linac ones.
- Two toroids.
- A scraper, in conjunction with a downstream toroid, will measure the energy and energy spread.

#### Fluorescent Screens

A good way of measuring the transverse dimensions of a charged particle beam [9] is to place in its path a fluorescent screen at 45° viewed from the top by a videocamera. In our case, the screen is 0.5 mm thick alumina homogeneously doped with 0.2 % chrome sesquioxide that has been extensively studied at CERN [10] where it was noted that non linear effects may arise only from the temperature inhomogeneity; the linearity is reported to be within  $\pm 15$  % in the 20 to 150°C temperature range. The screen is commercialized by Morgan Matroc (Great Britain). Placed in air inside a stainless steel tubular enclosure it enters the vacuum chamber for observing the beam. The screen is associated with a low cost CCD (charge couple device) videocamera (JVC model TK-S300 with HZ-C612U lens); A density of  $5 \cdot 10^7$  electrons/mm<sup>2</sup> give plenty of light.

A very useful feature is the digitization and memorization of the pixels (picture elements) by a frame grabber; a local process computer (LPC) calculates the beam position and rms size [11]; the results can be displayed on the TV monitor as shown in figure 4. The feature allows one to compute automatically the Linac emittance by acting on one or more quadrupoles located upstream of the fluorescent screen. Finally, a least square fit implemented at the high level software yields the emittance. The scheme has been successfully tested for measuring the emittance of the pre-injector [2].

A cheap industrial serial bus (Dupline), using a twisted pair cable that links all fluorescent screens devices to the LPC, commands the in/out position, the screen illumination, and the diaphragm aperture.

Due to both the fluorescent property of the whole of the ceramic volume and its partial transparency ( $\alpha = 0.8$  mm<sup>-1</sup>) [10], an ideal pencil thin beam would be seen on the camera as very thin along the x axis, but of finite dimension increasing with the screen thickness along the y axis. A

computer simulation showed the vertical resolution to be about half the screen thickness (250  $\mu\text{m}$ ). On the contrary, the horizontal resolution is limited to about 50  $\mu\text{m}$ , due to the scattering of the beam passing through the front wall of the stainless steel tube that isolates the screen from the vacuum.

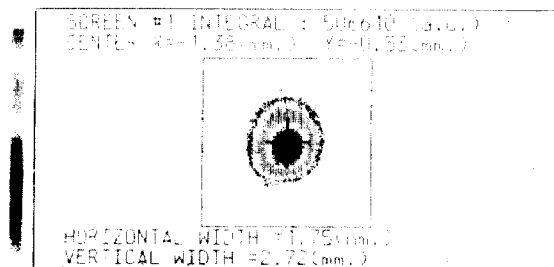


Figure 4. A beam profile display of the pre-injector. The little dots are the result of the radiation on the CCD. The original picture is color coded in density of light.

As explained later, the tests done on the pre-injector showed the CCD are sensitive to radiation. In the transfer line, the particles scattered downstream the scraper will have to be stopped. The monitors will also be set far from the faraday cup and the beam dump.

#### 4. THE 100 MEV PRE-INJECTOR DIAGNOSTIC LINE

A provisional diagnostic line [2] has been built for the commissioning and the acceptance test of the pre-injector. Three fluorescent screens, two faraday cups and an energy slit figure in its components.

The fluorescent screens are prototypes of those previously described. The working conditions are slightly different because of the additional free electron laser mode that the pre-injector features in the 30 to 75 MeV energy range. It may produce 300 nC/pulse at a 10 Hz rate. Such a current in conjunction with the minimum size of the beam is likely to break the alumina of the emittance-measurement screen. Being in air, it can be easily exchanged. However, a calculation prompted by a SLAC report [12] showed that any metallic part not in titanium, may break under the sudden dilatation of the metal under the heat deposited by the beam. Since it could trigger a vacuum leak, we decided to end the vacuum a few centimeters before the screen with a titanium window; The scattering across the window limits the resolution to 200  $\mu\text{m}$  at 100 MeV.

Right behind two of the fluorescent screens, there is a faraday cup in "densimet" (machinable tungsten). Because of this proximity, after a few days the pre-injector started to run, 200 rad of radiation dose were recorded on the camera. Many CCD pixels showed an abnormally high threshold at about 20% of their saturation level as a consequence of the radiation exposure; they are points that can be observed in figure 4. We think the damage is mainly done by the X-rays that leave the faraday cup in large number in the preferential directions forming a 70° to 110° angle with respect to the incident beam

direction. Increasing the distance of one of the faraday cup prevented the secondary shower from reaching the video camera. Unfortunately, the second fluorescent screen cannot be moved and during the energy measurements, all cameras even protected by a 10 cm lead wall currently take a radiation spray at each pulse. The present CCD have more than 50 % of the pixels damaged, but the image analysis algorithms still find the correct value of  $\sigma_x$  and  $\sigma_y$  most of the time. The diagnostic line performs well and it takes only a few minutes to complete an accurate emittance measurement.

#### 5. CONCLUSION

Besides the beam diagnostics of the 1.5 GeV Linac and transfer line of ELETTRA, we described the diagnostic line of the 100 MeV pre-injector. Most of them have been partially tested during the commissioning of the pre-injector. A few problems relative to EMI and ground induced signals will be worked out later. The CCDs that view the fluorescent screens were damaged by the radiation coming from nearby faraday cups; however, the algorithm that computes the beam size works well even in such bad conditions.

#### 6. ACKNOWLEDGEMENTS

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