Measuring the Beam Position in the Elettra Linac

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Abstract

A simple system is used to measure the beam position in the ELETTRA linac. Multiplexed signals coming from the beam position monitors are routed to the electronics that works independently of how high the bunching frequency is. The sum and difference of two opposite electrode signals are filtered and then digitized with a regular digitizing oscilloscope that is controlled via a GPIB bus. The measurement is controlled by a single computer running under the OS-9 operating system. Most of the hardware is commercially available or made of general purpose devices built in our laboratory. A system of the same kind will be installed for the transfer line.

1. INTRODUCTION

The ELETTRA linac and transfer line are equipped with stripline beam position monitors (BPM). The requirements about the accuracy, resolution and measuring rate are not stringent; we opted for a simple solution: one central digitizer together with multiplexers that connect sequentially the monitors to the electronics. The Linac operates in three different modes: single bunch , multibunch and free electron laser mode. The measurement is foreseen in multibunch mode with 20 mA of beam current.

2. SIGNAL PROCESSING

2.1. The Monitor

The BPM is of the stripline kind with four electrodes, 15 cm long, that are matched to 50 Ω. Each electrode covers 45°, so it intercepts about g = 1/8 of the image current (figure 1).

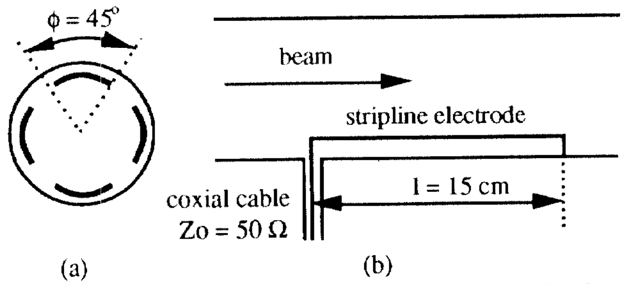

Figure 1. (a) Transverse section of the BPM. (b) Longitudinal section with only one electrode shown.

The matching condition for that angle and an electrode thickness equal to 1/20th of the vacuum pipe inner diameter D, is to set the electrodes at 0.07 D from the wall. Then the four stripline in parallel show an impedance of 12.5 Ω. Measuring them in parallel with a TDR (time domain reflectometer) is the right way to do the measurement because the four signals actually travel together. It is easy to verify that the characteristic impedance of an electrode measured alone is only about 44 Ω, while all four measured together were well matched to their 50 Ω cables. In fact the electric field lines are rather different in both cases.

2.1. The Electrode Signal

Let's define $i_b(t)$ as the beam current, g the fraction of the image current an electrode intercepts, Z_0 the cable impedance, l the stripline length and c the speed of light; then the electrode, being matched to its cable, has the following output signal [1],[2]:

$$v_o(t) = v(t) - v(t - \Delta t) \qquad (1)$$

$$\text{where } v(t) = \frac{g Z_0}{2} i_b(t) \qquad (2)$$

$$\text{and } \Delta t = \frac{2 l}{c} \qquad (3)$$

So the electrode response to the beam is composed of two signals of opposite signs and separated by Δt.

2.3. Normalization with a Low-pass Filter

The Linac beam is a 150 ns long macropulse that is bunched at 500 MHz as shown in figure 2. We can see later that the system works whatever the bunching frequency is.

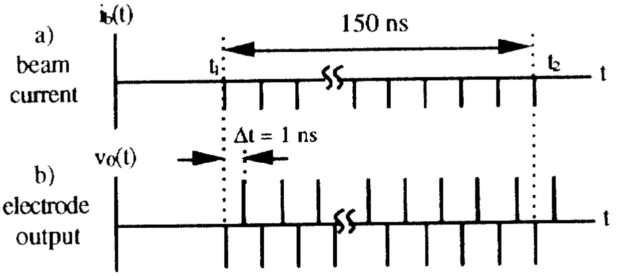

Figure 2. Structure in multibunch mode a) of beam b) of electrode output signal.

Let's introduce a low-pass filter at the electrode output. With a 20 MHz bandwidth the risetime becomes much larger than Δt = 1 ns defined in formula 3. Figure 3 shows the filter output; it is composed of two impulses, one in front of the macropulse and the other at the end. Each impulse corresponds either to the filter impulse response, if the beam current has a

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*The author undertook this work with the support of the "ICTP Programme for Training and Research in Italian Laboratories, Trieste, Italy" fast rise time or to the rise time derivative if the beam has its rise time much longer than the impulse response width.

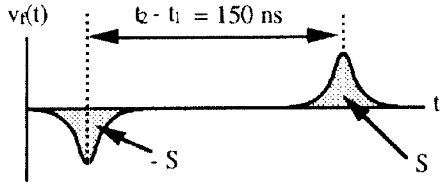

Figure 3. Low-pass filter response $v_f(t)$ to 150 ns long pulse train.

Whatever the rise time is with respect to the impulse response, the surface S of the front and end impulses is proportional to the macropulse peak current Ip:

$$S = \frac{g Z_0}{2} I_p \Delta t \quad (4)$$

$$\text{where } I_p = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} i_b(t)\, dt \quad (5)$$

How can this statement be justified?

A low-pass filter is a linear circuit, so its response to the sum of two signals is equal to the sum of the two responses. Considering a train of positive macropulses at high repetition rate at the filter input, the response is the same as if we had a step excitation of amplitude $V_a = I_p\, g\, Z_0/2$. In our case the electrode output signal can be thought as the sum of two pulses 150 ns long and of opposite sign, as shown in figure 4.

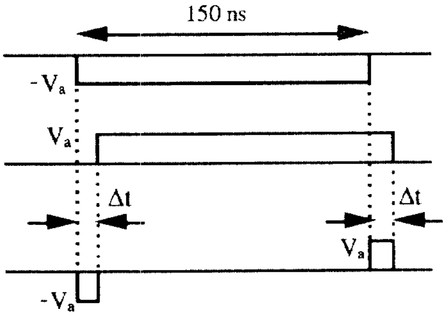

Figure 4. Equivalent signal at filter input: a) equivalence to the negative pulse train; b) equivalence to the positive pulse train; c) sum of a and b; equivalence to the signal of figure 2b.

The result are two pulses which are Δt wide, have amplitudes -Va and Va respectively, and have a surface $S = V_a \Delta t$. The filter response to such a signal is a pair of impulses whose surface S is independent of either the filter bandwidth or the beam risetime. We can, in the case of fast beam risetime, introduce a normalization factor that relates directly the output filter amplitude to the macropulse peak current.

2.4. The electronics

With the measuring scheme presented below, both x and y measurement of one BPM will need two Linac macropulses.

Figure 5 shows the four electrodes of the BPM #3 taken as an example, that are connected via four RG214 cables to the input #3 of the multiplexers. A total of nine BPMs will be connected in this way. Two more multiplexers switch alternate x and y measurements. All six multiplexers are of the ten channel PIN diode type. They are a slightly modified version of a general purpose module built in our laboratory. A hybrid junction yields sum and difference signals. This method requires the signal cables up to the hybrid junction to have their electrical length matched.

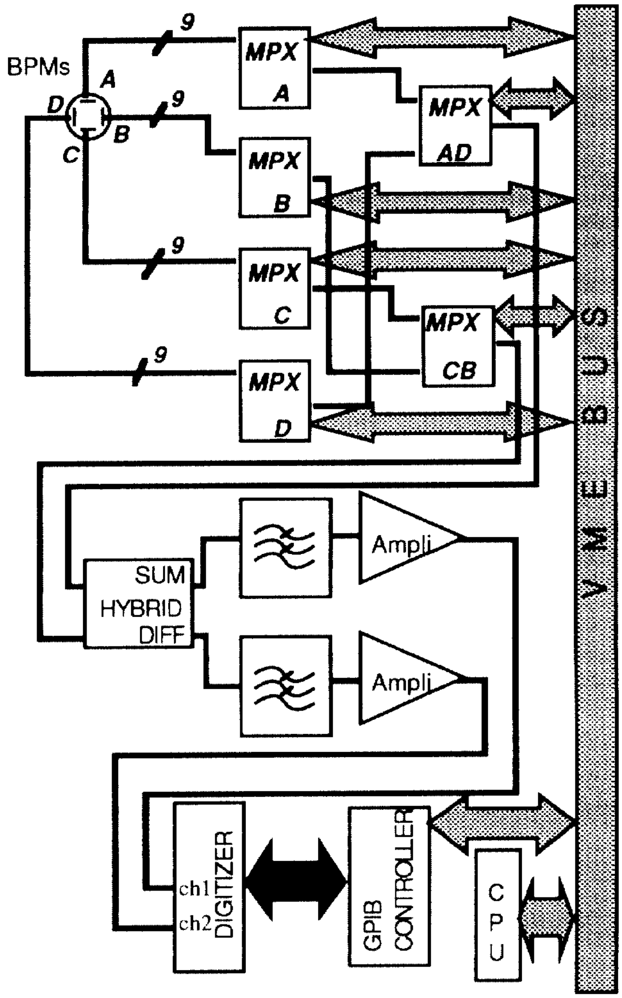

Figure 5. Beam position measurement block diagram for the Elettra linac. The analog multiplexers (MPX) are of the ten channel PIN diode type.

As low-pass filter we chose the Gaussian type in order to avoid overshoot and ringing [3]. They are modified (figure 6) for providing a good impedance match even in the stop band [4]; in this way we avoid multiple reflections in the cables. The choice of the filter bandwidth (20 MHz) is the result of a compromise between the thermal noise and the fluctuation due to the finite sampling frequency that is not synchronous with the beam. The amplifiers are Plessey SL611C.

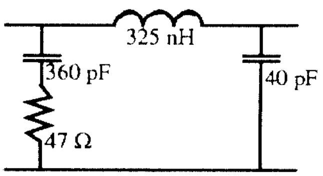

Figure 6. Modified Gaussian low-pass filter.

The digitizer is a Tektronix 2440 digital storage oscilloscope. This instrument has a maximum sampling rate of 500 megasamples/second for an analog bandwidth of 200 MHz. The built-in processing can provide 21 various parameters of the displayed waveform. We will choose later between peak value, area, and peak-to-peak value.

The hybrid sum output is connected to the channel #1 of the digitizer and provides also the necessary trigger. The difference output is digitized by the channel #2. The two resulting numbers are simply computed as follows:

$$x \text{ or } y = \frac{r}{2} \frac{V_{DIFF}}{V_{SUM}} \qquad (6)$$

where the radius of the vacuum chamber is 12 mm for the linac and 30 mm for the transfer line.

3. CONTROL OF THE MEASUREMENT

The measurement is controlled by processes running under the OS-9 operating system on the CPU in a VME bus environment . The following tasks are provided:

1. BPM and x-y plane switching
2. Sum and difference signal acquisition
3. Beam position calculations
4. Automatic vertical scaling
5. Other oscilloscope settings (trigger level, number of acquisitions for averaging, etc.)

The user interface is menu driven and permits to handle various tasks in a simple way. It also displays the results in real time.

4. PERFORMANCES

4.1. Resolution and Global Accuracy

The resolution $\sigma(I_b, |x|)$ is a function of the beam current I_b and of the absolute value of measured position ($|x|$ or $|y|$):

$$\sigma(I_b, |x|) \leq \sqrt{\sigma_1^2(I_b) + \sigma_2^2(|x|)}. \qquad (7)$$

The resolution $\sigma_1(I_b)$ for centered beam is mainly limited by the thermal noise $\sigma_{th}(I_b)$ and by the fluctuation $\sigma_s(I_b)$ due to the finite sampling rate:

$$\sigma_1(I_b) = \sqrt{\sigma_{th}^2(I_b) + \sigma_s^2(I_b)}. \qquad (8)$$

We measured σ_1 = 40 µm with a simulated beam current of 20 mA.

For off centered beams, the fluctuation due to the digitizer vertical scale granularity (8 bit) defines an other resolution limit $\sigma_2(|x|)$ that depends on the beam position:

$$0.004\ x \leq \sigma_2(|x|) \leq 0.02\ x \qquad (9)$$

The sum of the offsets due to the imperfections of the monitor and of the offset due to cables and electronics is less than 0.5 mm and were not measured.

4.2. Measuring Rate

The present system provides currently 1 measurement / second so the whole orbit of the linac can be measured in 18 seconds. The speed is limited by the communication between the CPU and the digitizer via GPIB.

4.3. Early Test During the 100 MeV Linac Commissioning

The first part of the linac with one BPM installed is currently under commissioning. The main problem comes from a spurious signal that occurs when the klystron modulator is triggered. This additional signal is a burst about 4 µs long that accompanies each linac injection, and is proportional to the modulator voltage, with its spectrum concentrated around 2 MHz. Its amplitude is larger than that of a 20 mA beam signal; so the digitizing oscilloscope cannot be triggered on its main time base. But in the present linac operation, the beam signal arrives after the burst disappears. The problem is temporarily solved by triggering the main time base on the spurious signal and by using the delayed time base. However if the beam signal has to be triggered within the 4 µs of the spurious signal, this latter signal will have to be drastically reduced.

5. CONCLUSION

The beam position measuring system of the Elettra Linac has been presented. It is based on a simple processing method that is independent of the bunching frequency and relates directly the beam current in multibunch mode and the amplitude of the acquired signal. Computer controlled general purpose PIN diode multiplexers made possible the use of only one digitizer. It is important to notice that besides the home-made Gaussian low-pass filter, the electronic circuits used are commercially available or are general purpose devices. We are currently working on the GPIB communication software to speed up the measuring rate.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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