EMITTANCE MONITOR FOR SPring-8 LINAC

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Abstract

Emittances of SPring-8 linac are measured by two methods. One is using a slit and a profile monitor, and another is using three profile monitors. Secondary emission wire is used for profile monitor. A high gain analog processor which is based on a charge sensitive amplifier has been successfully developed for the emittance monitor. Its maximum sensitivity is 1V/pC. A control and a data acquisition are performed using a VME computer.

Introduction

Generally a beam emittance is desirable to be small. In the SPring-8 linac to minimize the beam spot on the positron converter and to facilitate the beam injection to the synchrotron the emittance is desirable to be small. In the long beam transfer line like the linac an emittance growth occurs due to the misalignment[1]. The main purpose of emittance measurement is to optimize beam transportation and to minimize the emittance growth. In the linac a high current electron beam and a low current positron beam will be accelerated. Especially the emittance growth must be minimized for the positron beam because it has nominally large emittance.

The preinjector of the linac was already installed in Tokai Establishment of JAERI[2][3]. The rest of the linac is under construction. The emittance monitor was installed at the end of the preinjector. The emittance monitor consists of a slit and a profile monitor (slit and profile method). Now the beam energy is ~10MeV. When the preinjector will be installed at Nishiharima cite an accelerator tube will be added in front of the emittance monitor where the beam energy will be ~60MeV. At the location in front of the positron converter and at the end of the linac another type of emittance monitors will be installed. These emittance monitors consist of three profile monitors in the drift space (three-profile method). Table 1 shows the location and the method of emittance monitor.

Emittance Monitor

Slit and Profile Method

A density distribution $\rho(x, x')$ at the slit is measured[4]. The profile monitor is placed a distance L=3.3395m from the slit. A measured beam profile $\rho_m(X)$ corresponds to the angular distribution at the aperture position $x=x_a$.

$$\rho(x = x_a, x') = \rho_m(X) = \rho_m(x_a + x'L)$$

If the $\rho(x = x_a, x')$ is summed up in all x, whole distribution $\rho(x, x')$ is obtained.

The slit is made of copper with water cooled. An aperture width and a thickness are 0.3mm and 30mm respectively. This thickness corresponds to ~2 radiation length of 60MeV electron. The profile monitor is composed of three wires which are a measurement wire and two extraction wires. These wires are ϕ0.3mm tungsten wires. The slit and the profile monitor are moved by a stepping motor. The minimum step width is 0.02mm. A magnetic encoder is installed by the stepping motor instead of a position sensor. Fig. 1 is a schematic drawing of the emittance monitor used in the preinjector.

TABLE 1
Emittance Monitors for SPring-8 Linac

Location	Beam Energy	Method
Preinjector	60(10)MeV	Slit and Profile
In Front of Positron Converter	250MeV	Three-Profile
End of Linac	1GeV	Three-Profile

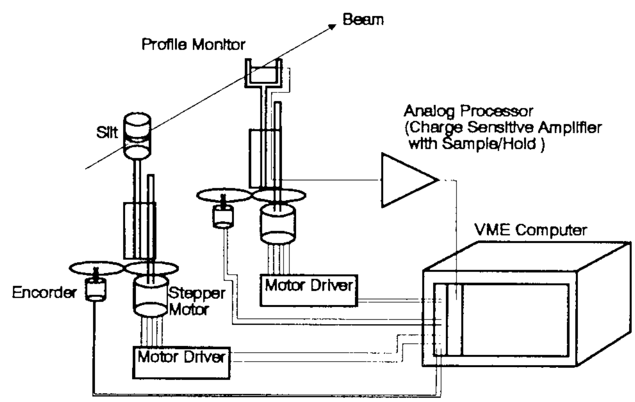

Fig. 1 Emittance monitor used in the preinjector.

Three-Profile Method

It is known that the beam envelope behaves quadratic in the drift space. For an unambiguous determination of size and orientation of the emittance ellipse, the beam size needs to be known at least three locations[5]. Consider addresses of profile monitors are #0, #1 and #2. Twiss parameters and a beam size at #i are α_i, β_i, γ_i and σ_i. In this paper σ_i is the half of the width which includes 90% of the distribution, but not the standard deviation. The length between #0 and #i is L_i. These parameters and emittance ε satisfy next relation.

$$\varepsilon\beta_i = \sigma_i^2$$
$$\beta_1 = \beta_0 - 2L_1\alpha_0 + L_1^2\gamma_0$$

$$\beta_2 = \beta_0 - 2L_2\alpha_0 + L_2^2\gamma_0$$
$$\beta_0\gamma_0 - \alpha_0^2 = 1$$

Solving these equations, the twiss parameters and the emittance are derived. Table 2 and Table 3 show the calculated beam size when the positron is generated and accelerated in the linac (positron mode).

TABLE 2
Beam Size: In Front of Positron Converter

Address	L_i (m)	σ_x (mm)	σ_y (mm)
#0	-	7.7	7.5
#1	2.454	4.4	4.3
#2	4.908	1.4	1.3

TABLE 3
Beam Size: End of Linac

Address	L_i (m)	σ_x (mm)	σ_y (mm)
#0	-	2.8	2.8
#1	3.749	4.0	4.0
#2	7.987	5.4	5.4

The profile monitor has five measurement wires and an extraction mesh behind the wires. The wire is ϕ0.3mm tungsten wire and each wire is spaced by 2mm. The profile monitor is also moved by a stepping motor with a magnetic encoder. If the beam size is smaller than the wire spacing, the profile monitor scans the beam by a small width. The minimum step width is designed as $\leq$0.01mm.

Analog Processor

An analog processor which detects the secondary emission charge from the profile monitor has been developed. The secondary emission charge is proportional to the incident electron beam which impinges on the wire. Its coefficient is called the secondary emission efficiency. The efficiency is reported 6~7% for total surface at 30MeV~1GeV[6]. Because of this low efficiency a high gain charge sensitive amplifier CS-507 (CLEAR-PULSE) was employed. The CS-507 has a sensitivity of 1V/pC nominally. The minimum charge is expected as $\leq$0.01pC/pulse at the positron mode so the minimum signal output is expected as $\leq$10mV. The sensitivity can be reduced by attaching the extra capacitors. The sensitivity is determined as 1V/pC, 0.01V/pC and 0.1V/nC. A sample and hold IC AD1154 (ANALOG DEVICES) is used because DC voltage signal is required for the data acquisition by the VME computer.

The analog processor was examined in the preinjector using the electron beam. Fig. 2 is the output of charge sensitive amplifier in the normal operation. Fig. 3 is also the output, but the noise appears in the base line and the peak is saturated by the noise. This noise came from the modulator. A semirigid cable to the analog processor touched to the modulator frame. It is understood the isolation of ground line is important for such high gain amplifier.

Control and Acquisition System

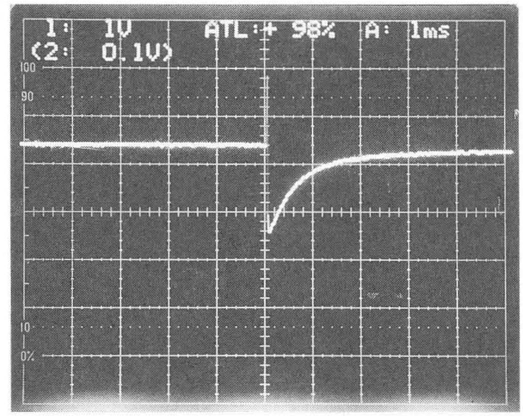

Fig. 2 Output of charge sensitive amplifier in the normal operation. Charge from profile monitor was ~1.8pC. Sensitivity: 1V/pC

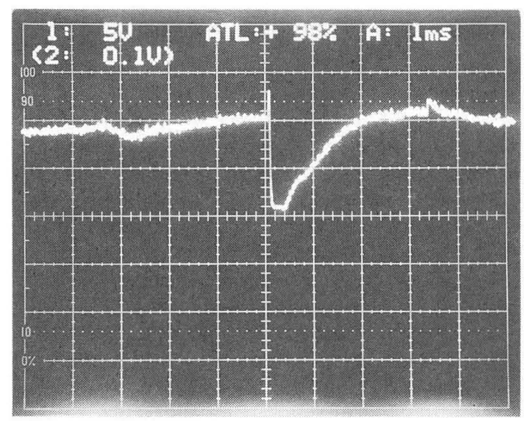

Fig. 3 Output of charge sensitive amplifier when the semirigid cable to the analog processor touched to the modulator frame. Output was saturated. Sensitivity: 1V/pC

All control and acquisition processes are performed by the VME computer. The stepping motor is controlled by a pulse generator and encoder module V-PAK601 (UNIDUX). The V-PAK601 has two drive pulse outputs (cw and ccw), four sensor inputs (+limit, -limit, origin and other) and pulse encoder inputs (A, B and Z). The sensitivity of the analog processor is changed by a pulse signal from the digital output. The pulse signal is transferred by the isolation transformer to separate the ground lines. The DC voltage signal from the analog processor is acquired by the ADC with an isolation amplifier. Its range and resolution are ±10V and ~5mV (12bit). In case of the positron mode the higher resolution type (16bit) may be employed.

Experimental Result

The beam profile and emittance were measured in the preinjector. Fig. 4 shows the beam profile of Y (vertical) direction. It took ~1 second to acquire one data point, because a noise from the stepping motor was too large when the motor was rotating. The line is the Gaussian fit. Its standard deviation σ_{std} is obtained as 6.3mm and σ is obtained as 10.4mm=1.65σ_{std}. A charge integral of all data points becomes 21pC. On the other hand the total charge of the incident beam was measured as ~500pC by a CT (Current Transformer). Taking into account of the geometrical factor the efficiency was obtained as ~7.0%. This agrees with one of the paper[6].

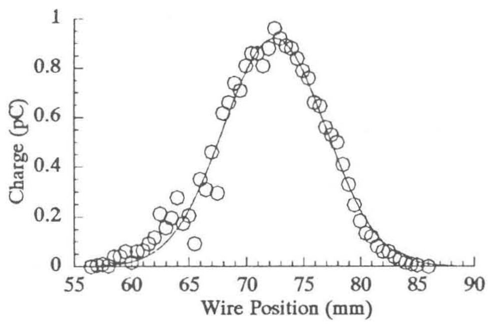

Fig. 4 Beam profile. Beam condition: 1A peak, 0.5ns FWHM and 10MeV

The noise level of the system was measured. Fig. 5 is the probabilities of ADC output when no signal was inputted. The open circles are the probability when no cable was connected to the ADC. Its standard deviation (noise level) is 2.3mV. The closed circles are the probability when the analog processor was connected to the ADC. Its standard deviation (noise level) is 5.1mV. The noise level of the analog processor is thought as 4.5mV. This value is quite comparable to the signal at the positron mode ($\leq$10mV), but the value is thought no more reduced. Small signal at the positron mode is obtainable by averaging it because the average of noise goes to zero.

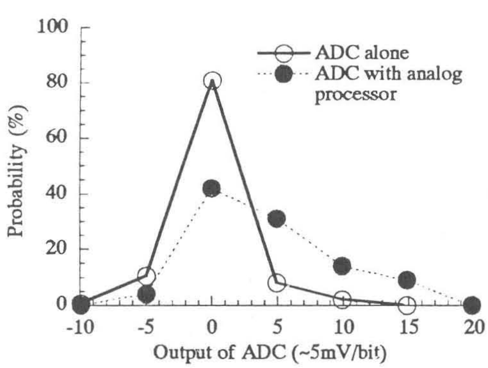

Fig. 5 Probability of ADC output. No signal was inputted. The standard deviation means the noise level. Sensitivity: 1V/pC

The emittance was measured using the slit and the profile monitor. Fig. 6 is the typical density distribution. The slit and the profile monitor scanned the beam by 1mm width. The emittance which includes 90% of the distribution is obtained as 8.6πmm·mrad. The total charge of the incident beam was measured as 10.7nC by the CT. In this condition 67pC was expected as the charge integral of the profile monitor taking into account of the efficiency of 7.0% and the geometrical factor. But the measured charge integral was 47pC. This means ~30% of the beam was lost at the slit because of the small aperture width. The lost part of the beam is thought the fringe part of the emittance ellipse. This loss will be small when the preinjector will be moved to the Nishiharima cite because the arrangement of the preinjector is planed to be improved.

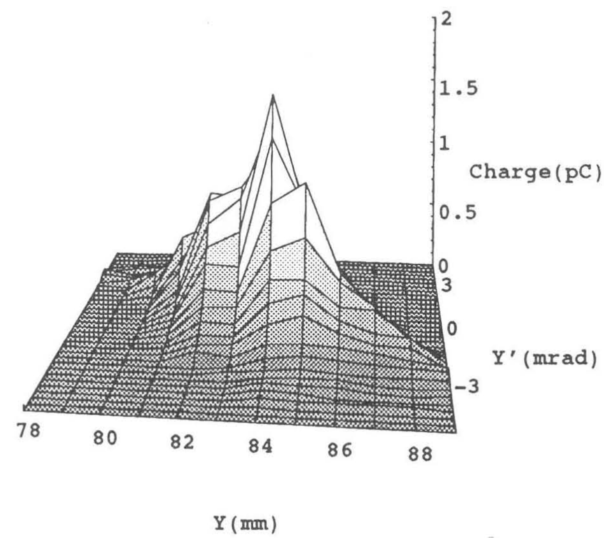

Fig. 6 Density distribution on the phase space. The emittance was obtained as 8.6πmm·mrad. Beam condition: 7.1A peak, 1.5ns FWHM and 12MeV.

Conclusion

The emittance measurement on the preinjector was carried out successfully. The components of emittance monitor (the slit, the profile monitor and the analog processor) shows the good performance. The control and the data acquisition can be performed using the VME computer.

References

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