BEAM DIAGNOSTICS FOR HESYRL, THE 800-MeV SYNCHROTRON RADIATION FACILITY IN HEFEI

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Summary

The beam diagnostic system for the 800 MeV synchrotron radiation facility is described here. A new type of monitor, a stripline and gap combined monitor, for both position and current is presented.

Introduction

An 800 MeV synchrotron radiation facility is being built in Hefei, Anhui Province, China. It is expected to provide researchers with an intense, stable and flexible synchrotron radiation source. The facility consists of a 200 MeV linac injector, (Fig 1) a 58 meter long transport line (Fig 2) which connects the linac and the storage ring, and an 800 MeV storage ring. (Fig 3) In addition to 12 bending magnets, serving many experimental stations, the ring is designed to accommodate several insertion device sources to provide enhanced spectral range and increased brightness. Presently planned insertions include a 5 T superconducting wiggler, a 1.5 T multi-pole wiggler and a low field undulator.

The 200 MeV linac includes a fast pulse electron gun which produces a 4 ns pulse with 0.7 ns rise time. There is also a prebuncher, a buncher, one 30 MeV linac sector and 4 60 MeV linac sectors. The 5 drift sectors are equipped with beam diagnostic devices for monitoring the beam current, position and profile.

Five bending magnets and 13 quadrupoles constitute the transport line which has sufficient space for beam monitoring equipment.

The following table gives the main parameters of the storage ring:

Table 1
Parameters of the Hefei VUV Ring

Energy:	800 MeV
Current:	300 mA (3.92×10^{11}e)
Circumference:	66.1308 m
Critical Wavelength:	24 A
Harmonic No.	45
No.of Quads:	32
Quad. Strength:	0.16-1.24 KG/cm
Quadruple Length:	0.3 m
No. fo Dipoles:	12
Dipole Field:	12 KG
Dipole Length:	1.16 m
Dipole Gap:	50 mm
Radius of Curvature:	2.222 m
Horiz.& Vertical Tune:	$\nu_x=\nu_y=3.25$
β max:	$\beta_x=\beta_y=13.2$ m
η max:	$\eta_x=1.64$ m
Momenteum Compaction:	0.05557
Bunch Length:	$2\sigma_z=82$ mm
Horiz.Emittance: (zero coupling)	0.131 mm-mrad
Energy Spread:	$\Delta E/E=4.6\times10^{-4}$
Damping Time:	$\tau_x=20.07$ ms $\tau_y=20.55$ ms $\tau_E=10.39$ ms
Touschek Lifetime:	20 h
RF Frequency:	204 MHz
No. of Cavities:	1
Rad.Power:	4.89 kW
Peak Voltage:	100 kV

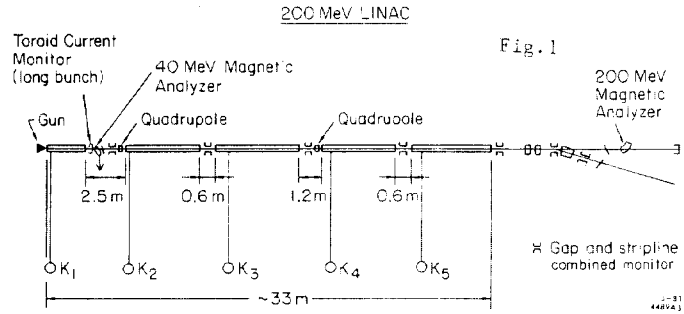

Fig.1

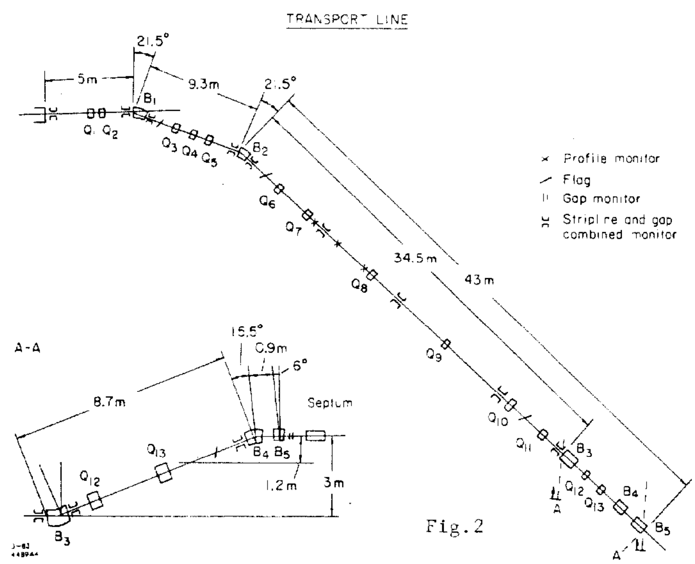

Fig.2

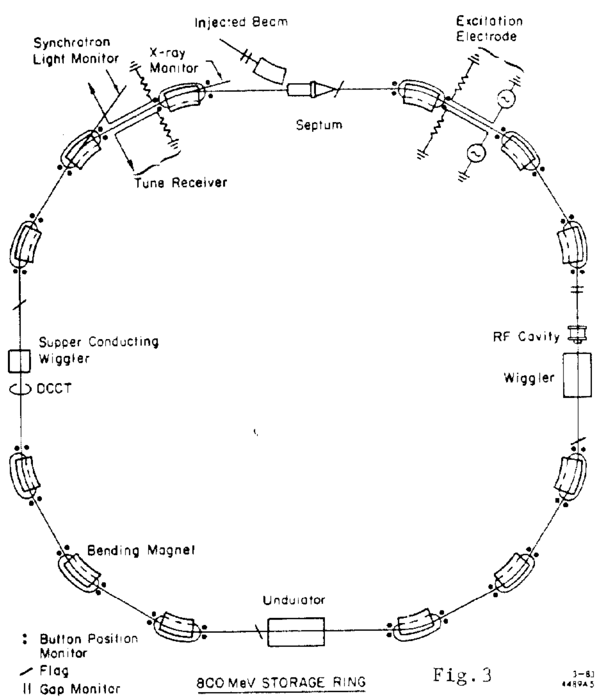

Fig.3

This paper describes the beam diagnostic system planned for this facility to measure the beam position, current, profile, emittance, tune, energy, etc. Since the linac beam is different from the beam in the ring, two different types of devices may be necessary to measure the same parameters. The following table lists, in priority order, 12 types of monitors planned for these functions in various parts of the machine.

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Table 2
The Beam Diagnostic System

Devices	Function	LINAC	Transport Line	Ring
Flag	profile	1	4	4
Buttons	position			24
Combined monitor	position &current	5	9	
4-striplines	tune exitation			1
2-striplines	tune receiver			1
Gap monitor	current		1	1
DCCT	dc current			1
Synchrotron light	profile emittance			1
X-ray	profile			1
Toroid	current (long pulse)	1		
Magnetic analyzer	energy spectrum	1 - 40 mev 1 - 200 mev		
Multiwire profile monitor	profile for emittance		3	

More details on some of these devices are presented below.

Gap and Stripline Combined Monitor (Fig.6)

Since the linac has two modes of operation (4 ns bunches for injection and 2μ s bunches for nuclear physics experiments) a combined gap and stripline monitor (see Fig 4) which can simultaneously measure the current and position of both the short and long bunches will be utilized. This avoids two separate diagnostic systems. This is possible because of the very short (0.7 ns) rise time of the electron gun. The output wave from these two modes of operation is the same, thus we can simplify the electronics.

A gap within the vacuum system is used to produce the beam current signal instead of a ceramic gap with shunt resisters as used for the common wall current monitors. The mechanical construction is quite simple and the sensitivity is very good. These gap monitors will be used in the linac and the transport line as well as the ring to monitor bunch current and length. Preliminary evaluation indicates that parasitic losses will not be a problem.

The output signal of the gap monitor is the overlay of the induced signal of the incident beam at the gap and the reflected signal from the end of the coaxial structure. If the beam bunch is longer than the length of the gap monitor as it is in one of our cases, the signal will be a bipolar signal with a pulse width of 2L/c where L is the gap monitor pipe length. For bunches shorter than the monitor length, two pulses of opposite polarity are obtained. These provide a good reproduction of the bunch shape and are also separated by 2L/c. (Fig 5)

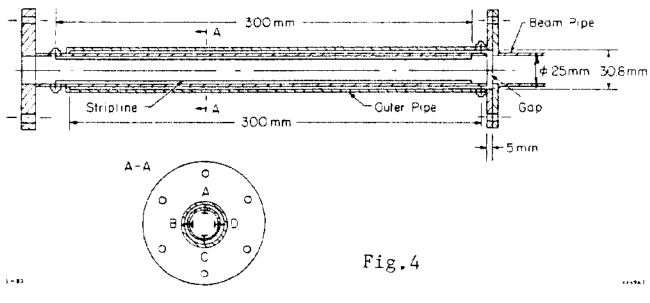

Fig.4

The beam current can be determined by $I_p = V_q/R$. Where V_q is the peak voltage of the output signal of the gap monitor, and R is the characteristic impedance of the coaxial structure. This gives an absolute current measurement. The sum of the signals from the 4 striplines can also be used to observe beam intensity. But to achieve the proper impedance and good sensitivity for position measurement, the striplines should be narrow. Therefore they can only pick up a part of the wall current signal induced by the beam yielding a relative measurement. For this reason the combined gap and stripline monitor is preferred.

To avoid any sensitivity to beam position the output signal is received from 4 output ports symmetrically placed around the gap. Then, a power combiner integrates the signals. They can then be amplified and the peaks detected.

The stripline position monitor (see Figure 4) is based on the principle of the traveling wave beam electrode. (1) It consists of a section of cylindrical steel pipe with 4 conducting steel strips of length L. The rear parts are grounded and the front parts are used as the outputs.

As a beam pulse passes adjacent to the front end of the stripline it induces signals V_1 & V_1' which travel in both directions, one towards the output and one towards the short circuit end, with the same speed as the beam itself. A similar process happens at the downstream end. The two signals that meet at the downstream end cancel each other. A remaining one travels towards the output.

Just as for the gap monitor, short bunches produce two bipolar pulses separated either by 2L/c or by the actual beam length when the bunch length is twice as long as the stripline. (2) This means that the length of the stripline or the corresponding beam pipe is a common factor for both measurements. The stripline position monitor uses the stripline and wall of the beam pipe as a transmission line. The gap monitor uses the coaxial structure made of the beam pipe and the outer pipe (see Figure 4). The two signals will only use two surfaces of the beam pipe. Hence simultaneous measurement of beam position and intensity is possible without interference between the two measurements. Accomplishing both measurements with a single device saves space and simplifies the diagnostic system.

The pulse amplitude of the stripline is proportional to the beam current and inversely proportional to the distance between the beam path and the stripline. By utilizing the sum and difference signals from the pairs of electrodes, the beam displacement can be measured.

$$X = K_x \frac{V_D - V_B}{V_D + V_B} \qquad Y = K_y \frac{V_A - V_C}{V_A + V_C} \quad \text{(see Figure 4)}$$

The linac is also equipped with two magnetic energy spectrum analyzers of 40 MeV and 200 MeV and a moveable screen to monitor the beam profile.

Button Position Monitors

The Button Position Monitors will be used for the 800 MeV storage ring. Since it is highly desirable to measure the beam position in at least 4 places per betatron wavelength and since there are 5.8 horizontal betatron wavelengths per turn we plan to have 24 position monitors around the ring. They will be located at the entrances and exits of the bending magnets.

Assume V_A, V_B, V_C, V_D are measured data from 4 buttons and form:

$$U = (V_B - V_A + V_C - V_D)/(V_A + V_B + V_C + V_D)$$
$$V = (V_A - V_B + V_C - V_D)/(V_A + V_B + V_C + V_D) \quad (1)$$

The chamber is rectangular with a very small linear area. K_x and K_y are non-linear functions of x and y. We plan to calibrate the monitors point by point. So we assume:

$$X = \sum_{n=o}^{N} \sum_{k=o}^{n} A_{n-k,k} U^{n-k} V^{k}, \quad Y = \sum_{n=o}^{N} \sum_{k=o}^{n} B_{n-k,k} U^{n-k} V^{k}$$

N = 4 will be accurate enough. For calibration, x,y can be determined mechanically. Then K_x, K_y can be calculated by the least squares method. The measured beam position can be obtained from the $V_{A'B'C'D}$ by eq.(1).

Stripline Beam Excitation Electrodes

If there is no coherent betatron oscillation of the beam then beam excitation electrodes are necessary to excite a betatron oscillation for tune measurement purposes.

If the external excitation of the beam is balanced by damping, then the beam will not be destroyed during the tune measurement. Hence the tune measurement can be done at any time during operation without interference with the users. A sweeping frequency (revolution frequency ω_o x q)(q is the fractional part of the tune parameter) is used to excite the beam. When the sweeping frequency is synchronized with the beam betatron oscillation, a position monitor will give a signal which includes ω_o, $(n-q)\ \omega_o$ $(n = 1,2,3...)$. The spectrum analyzer determines q very easily.

For this machine the sweeping frequency is 1-4 MHz. The exciting power is only a few watts. By properly exciting the 4 striplines which are in 4 corners of the beam pipe, magnetic fields in different directions can be obtained in the center of the chamber.

The DCCT

The DCCT (3) is used to measure the DC beam current of the storage ring. It consists of two identical ferrite toroids (I.D. = 12 cm, O.D. = 14 cm, width = 2 cm) coaxial with the beam. Both toroids have individual driving coils. The common coils are the feedback and sense coils which are wound with twisted wires. A 4 KHz rectangular current pulse signal is used to drive the two toroids and saturate them separately in opposite directions. When a beam passes through the DCCT, it biases the magnetic circuit and causes a second harmonic of the driving signal to be generated. This signal is synchronously detected and fedback as a DC current, cancelling the beam current effect. The feedback current is equal to the DC beam current and can be easily measured by a digital meter.

Synchrotron Light Monitor

A synchrotron light monitor is a very reliable, convenient and useful tool for measuring the ultra-relativistic electron beam size, current and emittance, and for directly observing the beam in the ring.

A pellicle film splits the optical beam into two parts, one is deflected by 90° out of the original path for use in observing the beam size. The other beam is further divided into two parts for beam profile measurement in both directions. A 120 Hz vibrating mirror reflects the beam and sweeps its profile over a slit. A photomultiplier receives the light through the slit and the electrical signals are sent to the control room. As the light spot is swept in different direction (x or y), the vertical and horizontal beam size are obtained. The emittance can be calculated from the beam size using the known β functions. $\varepsilon = \sigma^2/\beta$

X-ray Monitor

An easy and economical way to directly observe beam size is to use a TV camera to view synchrotron radiation x-rays on a fluorescent screen. Here, the principle of pinhole image formation is used. The pinhole is 0.1 mm, 2 m distance from the center of the bending magnet.

Flag

A flag is a simple but destructive direct observation device, especially useful in commissioning of the machine. There will be 4 in the transport line, 4 in the ring (one for each quadrant). We plan to use flags which are amounted in air in a cup as Brookhaven is using now to simplify the mechanics and changing of the screens.

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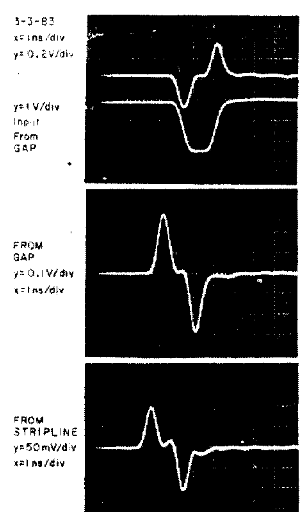

Fig.5

Fig.6