INSTRUMENTATION AND BEAM DIAGNOSTICS IN THE ISR

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(presented by W. Schnell)

1. Measurements of circulating beam current and luminosity

1.1 The ISR circulating beam current monitor

Intensity of circulating beam in the ISR is monitored with an instrument[1] consisting of a number of toroidal cores, in an arrangement schematically indicated in Fig. 1.

Toroid T1, the main current sensor, carries two windings which close the loop of a high gain operational amplifier (L/R integrator). The amplifier maintains a perfect balance between primary beam current and feedback current. This circuit alone covers a frequency range of 0.01 Hz to 50 MHz.

The d.c. component of beam current, or more precisely, any error in balance between effective beam current and feedback current, is detected with a magnetic modulator/demodulator circuit (T2;T3;T4) which produces a correction signal for the operational loop.

The system has a high loop gain (180 dB at d.c.) which guarantees high accuracy and linearity as a current monitor. The monitor has only one single range from 0 to 20 A equivalent beam current and a resolution and zero stability of ± 20 μA. This is, indeed, necessary since we have to observe decay rates as low as 10^{-5} per minute in a reasonable time.

Signals from the beam current monitor are distributed to digital displays, paper chart recorders (Fig. 2) and the computer data acquisition.

1.2 Measurement of the ISR luminosity

A measurement of the ISR luminosity L requires a measurement of the effective vertical beam height (h_{eff}) and of the two circulating beam currents I_1 and I_2.

The counting rate in a counter telescope of arbitrary geometry looking at the crossing point is

$$M = \eta\sigma_t L = \eta\sigma_t \frac{I_1 I_2}{ce^2\, h_{eff}\, \tan \alpha/2}$$

where η is the efficiency of the monitor, σ_t the total proton-proton cross section and α the crossing angle.

If the two beams are displaced vertically with respect to each other by steering magnets, and the counting rate M is plotted versus relative displacement, a bell shaped curve will result. It has been shown[2] that h_{eff} is equal to the area under this curve, divided by the maximum counting rate. The interesting aspect of this method is that this measurement of h_{eff} is independent of σ_t and η and only depends on a knowledge of the relative beam displacement. A typical curve obtained during a measurement of h_{eff} from which the luminosity can be calculated, is shown in Fig. 3.

A measurement of the luminosity also gives a value for $\eta\sigma_t$ of the particular monitor involved. In the course of a physics experiment all parameters I_1, I_2 and h_{eff} can change and therefore M must be monitored continuously to allow normalisation of the experimental data.

2. Electrostatic pick-ups and related instrumentation

2.1 The Beam Position Monitoring System

This system consists of 106 electrostatic pick-up electrodes with associated electronics[3].

Head amplifiers, high quality coaxial cables and end-of-cable amplifiers build up a wide-band observation chain for the beam induced signals with a bandwidth of 2 kHz to 100 MHz. Its frequency characteristic is flat within 0.1 dB (1 %) from 10 kHz - 30 MHz. This precision is needed to ensure the precision of the position readings (about 1 % signal per mm).

The video signals are selected in the main control room via remote controlled coaxial reed relays and equal length low loss coaxial cables[4].

In order to measure the beam position from the signals of a pair of plates, the mean value is sampled and held within a signal processor unit. The four channels are then read by the computer analog scanner[5]. Measurements are made either with repetitive injection - new PS pulse for the reading on each P.U. - or with a single pulse kept bunched by RF. Resolution of the system is better than ± 0.2 mm and the accuracy about ± 1 mm. Fig. 4 shows plots taken during the process of orbit corrections.

2.2 Special pick-ups and RF related signal observation

The signals from the pick-up electrodes are also used for the observation of the RF system performance. Bunch length, RF matching efficiency, phase oscillation frequency, are measured directly from the wide band signals displayed on an oscilloscope.

Two wide band P.U.'s based on the measurement of the beam induced current in the vacuum chamber wall, have been constructed and installed in the ISR. The wall current, image of the beam current, is picked up from a gap on a ceramic seal by wide band transformers. The bandwidth is 100 kHz to more than 1 GHz.

For beam instability studies two microwave P.U.'s, consisting of two pairs of vertical and horizontal loops of 30 mm length, have been installed in the vacuum chamber.

Current density distribution with momentum in stacked beams is measured with scanning buckets, generated by the same RF programme generator and RF cavities as are used for stacking. The signal induced in the electrostatic pick-up is filtered, amplified and displayed on a memoscope as a function of frequency, (Fig. 5).

2.3 Q-measurements

Our system for measuring betatron frequencies is described elsewhere in this conference[6]. This device consists essentially of pulsed beam deflectors, producing a coherent oscillation of less than 1 mm amplitude, and a system of filters, counters, and digital processors. A direct readout of the non-integral part of the Q-value is produced upon receipt of a trigger.

The precision is about $\pm 10^{-3}$ in the fractional part of Q. The measuring time is less than 1 ms. The system will measure a bunched as well as an unbunched beam.

2.4 Band-pass filter signals

The filter signals used for Q-measurements are also used for : (i) reducing the amplitude of coherent betatron oscillations at injection and (ii) to observe coherent transverse oscillations of a whole stack, e.g., due to resistive wall instability.

2.5 Dynamic frequency measurements

Two frequency meters per ring measure the frequencies picked up from the beam (30th harmonic of revolution frequency) and from the r.f. cavities. Each system consists of a ringing circuit, a mixer and local oscillator (about 6 kHz beat frequency) and a period-measuring counter (30 MHz clock frequency).

The accuracy is about 10^{-6} and the measuring time about 1 ms so that precision measurements can be performed at any time during acceleration. As the magnetic field is known with high precision[7] the system also yields the average radius to an accuracy of a fraction of a millimetre.

3. Profile measuring devices for the circulating beam

3.1 Beam scraping targets

Scraping targets (ST) are used when destructive measurements of beam profile and density are acceptable. The ST consist of thin tantalum scattering foils which can be moved into the beam to provide a sharply defined aperture limitation, either vertically or radially. These targets are located at azimuths where the ratio of vertical to radial betatron function is large; coulomb scattering of intercepted protons then increases mainly the vertical betatron amplitude. After a few tens of traversals, the scattered protons are absorbed by the dump block, which is the main vertical aperture limitation.

The scraping targets are used with the beam current transformer to make measurements of proton distribution in stacks, often in conjunction with RF scans for relating distributions in momentum and betatron space. ST position and beam current can be presented on an X-Y recorder or processed by the control computer for printing out. An ST radial scan of a full stack can be made in 5 - 10 seconds.

3.2 Ionization beam scanner

For vertical profile measurements (Fig. 6) an experimental Ionization Beam Scanner (IBS) similar to those in the CPS[8] has been installed in Ring 1. Ionization electrons, liberated by the protons from the residual gas, are fed on to a collector electron multiplier by a system of crossed electric and magnetic fields. Only electrons from a horizontal slice of the beam are collected at a given moment; scanning is achieved by moving this slice through the beam. Due to the low electron production rate at 10^{-10} torr, scanning times are 5 ms or longer. The minimum circulating beam current for which a profile is visible with 50 scans per second is 10 mA. Profiles of beam stacks above 1 A are distorted by space charge fields.

3.3 Beam scanning probes

Each ring is equipped with 2 horizontal and 2 vertical scanning probes used to measure the radial and vertical dimension of a stacked beam. Each probe consists of a thin rigid titanium foil which can be driven at a speed of 100 mm/s towards the edge of the beam by a stepping motor.

A secondary emission signal is obtained from the foil as soon as the probe enters the halo near the beam edge. At this moment the beam edge position is recorded and the motor rotation reversed to move the probe out again. The signal level for return is adjustable. Two probes can be used simultaneously.

The beam is scraped slightly; a measurement consumes at least 0.2 mA. The resolution is 0.2 mm. The probes can also be used to measure a beam density profile.

4. Beam transfer and injection instrumentation

4.1 Luminescent screens

The beam transfer channels between the PS and the ISR are equipped with 22 luminescent screen stations each equipped with a TV camera. The screens are used to observe the beam shape and position. The retractable screens are made of activated lithium glass; one type consists of a 1 mm thick disc, a second type of regularly spaced fibres[9].

The disc is more sensitive and therefore used for low intensity beams (2 bunches); the fibre screens are used for high intensity beam (20 bunches) and in cases where multiple coulomb scattering is to be minimised.

4.2 SEM beam profile monitor

The SEM monitors measure the beam intensity profile in the horizontal and the vertical plane. They consist of a row of thin secondary emission foils placed in each plane[9]. The associated electronics system[10] shows the profiles as histograms on a CRT or reads the individual signals into the computer for calculating the emittance ellipses. Three SEM monitors in each transfer channel and in the rings are used for betatron matching. The monitors in the ring are different in design, and can only be used for injection studies if the beam is stopped after one revolution.

The monitors are sensitive enough to work with 2 bunches. The resolution is of the order of 1 mm.

4.3 Beam position electrodes

Electrostatic pick-up electrodes, identical to those used in the rings, are placed at the beginning and at the end of each transfer channel. The output signals are read by the computer, so that changes in beam position and angle can be detected continuously.

The electronics for these pick-ups is somewhat special because the beam position has to be measured for a beam passing only once. The same technique is being applied for the pick-ups in the rings so that the orbit can be measured on the first turn of the beam or on any of the first 10 turns after injection. The precision for 20 bunches is ± 0.5 mm. For 4 bunches it is ± 1 mm in the beam transfer channels and ± 2.5 mm in the rings.

Two special horizontal pick-ups are provided on both sides of the septum magnet for adjusting the closed orbit at injection parallel to the septum plate.

4.4 Beam current monitors

Conventional beam current transformers are placed at the beginning and at the end of each transfer channel to measure possible current losses. The output signals are read by the computer which calculates beam losses in percentage and will provide warnings if losses are excessive.

References

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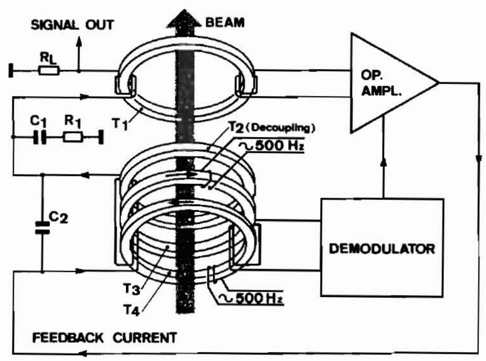

Figure 1
Schematic diagram of DC current monitor (PIDC)

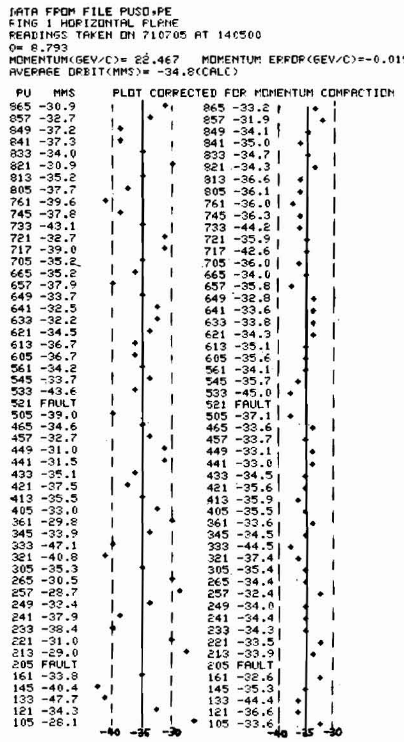

Figure 4
Plots of closed orbit position as recorded during correction

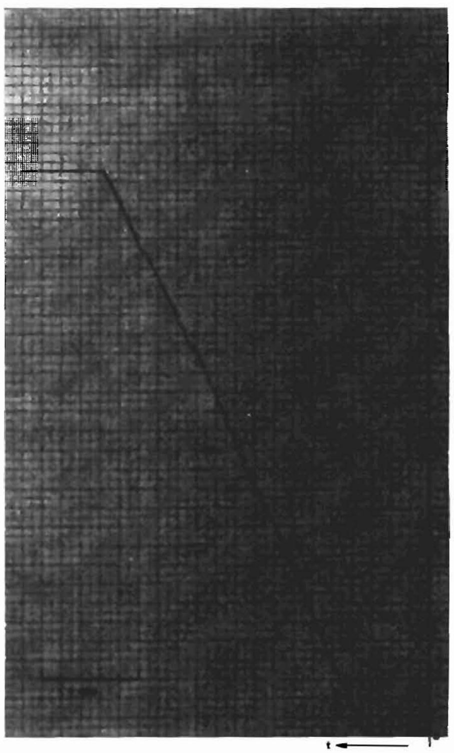

Figure 2
Beam current recording during stacking

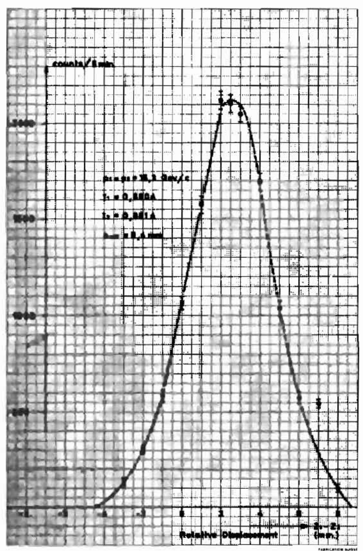

Figure 3
Measurement of the effective beam height or luminosity in an intersection

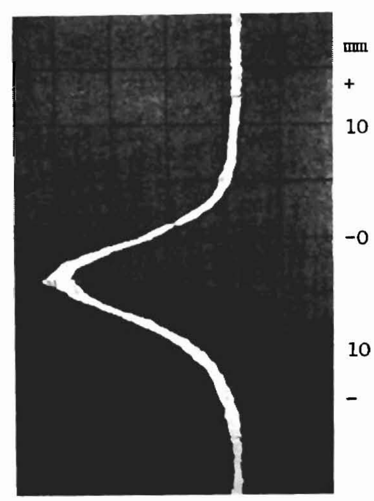

Figure 6
IBS scan of the stack vertical profile

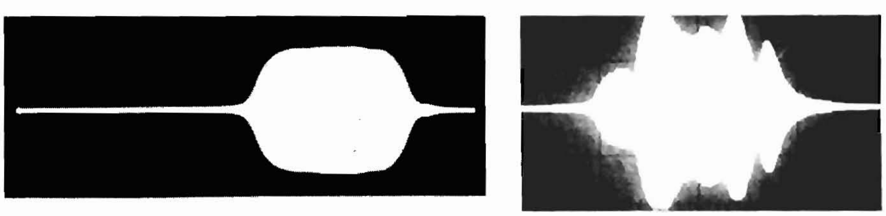

Figure 5

a. stack of 1 A, tail scraped

b. stack of 4.7 A, with effect of higher order resonances

DISCUSSION

M.Q. BARTON : Your monitor of luminosity requires a disturbance of the beam. Do you have a method for monitoring the luminosity without this disturbance ?

E. KEIL : The luminosity measurements made by displacing the beams with respect to one another give an absolute figure for the luminosity. This can be used to calibrate the relative luminosity monitors forming part of each experimental region. These may be connected to the control room and used for continuous non-destructive luminosity monitoring.

M.Q. BARTON : Can your pick-up electrodes be used for any orbit information on the stacked beam ?

W. SCHNELL : Only if modulation by empty rf buckets is applied.

M.Q. BARTON : I am surprised that your method of Q-measurements works in the presence of Landau damping. Does it work with a wide stack ?

W. SCHNELL : Yes, it works with even the largest Q-spread we use. We normally measure Q-spreads with low intensity test beams although the equipment works better with a full 20-bunch injected beam than with only 4 bunches.

D. POTAUX : Have you measured the Q-spread with a high-intensity beam ?

W. SCHNELL : We have made preliminary measurements of the incoherent space-charge Q-shift by observing the shift in position of a non-linear resonance as a function of beam-current. In reality, we observe the shift of the slot visible on the rf empty-bucket scan when a low-order resonance is situated within the stack.

E. KEIL : We shall soon measure the Q-spread in the intense beam by observing the decay of the coherent signal after the beam has been kicked.