BEAM DIAGNOSTICS AT SIN

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Summary

For the operation of a complex accelerator-system, such as the SIN facility, a large number of reliable beam diagnostic elements are essential. The interface to the control-computer has to be performed very carefully to facilitate fast collection and treatment of a large amount of data. The diagnostic elements have to work at high radiation levels and at high beam power. They deliver very small signals that have to be transported over long distances in a noisy environment. In this paper, the beam diagnostic elements used in the SIN cyclotrons and beam lines to measure beam intensity, profile, position, phase, loss are briefly presented with some application examples.

Introduction

The SIN Meson Facility consists of a series of accelerators producing beams of various energy, intensity and time structures [1,2,3,4]. The protons extracted from the ion-source have an energy of 60keV and an intensity up to 20mA. At the end of a short beam line connecting the ion source to the Cockcroft-Walton (CW), a magnetic beam chopper can pulse the injected beam with a repetition rate of 500Hz and a duty-cycle varying from 1% to 100%. The energy of the beam extracted from the CW is 870keV. Normal operation is with DC-beam, but during set-up the beam can be pulsed at 500Hz. This beam is transported using a 25m long beam line and injected into the first cyclotron (Injector 2). The extracted beam has an energy of 72MeV and an intensity up to 2mA. It has a time structure of 50MHz with a phase-width of 20 to 30 degrees. This beam is then transferred through a 60m long beam line into the second cyclotron (Ring Cyclotron) which boosts the energy to 590MeV. The extracted beam is then transferred by different transport lines to the pion production targets. The Ring Cyclotron can also be used in conjunction with the old injector (Injector 1) to accelerate polarised protons with a beam intensity ranging from 100nA to 3μA. The beam diagnostic elements used in the cyclotrons and beam lines to measure intensity, profile, position, phase and losses of the beam are briefly presented together with some application.

Beam Current

The beam intensity is measured either by beam stoppers or by non-intercepting devices. Beam stoppers are used only for energies up to 72MeV. They consist of an insulated copper block with a conical or V-shape hole to distribute the beam power over a large surface. They are directly cooled with water. Those for power up to 20kW can be moved pneumatically into and out of beam (Fig. 1). A 50cm long tube mounted in front of the stopper and electrically connected to it, collects the secondary electrons transforming the beam stopper into a Faraday-cup. In an appendix to the transport line between Injector 2 and the Ring, we have a beam stopper designed to absorb 150kW of beam power (2mA 72MeV). This conical and directly water cooled beam stopper is divided into three sections to allow a control of the beam distribution.

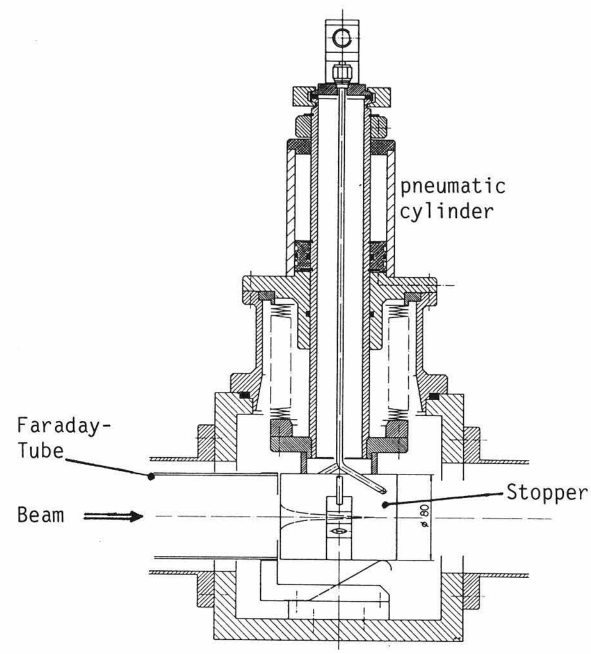

Fig. 1: Beam stopper for 72 MeV and 10 kW beam power.

Current Acquisition Module

The current of beam stoppers, collimators and beam probes are all measured using linear and logarithmic current acquisition modules (LLCAM), (Fig. 2). In these CAMAC modules, developed at SIN, the input current first passes through a logarithmic current-to-voltage converter. A current mirror regenerates the input current that is then fed into a linear current-to-voltage converter. The log-converter has a dynamic range higher than 6 decades - from 1nA to 3mA - with an error less then 2%. For higher current, it is possible to find transistors with good log-conformity up to 100mA. A peak detector, connected to the log-converter, measures the peak value of the current. The linear output has only a dynamic range of 3 decades but can be easily adapted to the different probes by changing the conversion factor. The error is less than 1%. An integrator, with autorange and connected to the output of the linear converter, gives the mean value of the current (5 decades dynamic). To protect probes against overload currents, two comparators, one for warning and one for interlock, are connected through a filter to the linear or the logarithmic converter. All the analog values can be digitalised by a 12 bit ADC and read through the Camac bus.

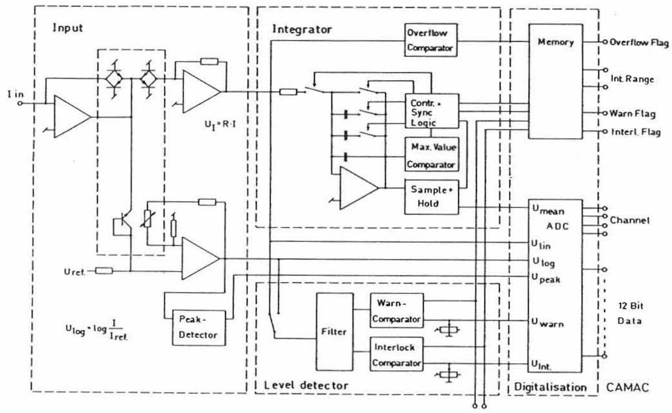

Fig. 2: Lin and Log Current Acquisition Module (LLCAM) for current from 1 nA to 3 mA.

Non Intercepting Intensity Probes

For the 870keV beam line, we developed a DC-current transformer. It uses a toroidal core and measures the beam current by the transductor principle. A second toroidal core measures the AC part of the current and suppresses the noise induced by the first [5].
The principal data of this transformer are:

range : 1 μA to 60 mA
precision: 0.3 % at 20 mA
risetime : 1.3 μs for 0 to 20 mA step
noise : 0.3 μA (with filter)
drift : 0.1 μA/0C, 1 μA/day

In the 72 and 590MeV beam lines, where the beam has a 50MHz structure, we use a coaxial resonator with a high Q-value, tuned at the second harmonic (i.e. 100MHz) of the beam repetition frequency. The beam crosses it axially and excites it in the TM01-mode. The amplitude of this oscillation, which is proportional to the beam intensity, is picked up by a 50 Ohm coil and measured by a SIN Camac module (Fig. 3). The HF-signal passes a mixer that converts it down to 50kHz. This is, after amplification, rectified by a linear rectifier, calibrated using a digital potentiometer and digitalised by a voltage to frequency converter and a counter-integrator. The counting time is 100ms and the integral value is written into a memory that can be read at any time through the Camac bus. This current measuring device has a dynamic range of 80dB with a linearity error less then 1%. The resolution of the counter-integrator is $4 \cdot 10^{-5}$.

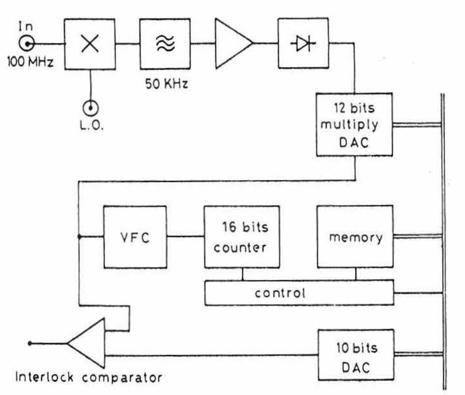

Fig. 3: Camac Module for nonintercepting current monitor. It measures HF-voltage from 15 µV to 150mV with a linearity error less than 1%.

Profile Monitors

Finger Profile Monitors

About 150 of these monitors are mounted in the different beam lines (Fig. 4). A thin molybdenum finger (0.5mm thick) or a foil (0.1mm) is scanned through the beam by means of an excentre driven by a DC-motor. The position of the finger is registered by a linear potentiometer and the current of the stopped protons and of the knocked out secondary electrons are measured by a fast current-to-voltage converter. The monitors with a finger are installed in the high energy beam lines and can be used for currents from 10nA to 1mA. Those with a thin foil are used in the 870keV line for currents up to 2mA. At higher current, the beam must be chopped. A microprocessor drives the profilmonitors through a multiplexer and digitalises the profile for the control computer. The profile is also directly displayed on a storage scope.

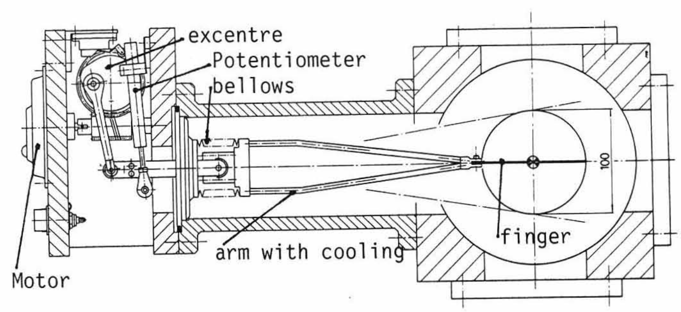

Fig. 4: Profile Monitor with thin finger.

Residual Gas Profile Monitor

For the low energy beam lines (60keV and 870keV), we are now developing profilemonitors that measure the light emitted by the residual gas hit by the protons. Tests made with a prototype show excellent agreement with the profile measured with the metallic foil (Fig. 5). The monitors for the 870keV line use a photomultiplier to measure the light and a mechanical system to scan the beam (Fig. 6).

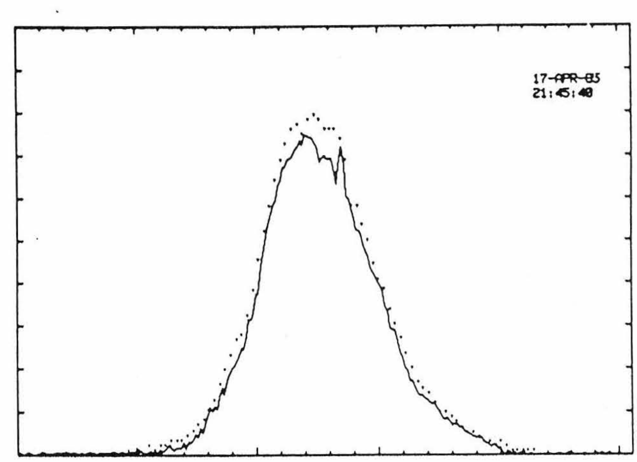

Fig. 5: Same profile measured with metallic finger (solid line) and with the residual gas profile monitor (dots).

A microprocessor based Camac module will control the high voltage for the photomultiplier, drive the stepping motor, read the photocurrent and store the profile in a dual-port memory that can be accessed by the control computer through the Camac bus. In the 60keV beam line, the light intensity is 100 times greater that at 870keV. This allows us to use a photodiode array instead of the photomultiplier and the scan mechanism. The scan period is in both cases shorter than 1 second and the resolution about 0.1mm.

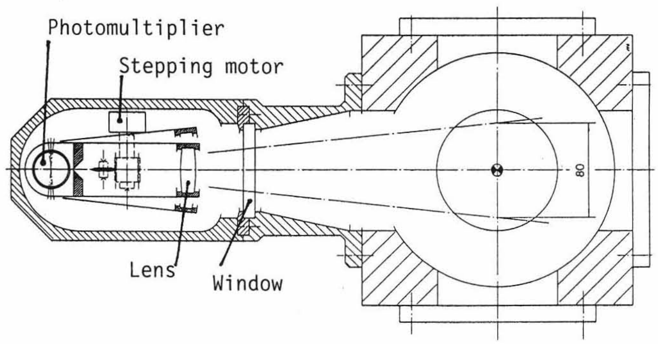

Fig. 6: Residual gas profile monitor.

Beam Probes For The Cyclotrons

In the cyclotrons, we have radial probes of different kinds. Fig. 7 shows, i.e., the long probe of Injector 2. It has a beam stopper and 3 thin wires, one vertical and 2 inclined at 45 degrees. With these fingers, it is possible to determine not only the horizontal but also the vertical position and width of the beam (Fig. 8).

A computer program can easily give a tomographic reconstruction of the beam shape, [7]. The probe is driven by a stepping motor powered by a Camac stepping-motor controller. The current of the fingers and stopper are read by LLCAM modules. The travelling speed is about 5 to 10cm/s and the resolution is 0.1mm. Some other probes have only thin wires so that they can be used at higher currents, up to some hundred μA. For fast scanning of a few turns in the injection and extraction region of the cyclotrons, we use also standard profilmonitors with thin finger.

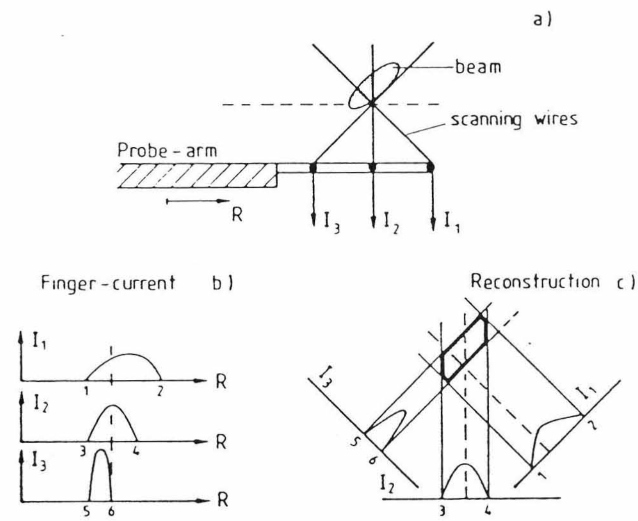

Fig. 8: Reconstruction of the horizontal and vertical beam shape (c) from the 3 wire-currents (b).

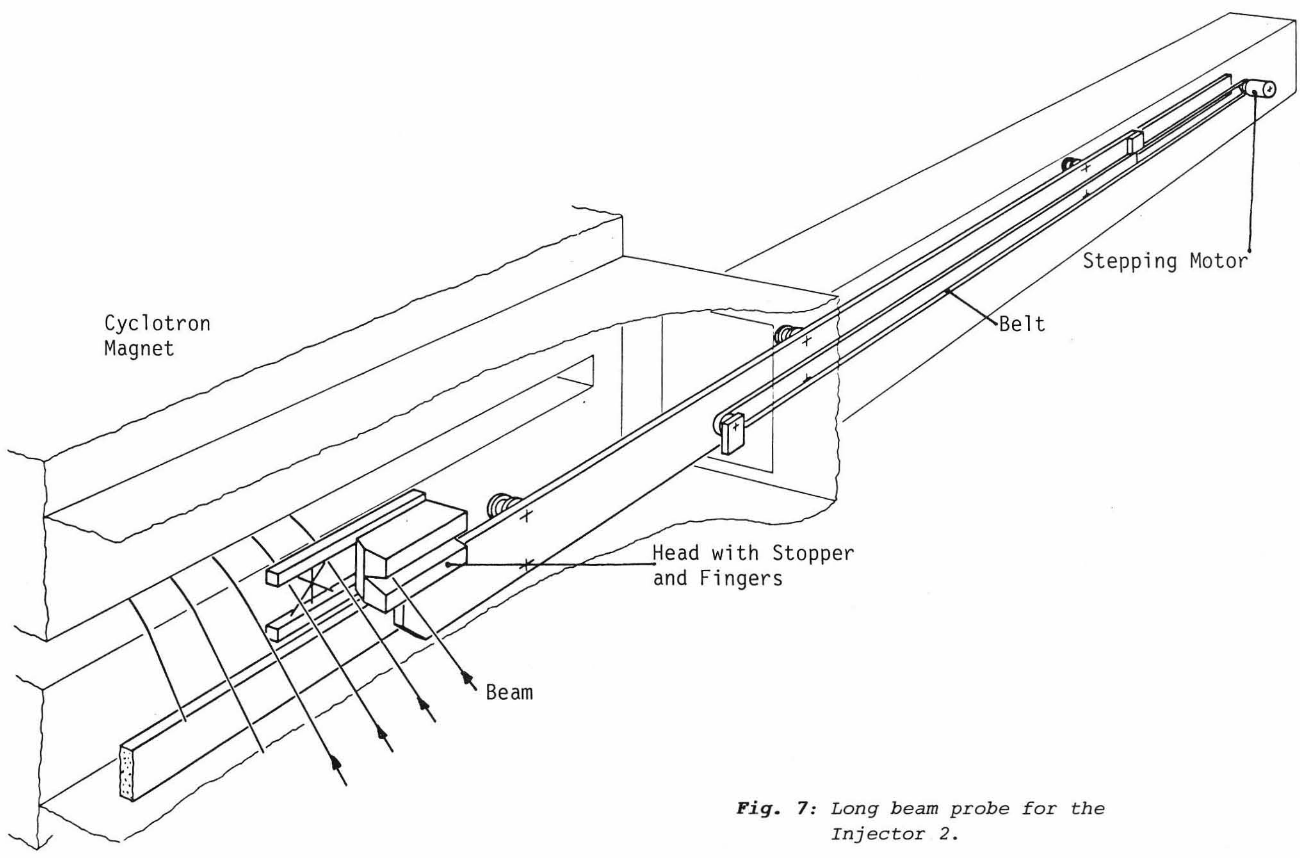

Fig. 7: Long beam probe for the Injector 2.

Beam Position Monitor

The 72MeV and 590MeV beam lines are equipped with non intercepting beam position monitors. They are mounted in the same box as the profile monitors. Each monitor consists of two stainless-steel coils (1 turn) besides the beam and tuned to the second harmonic (100MHz) of the beam frequency (Fig. 9). The output of the two coils is amplified alternatively (1kHz switching frequency) by a logarithmic amplifier. The difference of the two output signals is proportional to the displacement of the beam centre of gravity from the optical axis. They work down to a few μA with a precision of 0.1mm.

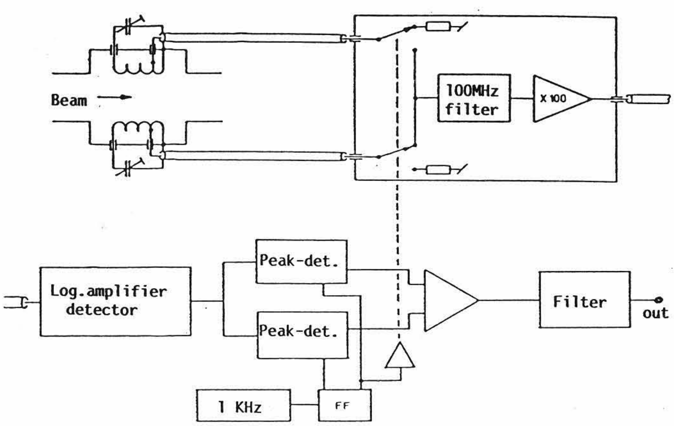

Fig. 9: Electronic for a non intercepting position monitor.

Phase-Probes

Phase-probes are used either in the cyclotrons to isochronize the field and in the transport lines to sinchronize the cyclotrons. In the cyclotrons, we mount 8 to 10 probes each consisting of two pick-up plates (60·30mm) connected together by a power divider. This adds the beam signal and subtracts the unwanted signal induced by the RF-field spilled by the accelerating cavities. The probes mounted in the beam lines are helixoidal (2-3 turns) to increase the sensitivity. The second harmonic (100MHz) of the probe signal is compared by a phase comparator with a reference signal that is shifted until the output of the phase comparator is reduced to zero. The beam phase is than obtained from a second phase-detector that measures the phase between the reference and the shifted reference. The phase measuring range is 60 degrees of the accelerating RF (50MHz) and the error is less then 0.5 degrees for a dynamic range from a few μA (limited by the unwanted pick-up of the accelerating voltage) to 2mA.

Beam Losses

The beam losses in the 870keV beam line are measured with collimators mounted at strategic points i.e. in front of quads or inside the vacuum chambers of bending magnets. They are directly water cooled and many can absorb beam power up to 1kW. The current of the stopped protons is measured the LLCAM current acquisition module. A zener diode of 15V, inserted in series between collimator and the LLCAM, suppresses nearly all the current due to emitted secondary electrons. At higher energy, we also use air-filled ionisation chambers mounted outside the vacuum chambers. The bias voltage is 500V. The chamber current is read by a logarithmic current-to-voltage converter and directly displayed in the control room. They are also connected to the interlock system to shut down the beam if losses are to high.

Applications

All the diagnostic elements are controllable and readable by the control computer. Many application programs have been written to facilitate the beam set-up and to stabilize the beam during operation. The most important tasks are:

- centering and matching the beam in the cyclotrons [6]
- beam tomography and isochronizing in the cyclotrons [7]
- beam tomography in the beam lines using at least 3 profile monitors [8]
- measuring and fitting the beam envelope for the transport lines [9]
- centering and stabilizing the beam in the transport lines and on the target [10]
- display the beam losses and calculate the factor of merit (bonus) of the accelerator [11].

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