The Beam Diagnostics System of the ALPI Post-Accelerator

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Abstract

The diagnostics system of the ALPI superconducting post-accelerator is here described. The main components of the system are a couple of grids for the horizontal and vertical beam profile, a Faraday cup for the current read out and a time and energy detectors for the longitudinal phase space measurement. Front-end electronics is also described together with the real-time system employed for the acquisition of the generated signals.

1 INTRODUCTION

ALPI, a superconducting post-accelerator, which will boost the specific energy of heavy ions coming from the XTU tandem from the 1 MeV/u range to about 30 MeV/u for light ions and to about 5 MeV/u for the heaviest ions like gold, is now in its final assembling phase at the Laboratori Nazionali di Legnaro [1].

A diagnostics box is foreseen after every module, i.e. at every second cryostat (Figure 1) in a double waist (horizontal and vertical) of the beam envelope, to provide an easier beam handling in ALPI,[2].

The diagnostics system provides informations on the beam transverse profile, the beam current, the average time length of the particle bunches and their average energy distribution. From these measurements a partial reconstruction of the six dimensional phase space of the representative points of the particle ensemble is possible.

This would allow to follow the modifications of the transverse and longitudinal emittances and eventually to reduce the beam losses.

All the diagnostics detectors are mounted inside a stainless steel box, with longitudinal dimension of 200 mm.

2 DIAGNOSTICS DEVICES

2.1 Transverse Phase Space

The transverse profile of the beam is measured with a Beam Profile Monitor (BPM) where advantage is taken of the electrons produced by means of the secondary emission process caused by impinging ions of the beam onto a grid of thin wires. The device is non-destructive to the beam, i.e. the beam transmission is greater than 90%.

The two grids used to define separately the horizontal and the vertical profile of the beam, consist of two planes of 39 gold plated tungsten-rhenium wires each (20 μm in diameter) with a wire separation fixed at 250 μm. The mechanical frame of the grid is made of PTFE-glass with a deposition of conductive material (gold) upon both faces where the wires are soldered with a pitch of 500 μm staggered by 250 μm.

Looking in the beam direction, the two grids are followed by two metal planes used to drain electrons stripped from the reading wires: during operation their potential is held at + 100 V so that the resulting electric fields between the grids and the planes ease the collecting action.

The assembly (grids and field planes) is tied to two stainless steel planes which can move independently, by fine screws, in horizontal and vertical direction to give the right alignment of the grids with respect to the box axis.

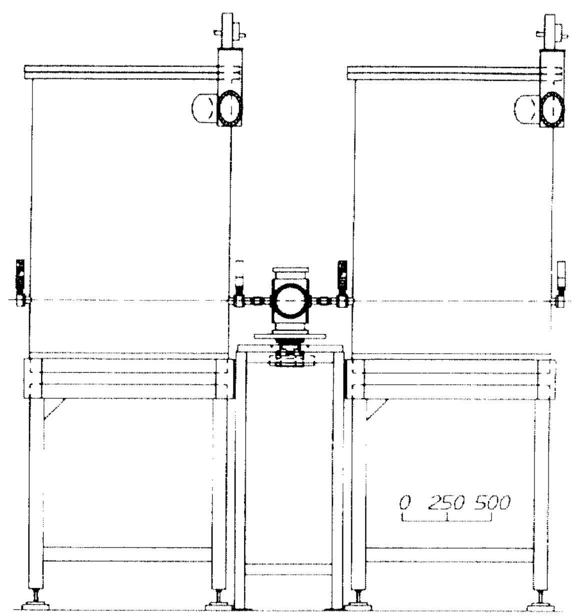

Figure 1: Side view of the Diagnostics box on the ALPI beam line between two cryostats.

2.2 Longitudinal Phase Space

The average time structure and the average energy spread of the bunches are measured with a silicon detector which detects the particles of the beam elastically scattered (20° out of the beam axis) by a gold foil (20÷300 μg/cm^2).

An alternative device to monitor the time structure of the particle bunches consists of a single wire, kept at negative electric potential (-500 V) in a cylindrical geometry, where the hollow cylinder (ϕ= 4 cm) which acts as the anode is held at ground; the fast electrons emitted from the wire by the impinging ions of the beam are multiplied by a Micro Channel Plate (MCP) located behind a narrow slit in the cylinder, 90° out of the beam line. The bias voltage of the MCP is fixed around 2 kV.

2.3 *Beam Current Monitor*

The read-out of the beam current is taken from a Faraday cup, made of a copper cylinder (gold plated) whose length is 43 mm, with an inner and outer diameter of 20 mm and 32 mm respectively. The cup is entirely covered by a stainless steel electron suppressor held at negative potential (- 400 Volt); the distance between the cup and the suppressor is 3 mm and the suppressor itself is tied to the cup with insulating screws. The cup can be cooled by means of compressed air circulating in the empty walls. Inside the copper cylinder, at the bottom, a tantalum cone is housed to prevent activation. The assembly is connected to its mechanical movement with ceramic break to insulate it from ground.

3 FRONT-END ELECTRONICS

The beam profile is obtained from the read out of the current delivered from each wire. The front-end electronics transforms these current signals in voltage signals measured serially from each wire.

For a wire plane the front-end electronics is made by:

1. an analog board, with 39 current to voltage conversion channels with a multiplexer system and an output buffer.

2. a logic board which gives substantially the multiplexer scanning, besides the reshape of the clock and the gain change signals.

As the bias currents normally required to excite electronic devices could play a major role in determining the sensitivity of the BPM detector, the current to voltage conversion of the signal of each wire is accomplished through the use of a very low bias current operational amplifier (25 pA) [3]; the gain of the operational amplifier can be changed with two analog switches, controlled by TTL signals. In this way the read out sensitivity can be 1 mV/pA or 0.1 mV/pA and, for each wire, the saturation level can be reached at 10 nA or 100 nA respectively.

Measurements undertaken during beam time show that the grid signals are still distinguishable from the noise when the average beam current is about 1 nA; this can be considered as the lower limit of the detector sensitivity.

The output voltage signals from the 39 preamplifiers must be sampled in turn by a remote VME ADC board; the selection is accomplished through the use of five analog multiplexers with 8 analog inputs each, while buffering of the selected output is obtained with a driving stage. The scanning of the multiplexers is given by a clock signal, coming from a VME clock board, and it is made by clusters of 40 TTL 200 μs period pulses each one, kept 1.6 ms apart.

On the logic board the clock signal and the logic TTL levels for the selection of the conversion gain pass also through a digital buffer which is suited to drive 50 Ω loads: this solution allows an easy daisy-chaining of these signals through subsequent boxes. The current absorbed by both boards is below 300 mA without signal at the input of the preamplifiers.

The front-end electronics for the Faraday cup remains basically unchanged with respect to the grid front-end; minor improvements involve four selectable ranges of the conversion gain and a larger measurable range of the beam current (1 nA to 10 μA).

4 ACQUISITION SYSTEM

4.1 *Grid and Faraday cup Signals*

In the diagnostics of many existing accelerating machines, the currents from the grid wires are pre-amplified and then transferred, as analog signals, to a remote acquisition station where they get converted to numerical values. In the ALPI diagnostics system, instead, the grid currents get digitized locally, through a VME ADC board driven by a Motorola MVME-147 CPU board based on a 25 MHz MC68030 and then transferred through an Ethernet network to a console room where a graphical machine (Sun Sparc Station) reshapes the beam profiles on the vertical and horizontal planes. Many independent, time-critical and virtually parallel tasks must be charged to the VME CPU in order to perform conversion and collection of data, to provide synchronization signals to the logics which interfaces the preamplifiers and the ADC's, to send data through the network and to act as a remote server for the control of the stepping motors in the injection/extraction movements.

For these reasons VxWorks, a high performance real-time operating system, has been adopted as a convenient environment to develop the software; defined priorities have been assigned to the time-critical tasks so that constraints are respected : as a result the stepping motor controlling task executes at the lowest priority, while the one generating the forty TTL pulses executes at the highest one.

In order to increase the number of services per CPU it was a design choice to avoid busy-waiting schemes when interfacing the hardware : while this was possible for the low priority tasks, it could not be achieved for the task driving the multiplexers because the average interrupt task response exibited by the kernel was substantially greater than the square pulse period required (200 μs) as shown in Table 1 [4].

On the graphical workstation two sets of horizontal and vertical planes are displayed at one time : the transmission rate through the network has been tuned so that a refresh of about fifteen frames per second is achieved, thus resulting in a live display effect.

Test Description	min/max/avg
Create/Delete Task	1378/1446/1423
Ping Suspend/Resume Task	174/182/177
Suspend/Resume Task	68/74/69
Ping Semaphore	228/234/232
Get/Release Semaphore	33/34/33
Queue Fill	19/21/20
Queue Drain	21/25/22
Queue Fill Urgent	70/76/72
Single Queue Fill/Drain	43/48/44
Alternate Queues Fill/Drain	366/376/371
Allocate Memory	67/71/68
Deallocate Memory	82/86/83
Interrupt Service Response	6/56/6
Interrupt Task Response	119/319/125

Table 1: Throughput Measurements of the VxWorks Services in μs.

4.2 *Time and Energy Signals*

The electronic acquisition chain for the longitudinal phase space measurements (both for silicon and for the MCP detectors) is of classical type, i. e. a pre-amplifier, which gives the energy and time signal, a shaper amplifier for the energy signals and a fast amplifier followed by a discriminator, producing a logic signal for the timing.

A further logic signal is originated from the 160 MHz master oscillator of the rf cavities of the post-accelerator by means of a frequency divider. The logic signals are used as start and stop of a time to amplitude converter (TAC). The analog signals produced by the TAC and the shaper amplifier are then stored and analyzed by the acquisition system (ADCs). The standard deviations of the time and energy distributions (in coincidence) are used to calculate the rms value of the longitudinal emittance.

5 LOCATION AND FURTHER DEVELOPMENTS

Special boxes, of double longitudinal length (400 mm), are placed in the object and image points of the two 90° analysing magnets of the injection line while one of them it is just at the entrance of the post-accelerator. The box in the object point of the first analysing magnet houses a Beam Profile Monitor (grids), the horizontal and vertical current slits, and the stripper foil frames; in the image point, the box houses the BPM, the current slits and a Faraday cup. Apart from the stripper foil frames, the same assembly is repeated at the second analysing magnet of the injection line.

The beam diagnostics at the entrance of the post-accelerator is of paramount importance for a good beam transport along the structure mainly for the matching of the longitudinal emittance. At this location the double box is equipped with the MCP-based device which allows a monitor of the bunch length determined by the bunching system of the injection line [5]. A further stripper foil mechanism is also located at the entrance box. The energy spread of the incoming beam will be measured downstream with the silicon detector at the second diagnostics box after the first module. Special grids with a wider active area will be located in the internal U-bend where advantage will be taken of the L-bend used in dispersive mode to proceed to the phasing of the superconducting cavities.

Finally, two devices for the emittance measurements will be installed in the injection and the extraction line of the post-accelerator.

The system described above, although integrated in the control system of the ALPI post-accelerator [6], has been confined to a separate network (Ethernet bus) connected with a bridge to the general network. The choice has been dictated because of the very high data flux due to the live refresh of the beam profile display and to the live function of the multichannel analyzer which will be developed for the on-line acquisition of the time and energy spectra.

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