Commissioning and Developments of the ALPI Diagnostics System

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Abstract

The medium-β section of the ALPI superconducting post-accelerator is now under commissioning and the most part of the diagnostics system has been installed and widely tested in the last six months. In addition to the Beam Profile Monitors based on the Secondary Emission Effect a device using the ionization of the residual gas has been devoloped and tested on the beam line. The device results to be extremely useful at the Tandem exit where the high beam current reduces the life of the grids. The average bunch length is now measured at different locations, in addition to the Silicon Surface Barrier Detectors, also with Micro Channels Plate electron multipliers and a Coaxial Fast Faraday Cup.

1 INTRODUCTION

The beam diagnostics system of the ALPI superconducting post-accelerator [1, 2], as described elsewhere [3], has been completely installed in the accelerator and tested during the first six months of this year (1994). The transverse plane is controlled by means of Beam Profile Monitors based on Secondary Emission Effect (SEM-BPM; grids of 39 wires with 20 μm in diameter separated by 250 μm). The grids are located at every transverse beam waist both in the injection/extraction line and in the post-accelerator.

The beam current is measured by means of Faraday Cups and a room temperature resonator.

The energy and time structure of the beam are measured with Silicon Surface Barrier Detectors (SSBD) located at the begining of each sub-section of the post-accelerator. At the same locations, because of the fast degradation of the SSBD with high energy heavy ions, the time structure of the bunches is controlled also with Micro Cannel Plate electron multipliers (MCP-em) which detects the electrons produced by the beam on a wire (20 μm) on the beam path.

To overcome the complexity introduced by the standard electronic chains and to have a direct measurement of the average bunch length a Fast Faraday Cup has been also developed and tested.

2 TRANSVERSE AND LONGITUDINAL PHASE SPACE

To see the horizontal and vertical profiles of the beam, 26 grid-systems (SEM-BPM) were installed along the machine and they revealed themselves to be very important in the beam transport because of the high sensitivity to very low beam current (less than 1 e-nA), but they revealed also to be quite delicate when the beam current is high; some wires turned out to be broken with the beam current in excess of 100 e-nA. In particular at the exit of the tandem, before the 90° magnet where the beam current is in the range of e-μA it is mandatory to substitute the grids with a more reliable BPM; a BPM based on the detection of ions of the residual gas will be installed in the next future (see section 4).

The horizontal BPMs in the middle of the internal U-bend, and after the last L-bend in the extraction line are used also to choose the working phase of the accelerating cavities.

To measure the beam current seven home made Faraday Cups were installed after each bending magnets and in the long straight sections of the machine, where more probable are the beam current losses. Two further commercial Faraday Cups has been used to check the reliability of the home made detectors. If the current to voltage converter (CVC) [3] is near the own Faraday Cup, the measurement is sensitive to the distance between the Faraday Cup and the ADC. Therefore, all the front-end the electronics of the Faraday Cups has been grouped near the ADC and the voltage signal from the CVC is sent to the ADC with cables of the same length. With this precaution a 100% transmission in the injection line, until the second bending magnet, has been reached, and 60% (with the continuous beam) at the end of the Linac.

Finally, the beam current, just after the first 90° magnet, is also measured with a non-destructive method based on the signal produced by the bunches on a room temperature resonant cavity [5].

For the longitudinal phase space, four silicon detectors (SSBD) were installed on the machine, the first at the entrance of the Linac to control the average time length of the bunch, 20 metres after the superconducting buncher, the second one after the first three cryostats of the medium-β section, sometimes also used to set-up the working phase of the superconducting cavities; a third detector is located after the internal U-bend to control the action of the rebuncher on the bunch length; the last detector has been located at the end of the high-β section to control the final beam energy and time structure.

The time measurement is made by a start-stop technique where the stop signal is obtained from a 5 MHz rf reference signal and the start signal is generated by the SSBD (or the MCP-em) via a standard NIM electronic chain; bunch lengths of about 300 ps (FWHM) has been obtained both with the superconducting buncher and rebuncher.

3 THE FAST FARADAY CUP

To measure directly the time distribution of the pulsed beam current a Coaxial Fast Faraday Cup (CFFC) was carried out and placed at the end of the low energy section in the ALPI post-accelerator.

3.1 Mechanical Design and Construction

Fig.1 shows the mechanical design of the CFFC. The coaxial geometry has been suggested by th N-type connector on which the detectors has been developed. The modified N-type connector has been mounted on a KF40 flange and it is fixed in the rear side of a diagnostics box on the low energy branch of the post-accelerator. The central electrode of the CFFC is copper gold plated to minimize the neutron activation and it is shaped to obtain, with the external grounded stainless steel connector, the 50 Ω characteristic impedance. The diameter of the central conductor of the CFFC is 5.4 mm at the impinging surface; the conductor is then tapered down to 3 mm, the standard diameter of N-male connector pin. In front of the central electrode 0.3 mm distant a grounded copper grid shields the cup from the induced signal of the longitudinal electrical field preceding the bunch [4].

A gold-plated copper collimator is placed 7 mm apart in front of the grid, separated from it by an insulating material and it is used as an electron suppressor with a negative voltage (-300 volt).

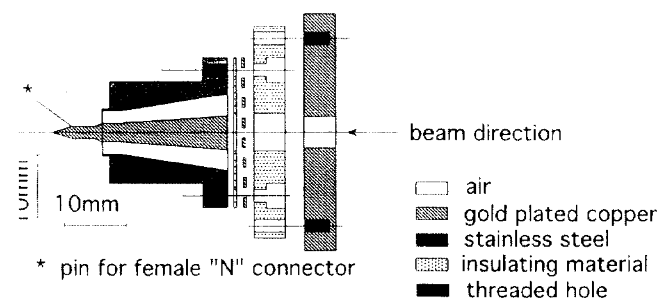

Figure 1: Coaxial Fast Faraday Cup, schematic drawing

3.2 Electrical Design

The goal of the CFFC is to measure average time bunch lenghts down to 100 ps, the phase acceptance of the 160 MHz cavities of the Linac, so we identified in its inverse, 10 GHz, the most high frequency to detect. The theory of the coaxial line with two conductors in circular geometry fixes the maximum sum of the inner and outer conductor diameter for the signal propagation in only TEM mode [6], the outer to inner diameter ratio for a fixed characteristics impedance for straight line conductor and the relation between the half-angles of the inner and outer cones for the tapered coaxial line [7].

The condition about the sum of the diameters fixes the acceptance of the CFFC; its shape was determined only by the ratio of the inner to outer conductor diameter and not by the angle of tapering. The analytical extimation gives 49.4 Ω of characteristic impedance in the tapered section of the CFFC. The signals from the CFFC are sent through the N connector into a broadband amplifier and then into a sampling oscilloscope placed near it with 20 GHz bandwidth (HP mod. 54120B).

3.3 Time Domain Reflectometry and Beam Test

The HP oscilloscope allows also to characterize the CFFC by a Time Domain Reflectometry (TDR) technique. The CFFC was tested by putting a step function pulse with the rise time below 60 ps and 200 mV amplitude into the modified N-type connector and looking for reflections along the coaxial line; the reflections are in the order of 10 mV, so the mismatching between the 50 Ω characteristic impedance of the cable and the Faraday Cup is about 5%.

Preliminary tests of the CFFC were done with a ^{58}Ni pulsed beam at 120 MeV; 600 ps of average bunch time length has been measured which was not in agreement with the start/stop technique (about 300 ps). The disagreement has been investigated and finally explained by the scarce bandwidth of the N-type commercial feedthrough which gave 200 ps of rise time of the step function signal in a TDR measurement. No further beam tests with a new feedthrough has been carried out because of lack of machine development shifts. The minimum current that the CFFC can still detect was estimated in 5 e-nA.

4 THE RESIDUAL GAS BEAM PROFILE MONITOR

A non-interceptive detector has been developed to measure the transverse profile of the heavy ion beam produced by the Linac. The device (100 mm in the direction transverse to the beam, 90 mm in the longitudinal one) detects the ions produced by the incoming beam on the residual gas of the "vacuum" pipe; the ions are accelerated in a homogeneous electric field (about 2 kV on 30 mm) and on the cathode they produce an electron avalanche in a Micro Channel Plate electron multiplier (MCP-em). The collecting anode of the MCP has been obtained by the assembling of 40 layers of copper (200 μm of thickness) separated by 40 μm of polipropilene insulating foils and cut in a polygonal shape with eight sides, one of which has been faced to the MCP. This solution revealed to be a very low cost one and also seems to be promising to reach higher resolution on the profile. The current from each strip is amplified by separated preamplifiers.

4.1 Tests with the Beam

The residual gas beam profile monitor (RG-BPM) was tested in a diagnostics box placed just before the analyzing magnet of the XTU tandem; a first beam test was done with ^{11}B and the terminal voltage set at V_t = 12.2 MV.

In the same box a standard BPM (grids) as been used as a reference. The ions collecting voltage is 3.5 kV and 1.9 kV is the voltage polarization of the MCP-em's in chevron configuration. The two profiles showed a misalignement of about 3 mm between the two devices and also a slight difference in the profile probably due to some non-linearity in the multiplication process of the MCP-em or a small difference between the pitches of the grid and the MCP-em anode.

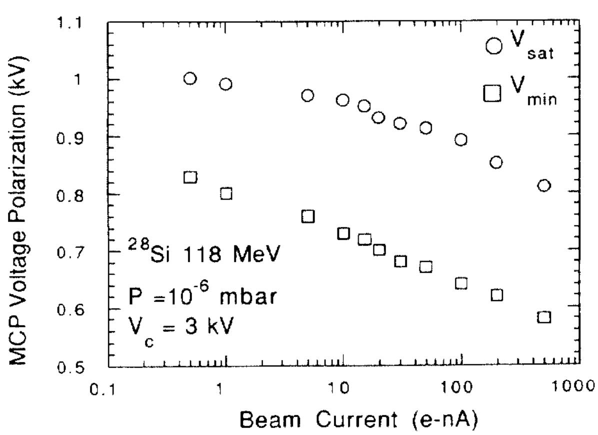

Figure 2: Dynamic range of the RG-BPM

In a test with ^{52}Cr and the terminal voltage at 14.2 MV, the beam current, measured after the analysis on charge state +9, was changed from 30 to 20 e-nA without any difference in the beam profile reproduced by RG-BPM; this seems to suggest that with this order of currents the electric field generated by the beam itself does not play any role in the collection of the ions before the avalanche moltiplication [8].

The sensitivity of the device revelead to be high, e.g. working at 10^{-6} mbar the signal from the anodes of the MCP-em, with a conversion gain of 1 mV/pA, is still 400 mV with 0.05 p-nA.

The correlation with the pressure of the residual gas has been also tested and it revealed to be not critical above 10^{-6} mbar; changing the pressure by one order of magnitude from 10^{-6} to 10^{-5} mbar gives an enhancement of the output signal from 1.1 V to 1.5 V.

To investigate further the dynamic range of the MCP-em a dedicated run with a beam of ^{28}Si and the terminal voltage of the XTU tandem at 11.8 MV has been executed with a fixed voltage (V_c=3 kV) on the cathode of the collecting region. During the run the total pressure of the residual gas has been maintained at 10^{-6} mbar. The beam current was measured on a faraday cup after the selection slits of the analyzing magnet on the charge state Q=+9. The dynamic range of the chevron assembly of the two MCP-em is shown in Fig.2 as a function of the beam current.

The upper curve corresponds to the saturation of more than half of the channel signals after the normal conversion gain of 1mV/pA where the profile of the beam is completely smeared out; the lower curve corresponds to the first born of the signals from the noise level where again the profile is not yet recognizable. The working points of the MCP-em for a defined beam current is approximately centered between the two sets of points.

5 CONCLUSIONS

During the first six months of the ALPI commissioning the beam diagnostics revealed to be quite reliable after some improvements on the acquisition chain of the Faraday Cup readings and on the stepping motor controls. The development of the CFFC and of the RG-BPM will allow a more direct measurement of the average bunch length and a reliable beam profile display also in high current sections. In the next future it will be mandatory to improve the reliability (against saturation effects on BPM preamplifiers) expecially for the BPM's used for the phase set-up of the accelerating cavities.

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