WIDE RANGE EXTRACTED BEAM INTENSITY MEASUREMENT AT THE IHEP

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Abstract

To measure the beam intensity in the range $10^8 – 3\bullet10^{13}$ ppp for slow and nonresonant slow extraction at the IHEP, we have developed a new technique, based on a second emission chamber as a monitor followed by a Current-to- Frequency Converter (CFC). The monitor comprises 5 signal electrodes sandwiched by collectorones.Each electrode is made of a Kapton film, on both sides of which aluminum is sputtered. This causes low amount of substance to be placed in the beam path (about 10 mg/cm^2 per monitor). To process the monitor signal varying over such wide range, the CFC with the conversion ratio of 1 Hz/pA is used. This paper describes the monitor, the electronics, and the calibration procedure.

1 INTRODUCTION

At present, the 70 GeV proton beam for the external targets of all experimental setups of the IHEP accelerator complex U-70 is extracted from the ring vacuum chamber through the single exit window at the Straight Section SS30. Slow and nonresonant slow extractions as well as single-turn fast ejection are used. The extracted beam intensity is varied in the range 10^8 - $1.5\bullet10^{13}$ ppp, burst duration of slow extractions is about up to 1,7 s. Around the world the intensity of such beams is measured with Second Emission Chambers (SEC) because of their unique DC response, high linearity and sensitivity. To decrease enough the signal component created by ionization of the residual gas, the SEC should be located in a good vacuum (at most 10^{-5} Torr). The vacuum in our beam transport line is rough (of the order of 10^{-2} Torr); thus, it is necessary to use a special vacuum box with two windows and a separate ion pump.

An alternative approach is placing the SEC inside of the accelerator vacuum chamber in front of the exit window, where there is a substantial distance between the equilibrium orbit and the trajectory of the extracted beam. The advantages are as follows:

- SEC operates in a good vacuum (better than 10 Torr), consequently, a separate vacuum box is unnecessary;
- a single SEC is sufficient for all extracted beams;
- the extraction efficiency can be optimized without accounting some beam losses in the transport line and developed by the exit window matter;
- having been calibrated with reference to the charge transformer when fast extacted beam passes, this SEC can be used as a reference device for the monitors measuring the beam intensity in front of the targets.

The penalty to pay for this decision is the care taken against the magnetic field of the main bending magnet.

2 SEC MECHANICAL CONSTRUCTION

Usually, SEC electrodes are metallic foils, mainly Al or Ti, of 5-20 μm thickness /1/. As distinct from that, we have built electrodes by sputtering in a vacuum Al of thickness 0,3 μm on to both sides of thin (10 μm) Kapton film. This choice allows one to decrease the intercepting mass of the monitor by an order of magnitude without loss of sensitivity. A sketch of the SEC electrodes assembly is shown in Fig.1.

The eleven electrodes alternatively are connected to the positive collector voltage and the processing electronics, so there are 6 collectors and 5 emitters. The films are fixed with epoxy-based adhesive on duralumin rings. The external and internal diameters of the rings are 50 and 44 mm respectively, the thickness is 2 mm. The rings are sandwiched without gap, so inter-electrode distance is actually 2 mm. The Al coating diameter is 40 mm. Electric connection is made in the following manner. On periphere of Al coating of each film a small through hole is done, onto both sides Ni washers of 0.2 mm thickness and 4 mm outer diameter are applied and fixed with flaring capillary tube of length of 2 mm. To this metallic spot polyimide insulated Cu wire is sold and then fed through lateral hole in the duralumin ring. The complete construction has been made in the home workshop.

Because of space shortage, we mounted the SEC in place where vertical component of the edge magnetic field of the main magnet is 0.15 T. To prevent spiralling emitted electrons, the whole electrodes assembly has been enveloped into an armco iron cylinder of thickness 10 mm. In addition, we use enlarged bias (1500 V).

To simplify the device we have chosen it to be stationary. This is not, however, a drawback of the system, as the intercepting mass of the SEC is only 15 mg/cm^2, which is of the same level as the mass (23 mg/cm^2) of the Ti exit window foil spaced at a distance 1.3 m apart. In other words, we may neglect the SEC influence on the beam. Additional negative fact following from the stationarity is a faster aging of the SEC as a result of beam exposure. Taking into account the experience of using Kapton-based beam profile monitors in the IHEP beam transport lines, one may estimate the life resource of such electrodes of order of 10^{19} protons/ cm^2

3 SIGNAL PROCESSING

Upon setting the secondary emission coefficient of each emitting surface to 5% /1/, we can calculate the range of currents developed by the SEC as 10 pA to 3 μA during of the slow extractions, i.e. varying over 5 orders of magnitude. We prefer to integrate such currents with circuitry based on a CFC followed by scaler whose count over the extraction time is proportional to the extracted beam intensity (digital integration). The full range is devided into 2 subranges: from 10 pA to 30 nA and from 3 nA to 3 μA, that roughly corresponds beam intensities subranges 10^8 - 10^{11} and $3\bullet10^{10}$ - $3\bullet10^{13}$ ppp recpectively. Fig.2 is a simplified circuitry of the SEC electronics.

A Front End Electronics is not used; the SEC current goes via 350 m coaxial cable to the processing electronics situated at the Extraction Control Room. After RC stretching (time constant is about 300 ms), used only for the fast extraction, the signal is fed to the CFC that uses the well-proven charge-balancing technique with an external 100 kHz clock. The Op Amp AD795KN is used as an integrator. The conversion ratio is Fc/Is, where Is is the compensating standard current defined by scaling resistors, R1 or R2. For the first subrange Is=100 nA and for the second one 10 μA, so the maximum conversion ratio is 1 Hz/pA.

A commercial Frequency -to - Voltage Converter (FVC) is used for scope monitoring the SEC current shape.

4 RESULTS

A question on accuracy of this system has no single answer because of very wide dynamic range. Ye may, however, estimate error for some subranges. Taking into account the good performance of the CFC, we anticipate the overall accuracy to be determined only by the SEC itself and calibration.

4.1 The SEC error

It is well known that the SEC is influenced by a number of noise sources, such as beam dimension and position, losses created by both circulating and extracted beam, industrial electrical noises, residual gas ionization, etc. Experimental studies have proved that for well set slow extracted beam high-energy knock-on electrons, produced on the inner wall of the accelerator beam pipe by losses, yield output less than 1% over the range from 10^{10} to $5\bullet10^{12}$ protons per burst. For lower extracted intensities, this component can increase to 5% provided the circulating beam intensity is over 10^{12} protons. Besides, in this case the beam setting is difficult because of poor low intensity beam diagnostic tools. As for higher intensities, the error increases to 1.5% because of beam loss increasing when the beam intensity grows.

Electrical noises are caused by dB/dt factor of magnets near the SEC and operating pumps of the vacuum system. The effect of the first factor is eliminated by the proper time gating; the second fact causes units of counts when the SEC maximum sensitivity has been selected.

To estimate the contribution of the residual gas ionization we have applied the results from /2 / to our case, then we have got this component is lower by a factor 10^4 than the useful one.

4.2 Calibration

Considering that the SEC has a linear yield independent on the burst duration in the intensity range of interest, we have carried out its calibration with reference to the Charge Transformer (CT) /3/, placed downstream of chain dipoles and quadrupoles at the head part of the transport line. The absolute laboratory bench calibration of the CT had been made some years ago with the precision 0.1%. The calibration stability is verified with remote control calibration during runs. However, over the beam intensity range 10^{10} ÷ $3\bullet10^{13}$ the CT accuracy is $(1+10^9/Ib)\%$ because of a number of factors occuring during the fast ejection. All readings of the CT and SEC signals were made multiply for well adjusted fast extraction over the intensity range 10^{10} ÷ $3\bullet10^{13}$ ppp during the two last runs. The statistical standard deviation of the ratios of these readings did not exceed 2%.

Thus, we may consider the whole error of the reported system to be 5% for the range 10^8 ÷ 10^{10} and 2% for the intensities up to $5\bullet10^{13}$ ppp.

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