ABSOLUTE PROTON BEAM MONITOR BASED ON AN IONIZATION CHAMBER WITH A TRANSVERSE ELECTRIC FIELD

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1. Introduction

The physical properties of an absolute proton beam monitor operating in real time are investigated. The monitor detector consists of two air-filled ionization chambers (IC) combined into one module with a transverse electric field relative to the beam path. In the chambers, the signal electrodes have different lengths along the beam. High-voltage electrodes are located from the signal electrodes at a distance equal to or proportional to the length of the signal electrode. The ability to vary the length of the electrode allows one to quickly change the measured range of the proton fluxes.

2. Ionization chamber with a transverse electric field

When conducting radiation research at the PNPI synchrocyclotron, absolute monitors are used based on a plane-parallel dual-section ionization chamber (DIC) [1, 2] through which a beam of protons with energies of 50–1 000 MeV passes perpendicular to electrodes made of thin aluminium foils (10–20 μm). In order to expand the measured range towards higher values of proton fluxes, in this paper, we considered an ionization chamber monitor with a transverse electric field relative to the beam direction and, consequently, with no foils in the beam path, but designed in such a way as to preserve the method for determining the quantitative characteristics of the flux and the total number of protons, previously developed for the DIC monitor.

A beam detector with a transverse electric field relative to the beam path [3] consists of two ICs combined into one module with plane-parallel high-voltage and signal electrodes. The chambers differ in the lengths of the signal electrodes and are arranged in series along the beam path. In each IC, the distances between the high-voltage and signal electrodes are different in magnitude, and the lengths of the signal electrodes along the beam direction are equal or proportional to the inter-electrode distances of the corresponding ICs. Equal-rated capacitors are connected to each signal electrode, which are charged by induction currents of external circuits equal to the ion currents of the chambers. The number of protons passing through these chambers is calculated from the voltage measured simultaneously on the capacitors using a developed algorithm [1]. A technical drawing of a dual-chamber ionization detector (DID) is shown in the Figure.

The number of ion pairs n', formed by N beam protons passing in the inter-electrode space IC_1 and IC_2 during the integration time T is

$$n'_{1(2)} = N\left[-\frac{dE}{dx}\right]L_{1(2)}\omega^{-1}, \tag{1}$$

where $[-dE/dx]$ is the specific ionization loss of a proton in air at normal pressure; $L_{1(2)}$ is the total length of the electrode ($L'' + L'$); ω is the energy spent by the proton on the formation of one pair of ions.

If $\left[\frac{L_{1(2)}}{d_{1(2)}}\right] = k$, then

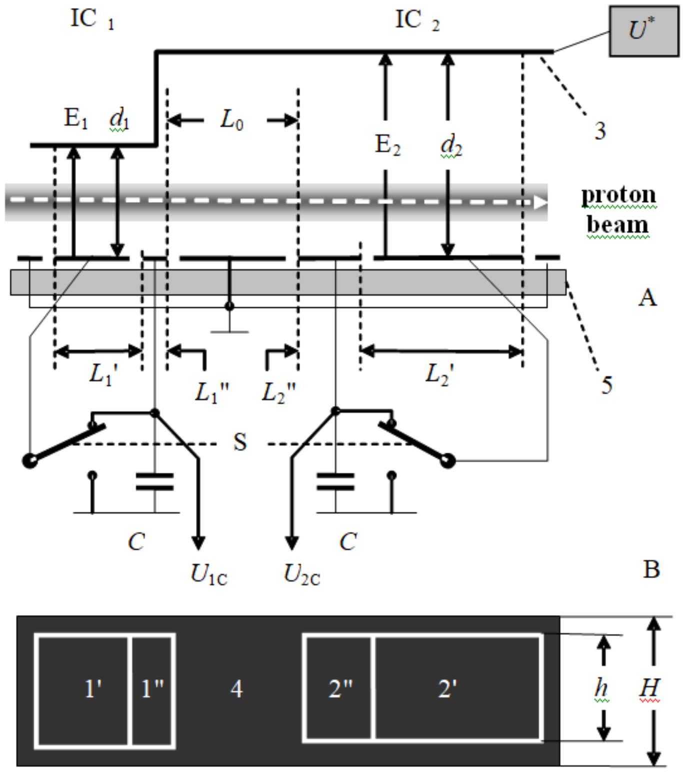
$$n_{1(2)} = N\left[-\frac{dE}{dx}\right]d_{1(2)}k\omega^{-1}\lambda_{1(2)}. \tag{2}$$

The voltage $U_{C1(2)}$ on the capacitor $C_{1(2)}$ in the signal electrode circuit of each IC with inter-electrode distance $d_{1(2)}$ is equal to

$$U_{C1(2)} = \frac{n_{1(2)}e}{C}. \tag{3}$$

The number N of beam protons passing through the chambers can be determined as

$$N = \frac{U_{C1(2)}C}{\left[-\frac{dE}{dx}\right]d_{1(2)}ke\omega^{-1}\lambda_{1(2)}}. \tag{4}$$



Technical drawing of a dual-chamber ionization detector: *A* – frontal projection; *B* – top view of the board with the signal electrodes. IC_1 and IC_2 – the first and second ionization chambers; 1', 1" – signal electrodes of length L_1', L_1'' along the path of the beam in IC_1; 2′, 2″ – signal electrodes of length L_2', L_2'' along the path of the beam in IC_2; *3* – high voltage electrode; *4* – grounded electrode; *5* – printed circuit board with electrodes; d_1 and d_2 are the inter-electrode distances between the signal and high voltage electrodes in IC_1 and IC_2, respectively; E_1 and E_2 are the electric field strength vectors in IC_1 and IC_2; L_0 is the distance between the signal electrodes; U_{1C} and U_{2C} – the measured voltages on capacitors *C*; *S* – the key for switching the proton flux measurement range; *h* – width of the signal electrodes; *H* – width of the panel with signal electrodes

3. Results and conclusion

The operation of a DID with a transverse electric field with respect to the beam path and the principles for calculating the absolute value of the number of particles in a beam were tested at the PNPI synchrocyclotron using a collimated proton beam. It was shown that the experimental values of the proton flux measured using a two-chamber ionization detector and using a two-section ionization chamber at a constant current of a relative monitor located in the main hall of the accelerator coincide within 10%. Note that there are no physical restrictions for measuring large flows. By changing the length of the signal electrodes, as well as changing the capacitance of the capacitors and the integration time, it is possible to measure the proton flux over a wide range during the experiment.

An ionization detector of this design can be used in heavy particle accelerators, where the problems of correct measurements of fluxes are necessary and important, as well as in the cases where beam broadening is unacceptable (for example, in proton therapy, ophthalmology).

References

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3. N.A. Ivanov, O.V. Lobanov, V.V. Pashuk, Two-Chamber Ionization Detector, Message No. 3012, 12 (2017).