HIGH-SENSITIVE IONIZATION DETECTORS OF TRANSVERSE DISTRIBUTION OF ACCELERATED PARTICLES BEAM

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ABSTRACT

Devices for the high-sensitive contactless diagnostics of accelerated particle beam, using residual gas ionization products, were considered. Similar facilities make it possible to measure effectively the beam profile, position of a center of gravity and its displacement, to assess the beam averaged density distribution via its cross-section. The ionization sensor developed at IAE was described. The sensor provides an operative representation of a real cross-section of the accelerated particle beam with information display on a TV screen, as well as a monitoring of the beam impulse and average currents. The sensor beam cross-section sensitivity is about 10^{-8} A, the resolution at visual check - 1 mm, the dimension of a region under control - 40x40 mm. The results of the beam cross-section sensor operation are presented at various accelerators.

1. INTRODUCTION

Practically any operation with the use of an accelerated beam is associated with the necessity of measurements of its sizes and position. Among a variety of sensors of these parameters [1] one can single-out sensors based on detection of electrons or ions arising at ionization by a residual gas beam in a path of accelerated aparticles transportation. The interest in them is caused by their complete transparency for a controlled beam the lack of additional radiation backgrounds and high potentialities.

In the simplest case electrons or ions of residual gas are transferred by a transverse electric field to a collector. To record a distribution of the residual gas ionization particles current density over a profile of the beam under investigation use is made of screen covered by phosphor. An optical image of the current density distribution over its profile is TV reflected on a telemonitor by means of a TV camera. Simile censors are used in synchrotrons operating at relatively high beam currents - 10^{12} - 10^{13} particles in the cycle of acceleration [2,3]. To reduce the effect of the beam space charge a combination of electric and magnetic field is used sometimes.

According to data on ionization losses for particles with energies of 10-100 MeV [4], which are typical of the majority of cyclotron beams, assessments were performed of the number of N electron-ion pairs generated on the 1 cm path at a pressure of 10^{-5} torr by various particles (Fig.1). Using these estimations it is easy to see that at the protons current J = 1 mkA with energy of 30 MeV on the 1 cm path 10^{8} electron-ion pairs are generated for 1 sec. This means that in cyclotrons operating, as a rile, with mean currents of 10^{-5} - 10^{-8} A, an output current of ionization sensors is so low that is direct recording is very difficult. In this connection there appears the problem of increasing the ionization sensors sensitivity.

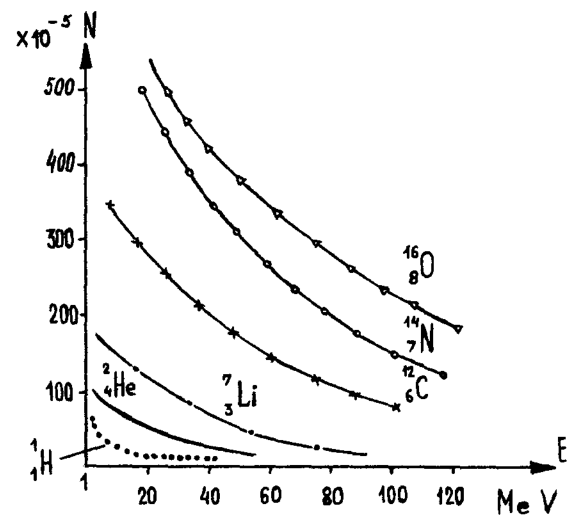

Fig.1. The calculated dependence of ionization power on a beam energy for various particles.

2. IONIZATION PROFILOMETERS WITH OUTPUT CURRENT MULTIPLICATION

An illustration of the possibilities of increasing the ionization sensor output current can be profilometers of DESY III and PETRA II installations whose data were published in the late eighties [5]. The DESY III installation profilometer diagram is presented in Fig.2. Here in the working volume between the anode and cathode a homogeneous electric field was formed. Ionized Residual gas electrons are shifted to the anode, ions - towards the cathode having a secondary emission ratio of 2-3. A glow of the phosphor screen placed in the anode plane can be caused by both ionization and secondary-emission electrons. The beam profile picture is read-out by the TV camera for a further presentation and processing. Various operating conditions of the profilometer were investigated, which are distinguished by voltage distributions between electrodes. Optimum results were obtained while using secondary-emission electrons only the amount of which correspondingly by 2-3 times exceeds the amount of ionization ones. In these conditions a voltage on electrodes amounts to U_{G1} = +1 kV, U_{G2} = -1 kV, U_A = + 18 kV, U_K = - 18 kV.

In the PETRA II installation profilometer one microchannel plate (MCP) of 60x60 mm size is placed in the anode plane, which allowed the sensor output current to be increased by $3\cdot10^3$ times. In conformity with this the results of measurements of the beam profile at the DESY III synchrotron given in the publications, were obtained at proton current of 20 mA, on the PETRA II accumulator - at proton current of 20 mkA. The measurements were carried out under conditions of almost identical vacuum and beam energy - 10^{-8} and $2.5\cdot10^{-8}$ mbar, 5 and 7.5 GeV, respectively.

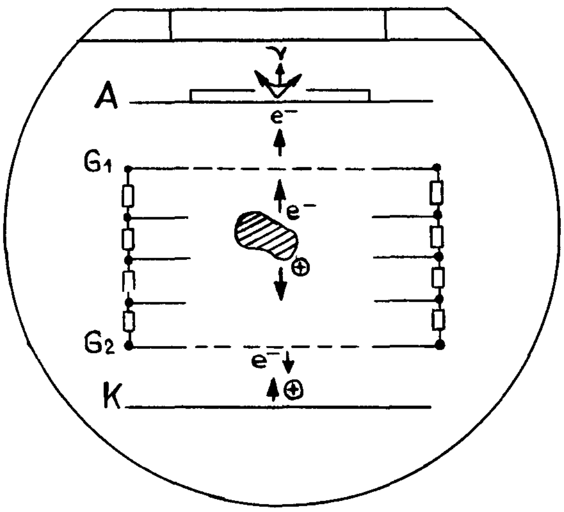

Fig.2. The DESY III installation profilometer diagram.

Thus, the radical way to increase the output current of ionization sensors is the use of position-sensitive electron micro-channel plate multipliers on. To the authors'knowledge, the first suggestion on the use of MCP to increase the output current of ionization sensors of cyclotron parameters beam was made in [6]. To develop this suggestion in [7] was described the ionization profilometer of cyclotron beam with an amplifier on cheron out of two MCP and with a TV watch and presentation of information (Fig.3). The MCP size is 90x70 mm, the sensor aperture is

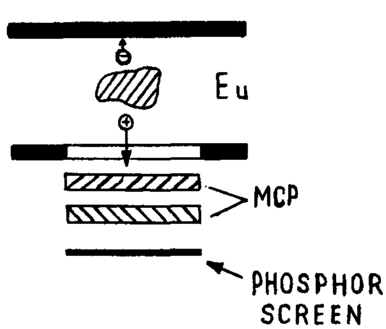

Fig.3. The cyclotron extracted beam profilometer.

restricted only in one coordinate by a gap between the deflector and the MCP and is 70 mm. The ion component of the ionized residual gas is transferred to the MCP by the plane-parallel electric field. An amplified current of secondary-emission electrodes creates on the phosphor a bright picture of the studied beam intensity distribution over a profile. The profile image is displayed by the TV camera on a TV monitor in order to be effectively presented to an operator. At the same time a signal from the TV camera is processed by a microprocessor. Digited information is transmitted to a colored display where the envelope of profile is presented for the given moment as well as (in another color) the shape and position of the envelope of profile during several last measurements. The sensor sensitivity for a beam of protons with energy of 30 MeV at a vacuum of 10^{-5} torr comes up to 10^{-8} A, the spatial resolution - 1 mm.

The works on the cyclotron beam profile diagnostics have been developed creating a high sensitive profilometer for a fast-cyclic heavy-ion synchrotron [8]. The block diagram of this profilometer is analogous to that depicted in Fig.3. Here use was made of two MCP the gap between which is shifted to a closed state and is opened during a measurement of a driving pulse. The pulse duration is regulated from a few microseconds to a time of the acceleration cycle. The pulse is delayed with respect to a beginning of the cycle and synchronized with an accelerating h.f. voltage. Such a regime makes it possible to follow the dynamics of the beam profile in the cycle of acceleration.

The particularity of the profilometer is the application of non-standard operating conditions of the TV camera photodetector based on a matrix charge-coupled device (CCD) array. The CCD matrix lines are oriented perpendicularly to an ion-conductor. A charge previously distributed over all lines of the matrix storage section. Such a regime of matrix increases the instrument sensitivity by more than one order of magnitude in comparison with a usual TV regime. Besides, in the matrix storage section lines information is accumulated on several sequential measurements of the beam profile per one cycle of acceleration, which later on is read-out by processing and representation units it a tempo of these unit operation. This makes it possible to follow the dynamics of the beam evolution in every cycle of acceleration.

On the accelerator model at a vacuum of $5\cdot10^{-8}$ torr an ultimate sensitivity was reached which was limited by the number of input events per time of exposure, which was sufficient for a statistical description of the beam profile. Assuming that to describe the beam profile 10^3 events are sufficient and in terms of the beam of protons with energy of 30 MeV during an exposure time being equal to the TV frame duration of 40 m.sec, 10^8 particles should pass through the profilometer working gap, which corresponds to the beam current of 10^{-10} A. A spatial resolution depends on a deflector voltage and at an extracting field voltage of 1 kV/cm has the value less of 1 mm.

3. THE IONIZATION SENSOR AT ACCELERETED PARTICLES BEAM TRANSVERSE CROSS-SECTION

The units considered above make it possible to detect vertical and horizontal beam profiles but unable to control a real beam distribution over a cross-section. A practice shows, however, tham complicated systems for cyclotron beam with allowance for multicirculation of release can form beams of rather complicated shape which cannot be restored by measuring simultaneously the horizontal and vertical profiles. Besides, the simultaneous measurement of the beam profile via two orthogonal directions is associated with the necessity to place of an additional equipment in the beam transportation path. Therefore, a creation of a beam transverse cross-section sensor having all advantages of ionization profilometers seems to be actual.

One of the first proposals on observation of a two-coordinate beam distribution over cross-section by means of the ionization sensor has been given in [9], sufficiently long ago; however, its practical realization, in any event for cyclotron beams, has become possible only with an appearance of microchannel plates.

In [10,11] the authors have suggested the method and construction of sensor (Fig.4) for an operative observation of the beam transverse cross-section based on spatial and energy analyses of residual gas products ionized by the beam.

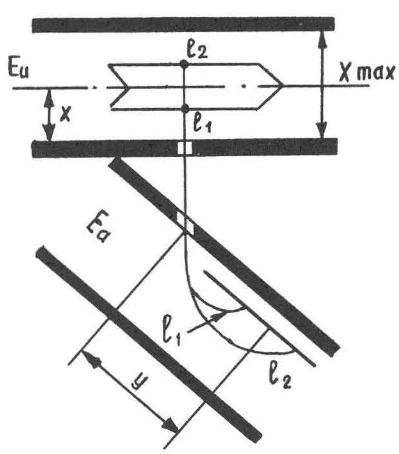

Fig.4. The transverse beam cross-section sensor diagram.

The sensor contains extracting and analyzing condensers, a current collector made as electron-optical convertor (EOC) with a microchannel plate-base amplifier and appropriate power sources. Residua gas ions are accelerated by a plane electric field towards extracting electrode provided with a forming slit of 1x50 mm size directed across the ion-conductor axis. Pathing through the forming slit the accelerated ions form a sheet beam in which a spatial distribution of particles in the direction along the slit corresponds to the distribution of particles in the controlled beam in this direction. Energy distribution of extracted ions corresponds to the distribution of the investigated beam over the other orthogonal coordinate. The analysis of this energy distribution is accomplished by the electric field of the analyzing condenser. As a result, on the current collector screen of EOC is formed the two-coordinate optic image of extracted ions distribution, corresponding to the transverse distribution of particles in the accelerated particles beam under control. The location of the analyzed condenser at an angle of 45 to the direction of extraction and plane of the extracted electrode provides a linear coupling between sizes of the obtained image and controlled beam sizes. the image size Y corresponding to the beam size X in the direction of extraction is linked by the dependence:

$Y = 2 \cdot X \cdot E_u / E_a$, where E_u and E_a are strengths of the extracting and analyzing fields, respectively. Record of the optic image of the beam transverse cross-section is performed by the commercial TC camera.

The standard device to control sizes and displacement of an accelerated beam has presently been developed on the IAE cyclotron. Structural elements of the beam cross-section contactless sensor are placed in the standard diagnostic section with external dimensions of 230x230x230 mm and diameter of flange holes of 166 mm. Admission of supply voltage is accomplished via the flange on which the extracting electrode and analyzing condenser with EOC are fixed. A record of an optical image of the beam cross-section is performed by the TV camera.

From one of lateral sides of the diagnostic box a remote-controllable drive was placed ensuring mounting of the fluorescent screen into the gap of the extracting condenser. This makes it possible to conduct pretuning of the beam using traditional diagnostics means. Photo fig.5 shows the example of the complex form beam cross-section from the EOC screen.

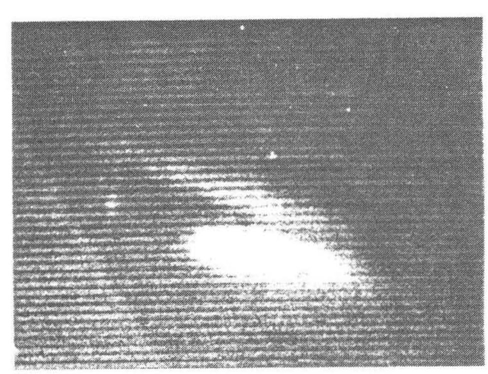

Fig.5. The example of the complex form beam cross-section from EOC screen.

The sensor design makes it possible to monitor the controlled beam intensity. To this end, it is sufficient to measure current on the EOC screen. However, the device sensitivity depends on pressure in the beam transportation path. In [12] to exclude this dependence it was suggested to change transmission factor of the MCP multiplier in accordance with changes in pressure in the beam transportation path.

Additional conveniences for user creates the unit of quasi-colored representation of TV signal. In this case on the monitor screen a colored image of the beam cross-section is formed, and the shape of colored closed bands of each color corresponds to intensity distribution of the investigated beam on the present level of comparison. Processing of cross-section parameters of the beam controlled is provided by means of computer.

The main parameters of the beam cross-section contactless sensor are given in Table

Size of controlled region	40x40 mm
Aperture	60 mm
Spatial distribution at visual check	< 1x1 mm
Sensitivity of 30 MeV proton beam	10^{-8} A
Working pressure range in ion conductor	< 3*10 torr
Feed source voltage	10 kV
Utilized current	100 muA
MCP multiplier amplification factor	10
Time of image formation	100 nsec

4. CONCLUSION

At the present time similar beam cross-section sensors have been tested on cyclotrons and tandems and are successfully operated at I.V.Kurchatov IAE (Moscow), INR (Kiev), INF (Rzez in the environs of Prauge), ZfK (Rossendorf in the environs of Drezden); the same sensor was passed to the University of Jyvaskyld (Finland). A part of these sensors was made in the ISO standard used at European accelerator centers. A sensor design was developed for an investigation of a beam with energy of a few kilovolts. Measures were taken in it on compensating a beam displacement in the transportation path due to the effect of extracting voltage of the sensor deflector. The sensor to control uniformity of the tandem scanning beam was also developed in producing nuclear filters [13]. Thus, it is seen that ionization sensors of accelerated particles beam cross section find more and more increasing use of various accelerators.

REFERENCES

1. V.A.Rezvov, L.I.Yudin. Diagnosis of particle beams in cyclotrons (Review). Instruments and experimental techniques. Vol. 33, No.6, part 1, 1990. Translated from Russian.

2. V.Agoritsas, S.Batisti, K.D.Johnson, G.Shnaider. Methods for measuring accelerated particle beam parameters. Proc. II All-Union Conf. on Charged Particle Accelerators; vol. II, p.82. M., Nauka, 1972.

3. L.Rezzonico. Beam diagnostic at SIN. XI Intern. Conf. on Cycl. and their Appl. pp.457-461, 1987, Jonics Publishing Comp. Tokyo

4. N.N.Pucherov, S.V.Romanovskii, T.D.Chesnokova. Tables of mass retardin ability and pathes of particles with energy of 1-100 MeV. Kiev, Naukovadumka, 1975.

5. W.Hain, F.Horstra, A.Lazos at all. Beam profile monitors for HERA proton acceleration. Proc. EPAC 90, Nice, June 12-16, v.1, p. 759-761, 1990

6. V.A.Rezvov, I.N.Serikov, L.I.Yudin, et al. Possibilities of use of ionization sensors to control a cyclotron beam. Proc. All-Union Conf. on Low and mean energy ion accelerators, p. 68, Kiev, Naukova dumka, 1982.

7. P.Yu.Komissarov, V.G.Mikhailov, V.A.Rezvov et al. Proc. X All-Union Conf. on charged particle accelerators. JINR, D9-87-105, vol. 1, p. 61, Dubna, 1987.

8. V.G.Mikhailov, V.A.Rezvov, A.A.Roshchin et al. The high-sensitive profilometer for a heavy-ion synchrotron. Proc. IX All-Union Conf. on charged particle accelerators, vol.1, p.83, Dubna, 1986.

9. V.V.Elyan. The method for measurement of a transverse density distribution in charged particle beams. - Cert. of Authorship SSSR No. 556697, BOJ No.39, p.230, 1977.

10. V.A.Rezvov, L.I.Yudin. the method for measurement of a transverse distribution of charged particle beam density. Cert. of Authorship SSSR No. 1392645. OI No.16, 1988, p. 32.

11. V.G.Mikhailov, V.A.Rezvov, V.I.Sklyarenko, L.I.Yudin. The ionization sensor of charged particle beam density distribution over a cross section. Cert. of Authorship, SSSR No. 1462521 OI, No.8, 1989, p. 294.

12. P.Yu. Komissarov, V.G.Mikhailov, V.A.Rezvov et al. The contactless control a transverse distribution of accelerated beam particles. Proc. XI All-Union Conf. on charged particle accelerators, vol. I, p. 87, Dubna, 1989.

13. S.T.Latushkin, V.A.Rezvov, L.I.Yudin. The contactless sensor of charged particle accelerated beam parameters. Cert. of Authorship USSR No. 10009219. BOI, 1984, No. 7, P. 211.

14. V.G.Mikhailov, V.A.Rezvov, V.I.Sklyarenko et al. The device for control of beam parameters in the course of irradiation of nuclear filters. X All-Union Conf. on exchange of operation experience and improvement of electrostatic accelerators, November, 1991.