NON-DESTRUCTIVE BEAM CROSS-SECTION DETECTOR AT THE MMFL LEBT

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The maiden outcomes of a television application for monitoring on the MMFL Proton Injector beam parameters are adduced. In the basis of a system it is non-interrupted ionization detector reshaping the beam cross-section image. The system provides rendition of cross-section and storage information, allows controlling the density distribution, its vertical and horizontal profiles and their width as well as position of the beam main point. The capability of temporary parameters diagnostics are beam structure shape and extension is simultaneously afforded.

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1. INTRODUCTION

The Moscow Meson Facility Linac (MMFL) does not suffer from surplus of diagnostics obviously, and of not-destructive ones in particular [1,2]. Therefore, it is very urgent to use the detectors of new types.

Among very important beam diagnostics problems the measurement of beam transverse dimensions and position is the most needed one. The ionization profilometers are offered for a long time and are widely adopted for these purposes [3,4]. This type of detector is distinguished due to its full transparency to the beam to be controlled, absence of an additional background radiation, a weak dependence of its sensitivity on the accelerated particle type and energy, simplicity of information visualization, and its high possibilities. Such devices work very well at different charged particle accelerators [5].

However, detectors of such a kind do not allow one to observe an accurate quantitative density distribution across the beam.

2. IONIZATION DETECTOR OF ACCELERATED BEAM

The method and the design of an ionization detector for the operative observation of the real spatial density distribution over accelerated beam cross-section were proposed in [6]. The structure of the Beam Cross-section Image Detector (BCID) was described in detail in [7], its functioning was described in [8], so let us remind only the working principle.

The BCID register ions created by the beam investigated in residual gas. The transverse homogeneous electric field is used here for extraction and energy analysis of residual gas ions. The extraction electric field draws out ions through the narrow slit into the analyzer. The distribution of these ions along the analyzer's slit corresponds (after the slit) to the beam intensity distribution in the slit direction. The extracted ion energy distribution corresponds to the beam intensity distribution along the other orthogonal coordinate. The analyzer of electric field transforms the energy distribution of ions into the spatial distribution. As a result, a two-dimensional optical image of the distribution of extracted ions in the plane passing through the capacitor exit slit and perpendicularly to its plane is generated on the image converter tube (ICT) screen. ICT is developed on the micro-channel plate (MCP) basis. The analyzing capacitor is set at an angle of 45° to the ion extraction direction and to the extracting electrode plane. This ensures a linear relation between the accelerated beam dimensions and its image. The image dimension X corresponds to the beam dimension X_I in the extraction direction $X_I=2X\bullet Eex/Ea$, where Eex and Ea are the extracting and analyzing fields strength, respectively. The optical image of the accelerated beam cross-section is recorded from the ICT screen by TV camera for monitoring and computer processing.

However, to control the beam geometric parameters using single frame image is not so correct. The averaging of profiles for a number of frames gives better results.

The main BCID parameters:

- working pressure in the beamline is about 10^{-6}Torr,
- total amplification reaches 10^7,
- the threshold sensitivity is less than 10 nA/cm^2,
- observation area diagonal is 60 mm,
- spatial resolution in visual control is of about 1x1mm.

It should be noted that the converter output current at a stable vacuum is proportional to the accelerated beam current.

3. PROCESSING AND INFORMATION PRESENTATION

The computer display provides the visual control of the beam pulse shape, beam profiles and the beam center-of-mass position. The frame resolution is 384*288 points with 64 brightness levels. The full amount of frames that can be saved in the computer is up to 256, in the Targa, GIF, or PCX formats.

The software gives us on-line possibility of:

- discrimination of a background from each frame;
- presentation of the vertical and horizontal beam profiles, consisting of 128 points for every registered image;
- presentation of the averaged vertical and horizontal profiles;
- integration up to 256 frames resulting in the absolute sensitivity growth and signal to noise ratio increase more then an order of magnitude;
- fitting by the least square method a Gauss distribution for every frame to find out the beam position;

PROBLEMS OF ATOMIC SIENCE AND TECHNOLOGY. 2004. № 1.
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- calculation of the beam position distribution dispersion (from Gauss fitting results);
- calculation of an average beam position, it's dispersion and statistical errors (from Gauss fitting results);
- calculation of the beam center-of-mass for each frame as an alternative to the Gauss fitting method;
- comparison of results for different methods of the beam center position processing.

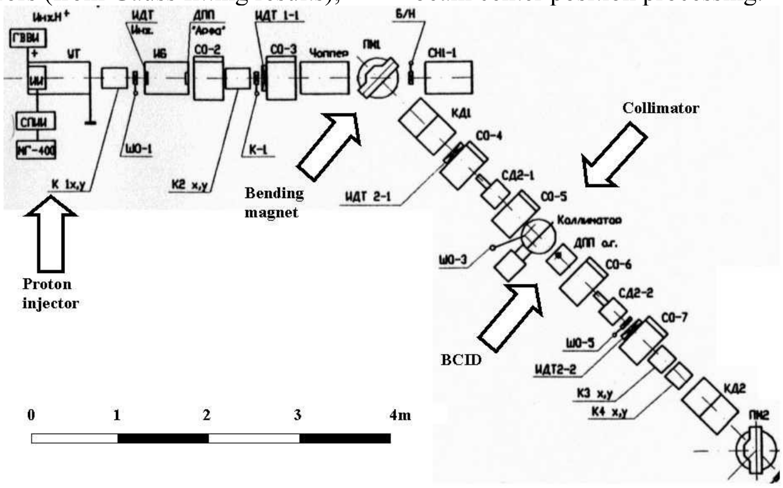

Fig.1. The MMFL beam channel initial part

4. FIRST EXPERIMENTS ON THE MMFL PROTON BEAMS. SENSITIVITY AND RESOLUTION

The first experiments were executed at the input of the Isotope Production Complex. The experimental conditions were as follows: proton energy 100...160 MeV, proton pulse current - up to 14 mA, pulse duration – 150 µs, repetition rate – 1...50 Hz. These measurements confirm the possibility to record the proton beam characteristics with the help of BCID. However, the BCID installation site was chosen incorrectly: BCID was situated next to the accelerating resonator, and as a result, the powerful electron flow from the resonator created strong background luminescence.

The next experiments were carried out on the Proton Injector beam. Fig.1 gives the BCID installation site for this case. The experimental conditions were as follows: proton energy – 400 keV, proton pulse current - up to 125 mA, pulse duration – up to 200 µs, repetition rate – 1...50 Hz. The size of non collimated beam was about of 15...30 mm. Fig.2 represents the cross-section image and profiles of the 115mA proton injector beam. Fig.3. represents the same beam after its passing through a collimator.

The detector sensitivity depends, first of all, on the ionization losses of the accelerated beam *de/dx* (MeV·cm^2/g) in residual gas. The air (under normal conditions) stopping power depending on the kinetic energy of various particles is considered in [9]. The ionized particles current I_c to the collector is related to the accelerated beam current I_b and the width L of the extraction slit in the current collector and determined by the expression: $I_c = K_{col} \cdot L \cdot (p/ep_0) \cdot (dE/dx) \cdot \rho \cdot I_b$- here $K_{col} \approx 1$ is the ionized particle stacking coefficient; p is the working pressure in the beam pipe; p_o is the normal atmospheric pressure; e is the particle energy loss due to electron-ion pair production ($e \approx 30$ eV); ρ=1,3·10^{-3}g/cc is the air density.

For a 400 keV proton beam dE/dx =180 MeV·cm^2/g. At a typical MMFL the pressure is about 10^{-6}Torr and for the injector beam current of 10^{-1}A and a slit width L= 1mm the collector current I_c= 3·10^{-7}A.

The threshold sensitivity of the detector was estimated experimentally. The experiments showed that the signal-to-noise ratio >3 is ensured when ICT phosphor current density is about 10^{-9}A/mm^2. This corresponds to the mean current of ≈10^{-16}A/mm^2 of residual gas ions or 600…700 particles/mm^2·s when MCPs with a gain of ≈10^7 are used. This level is essentially higher than the MCP internal noise level.

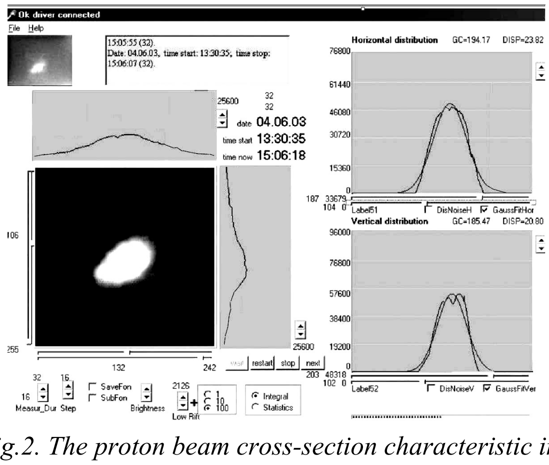

Fig.2. The proton beam cross-section characteristic image and profiles on the program's interactive display

The resolution of the diagnostic system as a whole is determined by the detector design and parameters, the ICT and the TV system resolution, and the parameters of the beam under investigation. As a rule the resolution of the ICT and the TV camera is proves to be better than 30line/mm. The slit width L influences the energy analyzer resolution directly. At a permissible scatter of 5% for the beam dimension D =10mm the permissible value of L is 1 mm.

As is shown in [10], the most of the residual gas ions have energy of about 0.02eV for 0.01…100MeV beams.

PROBLEMS OF ATOMIC SIENCE AND TECHNOLOGY. 2004. № 1.
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The displacement of ions due to their own velocities can be ignored at field strength in the detector E=1...2 kV/cm.

The estimation must be made for 400 keV beam displacement by the detector field. The beam deviation occurs in the middle of the extracting capacitor to be $h_{max}=E\cdot d^2/2\epsilon$. At the MMFL injector beam with the energy ϵ=400 keV and detector parameters d=7,5 cm, E=1,2 kV/cm the beam displacement is $h_{max}\approx$0,1 cm, while the angular deviation reaches 13mrad. Therefore, it is necessary to allow for the compensating field when designing the detector.

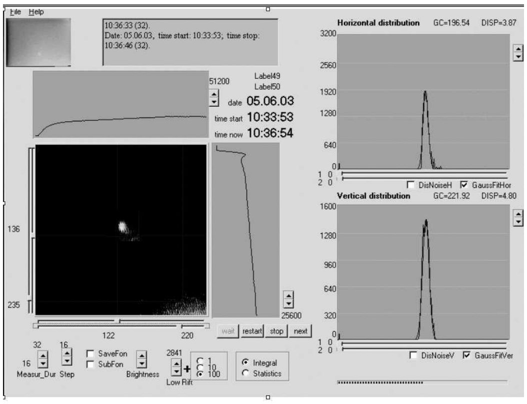

Fig.3. The beam image after ∅1mm collimator

The usefulness of such detectors in beam supervision and control at other sites of the MMF proton accelerator is considered now. The estimates allow us to expect that the ionization detectors will be successfully used for MMFL controlling.

4. CONCLUSION

A low-energy beam ionization detector has been prepared for testing at MMFL LEBT. The experience of work with this device revealed its rich potentialities, sensitivity and sufficiently high reliability. The experiments showed that it is quite possible to carry out visual and quantity on-line monitoring of a powerful proton beam. The non-destructive detector ensures the operative control of the beam dimensions, its density, the beam center-of-mass position and displacement, as well as the beam current value. The computer processing of TV-signals allows to carry out the beam cross-section basic parameters quantitative processing and to create the images library. Information accumulated from different TV-frames gives the possibility to increase the sensitivity of the method more then by an order of magnitude in the wide ranges of energies and intensities. The completed experiments demonstrate the potentiality to measure proton beams with the size of 1mm and less, that permits to fulfill the two-coordinate beam focusing. High statistic precision of the beam center-of-mass position (up to a few microns) was achieved. It is evident that such detectors placed at some distance can measure the beam angular deflection with a high precision. It is obvious also, that they can be used at various accelerator sites and for various kinds of beam application.

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НЕНАРУШАЮЩИЙ ДАТЧИК СЕЧЕНИЯ ПУЧКА НА ИНЖЕКТОРЕ ЛУ ММФ

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Приведены первые результаты применения ТВ контроля параметров пучка протонного инжектора ЛУ ММФ. В основе системы – ненарушающий ионизационный датчик, формирующий изображение сечения пучка. Система обеспечивает визуализацию сечения и архивацию измерений, позволяет контролировать распределение плотности пучка по сечению, его вертикального и горизонтального профилей, их ширины и положения центра тяжести пучка. Одновременно предоставляется возможность диагностики временных параметров – формы и протяжённости структуры пучка.

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Приведено перші результати застосування ТВ контролю параметрів пучка протонного інжектора ЛП ММФ. В основі системи – непорушуючий іонізаційний датчик, що формує зображення перетину пучка. Система забезпечує візуалізацію перетину й архівацію вимірів, дозволяє контролювати розподіл щільності

пучка по перетині, його вертикального і горизонтального профілів, їхньої ширини і положення центра ваги пучка. Одночасно надається можливість діагностики часових параметрів – форми і довжини структури пучка.

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