Preliminary Study for a Residual Gas Beam Profile Monitor

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ABSTRACT

A non-destructive monitoring of the beam density profile is a very important tool to study the cooling process of an ion beam circulating in a storage ring. Actually, two beam profile monitors can be used to measure the transverse beam temperature during the cooling process and then study heating phenomena in the beam itself. A residual gas beam profile monitor has been designed and constructed. The new feature of this device is the read-out system that can lead to a sensitive improvement of the spatial resolution (about 70 μm).The design, the construction problems and the preliminary test arrangement, for an ion beam of an electrostatic accelerator, are presented.

1 INTRODUCTION

Non-destructive diagnostic methods that give vertical and horizontal density profile of beams circulating in a storage ring are of great importance for accurate studies of beam cooling process and to set-up experiments in storage ring to reach high quality ion beams.

A powerful non-destructive diagnostic method based on the residual gas ionization produced by the ion beam has been developed and used on several accelerators [1,2]. In these devices the residual gas ions produced by the beam are collected, detected and spatially resolved in certain point of the accelerator by applying a transverse electric field plus a position sensitive detector. However the high vacuum needed (< 10^{-11} mbar) for the storage ring operation leads to a very low ion production rate. This drawback has been overcome by using a vapor target to increase, locally, the background gas density. However, this technique perturbs the beam and if high quality beams are wonted it is no more useful.

Recently a new type of Residual Gas Beam Profile Monitor (RG-BPM) has been realized and utilized on the Test Storage Ring (TSR) of Heidelberg [3]. It employs a single-particle counting technique to increase the sensitivity of the ionization products' detection and takes a beam profile. The spatial resolution of this device was about 260 μm. The spatial resolution limitation was mainly due to the electronic of the read-out system connected to the resistive anode used as detector.

In this work we present the design and the construction of a similar diagnostic device with a modified read-out system capable to give a much better spatial resolution.

2 WORKING PRINCIPLE

The working principle of a RG-BPM is shortly described in the following. A transverse electric field is applied in a small region (10 cm) of the storage ring, then the ionization products coming from the scattering of the beam with background gas are accelerated towards the electrodes. The rate of ionization products is, of course, proportional to the background gas pressure inside the vacuum pipe of the storage ring. The rate of ion collected on the electrode is given by [3]

$$N_D = \frac{I}{q \cdot e} \cdot n \cdot l \cdot \sigma(E) \quad (1)$$

where σ(E) is the cross section of the ionization reaction: $I_{q+} + H_2$, n is the residual gas density and l is the detector active length. The rate of ion production for a residual gas pressure of 5×10^{-11} $mbar$ (as usual in a storage ring) is very low, then the detector signal would be very low too and profile measurements also would be very hard to be done. The electric signal on the collecting electrode would not be directly detectable by the charge sensitive amplifier. This problem can be solved, as done in ref. [3], by using, as multiplier, a Micro Channel Plate (MCP) in single particle counting mode for the impinging ions. In that reference a resistive anode as charge detector was used and the sensitivity to charge position was obtained by the rising-time ratio of the electric signals taken at the edges of the anode.

The spatial resolution limit achieved with this technique is about 260 μm and it is mainly due to the electronic of the read-out system. To improve this spatial resolution limit we have used the same technique of the image intensifiers with "single photon counting".

The image intensifiers are normally used to amplify an input light signal by using a photocatode connected to a MCP. The photoelectrons produced by the light signal are collected by the MCP and then, multiplied and accelerated on a phosphor screen that will produce the same light signal amplified in the output. The MCP multiplication ratio, in this operation, is kept in the range 10^2 to 10^4 to prevent the saturation of the electric charge produced in the MCP. This kind of operation is said 'analog mode'. When the light level is lower than 10^{-5} lux, the photoelectron number produced is so low that no more than one photoelectron can hit each MCP channel. For this reason, in this case, the MCP multiplication ratio is increased to 10^6 (by applying a voltage of 1.8 kV on the MCP faces) so that for each photoelectron a single light spot of 60 µm of diameter is generated on the phosphor screen. Since, with this multiplication ratio, the MCP reaches the space charge saturation the light spots produced on the phosphor screen have uniform intensity. Under these conditions, the output signal loses the proportionality with the input signal but the position sensitivity, to which we are interested, still remains. A camera, or other devices, can be used to store the output image, enabling a time storage of the incident light and the reconstruction of an image.

This technique can be used to reconstruct the ion beam profile by detecting the residual gas ions produced by collisions with the beam itself. Actually, the single residual gas ion, accelerated by the applied transverse electric field, reaches the lower face of the MCP producing an electron pulse that is accelerated on a phosphor screen. The light spot coming form the phosphor screen is collected by the MOS linear image sensor (see below) that reconverts the light in electrical signal. For coupling the phosphor screen to the MOS a fiber optic plate (FOP) is used (the FOP transmits the optical signal with a very high efficiency: 4 - 5 times higher than the lens coupling transmission). In this type of device the output signal (video), coming from the linear image sensor MOS, is discriminated into two levels by digital processing to reconstruct correctly the beam profile. The discriminator level is set at a point slightly above the video signal "dark" level (due to dark current) to code the video signal into an *on* or *off* regions (0 or 1) and then it is transferred to a storage memory. Shortly, when the video signal will be greater than the "dark" level, it will be counted for the MOS related pixel.

The MCP are assembled in the chevron type configuration and can reach a multiplication factor of 10^6. Their detection efficiency, for positive ions, in the range of energy used for the beam, is about 70%.

3 MOS LINEAR IMAGE SENSOR

The MOS linear image sensor is a self-scanning linear photodiode array with a single video output line, [4]. These kinds of sensors have a wide photosensitive area with a pixel height of 2.5 mm, a pixel pitch of 25 µm and, a number of pixel of 1024. The whole photosensitive area is, therefore, 2.5 mm x 25.6 mm. The MOS feature presents a good output linearity over a wide dynamic range and has low power consumption. It has a high sensitivity in the range 500-800 nm, which is close to the spectral emission of the P-20 phosphor (pick at about 550 nm).

5 ELECTRIC SCHEME

The electric scheme of the device is shown in fig.1.

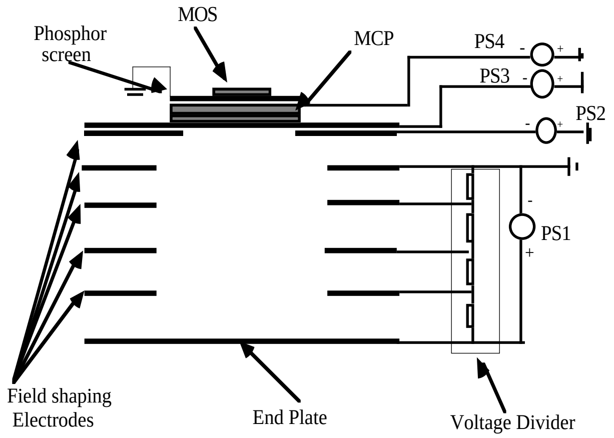

Fig.3 Electric scheme. PS1, PS2, PS3, PS4 are the Power supplies.

The transverse electric field needed to accelerate the residual gas ion toward the MCP is given by the high voltage generator PS1 (16 kV) and PS2 (-4kV). The lower face voltage of MCP is given by PS3 and the upper face by PS4. Notice that the ions have positive charge while the electrons, produced in the MCP, have a negative one. This means that we need to change polarity to the electric field since, from the mechanical construction, the phosphor screen is set to the ground. For this reason we have used the electric scheme of fig.1 with four power supplies. Furthermore the four power supplies allow of changing the voltage between the MCP faces and with respect to the phosphor screen in an independent way. This possibility makes the device usable for a very large range of residual gas ion production rate. In fact, this RG-BPM could be used also in analog mode for the case of high residual gas ion production rate. It can be done by lowering the voltage between the MCP faces. In this way the MCP gain can be reduced to a factor of 10^2-10^4.

6 CONSTRUCTION AND TEST ARRANGEMENT

In fig.2 is shown an exploded view of the RG-BPM mechanical design.

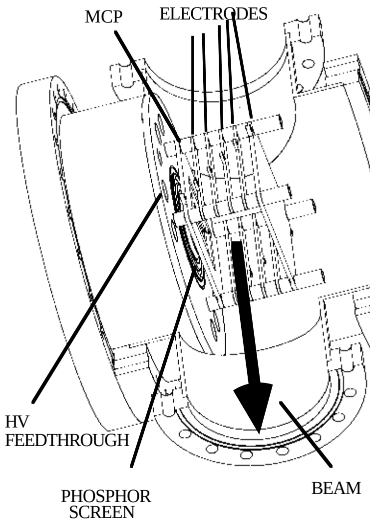

Fig.2 Mechanical design of the RG-BPM.

To reach a spatial resolution better than 70 μm, the residual gas ion trajectories have been carefully studied in the electric field given by the HV electrodes. In fact, the presence of a groove on the last electrode, where the bottom face of the MCP is placed, causes a distortion of the electric field lines and then also of the ion trajectories.

Computer simulations, made by the EGUN code [5], have shown, for the residual gas ions, that the distortion of the trajectories on the collecting electrode is, in average, greater than 900 μm when the last electrode and the bottom face of the MCP are set to the same voltage (3a). An impact point error smaller than 40 μm can be reached if a voltage difference of 2 kV is set between the last electrode and the bottom face of the MCP (3b).

The RG-BPM has been constructed and a preliminary test on the ion beam of the LNL Tandem accelerator has been arranged. The vacuum pressure of a Tandem accelerator is around 10^{-7} mbar. This kind of pressure is about four orders of magnitude higher than the pressure of a storage ring, then, being the ion beam current of a tandem one order of magnitude less than the current of a storage ring, we expect a production rate N_D about 3 order of magnitude greater than that evaluated for the storage ring in ref. [3] (see the formula (1)). For this reason, in this first test on the Tandem, our RG-BPM will be operated in the analog mode. The video signal coming from the driver-amplifier will be seen directly on the oscilloscope.

To test our RG-BPM also in ion counting mode, we foresee to reduce, in a second stage of the test, the ion beam current in order to lower the residual gas ion rate production to the same level of that produced in a storage ring.

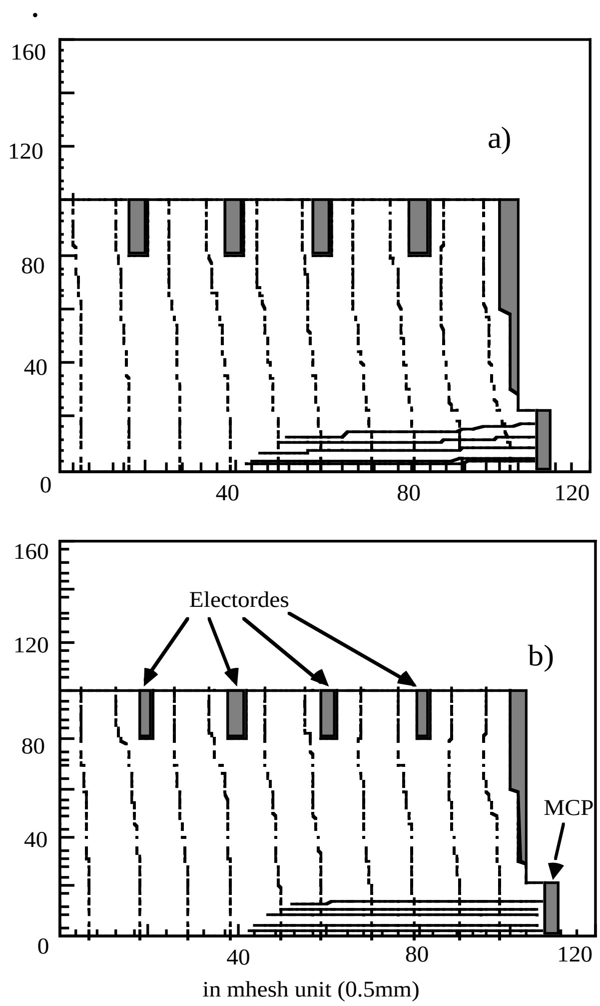

Fig.3 Trajectory simulation of residual gas ions with slightly different typical initial conditions.

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