ADVANCED RESIDUAL GAS PROFILE MONITOR FOR HIGH CURRENT SYNCHROTRONS AND COOLER RINGS

P. Forck[1], T. Giacomini[1], A. Golubev[2], D. Liakin[2], V. Skachkov[2], A. Vetrov[3]

[1] Gesellschaft für Schwerionenforschung - GSI, Darmstadt
[2] Institute for Theoretical and Experimental Physics - ITEP, Moscow
[3] Moscow State University - MSU, Moscow

Abstract

The modern ion accelerators and storage rings require faster beam profile measurement with higher resolution. We propose a new residual gas monitor, which will operate on secondary electrons whose trajectories are localized within ∅ 0.1 mm filaments along uniform magnetic field lines excited by a permanent magnet. To adopt this resolution into the data acquisition system a CCD camera with upstream MCP-phosphor screen is used. To realize a fast turn-by-turn readout a photodiode array of 100-channel with amplifier and digitizer is foreseen.

DESIGN CRITERIA

Non-destructive profile measurement systems are needed to yield the beam emittance and it's evolution during the storage in a synchrotron. An advanced high performance residual gas monitor (RGM) system seen in Fig. 1 is under development. The main features are an applied magnetic field by permanent magnets and a fast turn-by-turn as well as a high-resolution read-out mode. It will be constructed to operate in numerous wide current and energy range synchrotrons as well as low current cold beams in cooling rings.

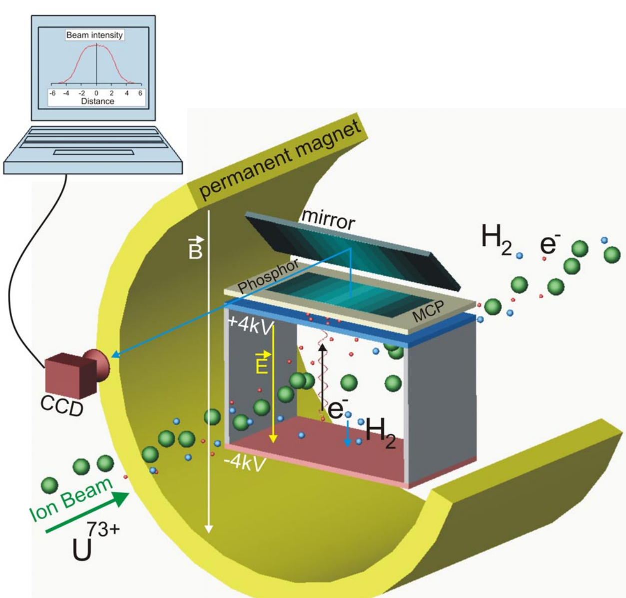

Figure 1: RGM operational principle.

It will serve as a prototype for the various existing and planned ring accelerators at the GSI facility [1].

In RGMs an electrostatic field accelerates the ionization products by the beam and residual gas towards a Micro Channel Plate (MCP). When these particles reach the MCP secondary electrons are produced and accelerated against a phosphor screen, where they produce light spots. These can be observed by a CCD camera or by a photo-diode array.

True beam profile: Beside the applied external electric field, the beam space charge field accelerates the ionized particles. To obtain an undistorted beam profile the particles are guided to the MCP surface by an external magnetic field parallel to the external electric field. Only when a magnetic field of about 0.1 T and an electric field of about 0.5 kV/cm are applied, the primary electrons are guided straightforward to the MCP as calculated for Fig. 2. The parameters are typical for a high current operation of the SIS synchrotron at GSI. To achieve 0.1 mm resolution limited by the MCP resolution, the applied magnetic field has to provide a cyclotron radius of the same size respective a field uniformity of 5% from starting point to the MCP. In general the cyclotron radius is given by the initial electron velocity after ionization.

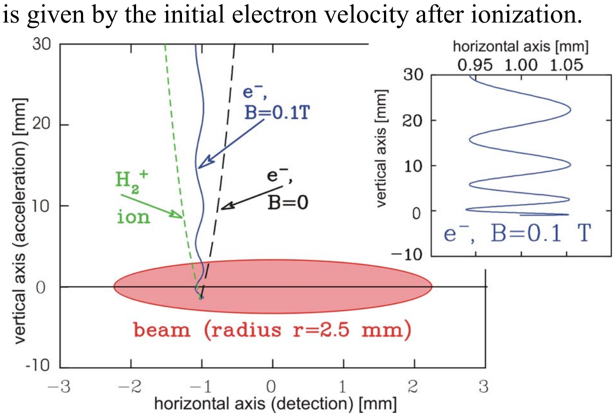

Figure 2: Trajectories of residual gas particles with and without magnetic field (10^9 U^{73+} per 10 m long bunch).

In different synchrotrons and storage rings various operating modes and different demands exist. We intend to provide a high-resolution (HRes) mode and a fast read-out mode (FRout).

HRes: For precise beam observations during the acceleration or cooling, a high spatial resolution down to

[1] Corresponding author: T.Giacomini@gsi.de

0.1 mm is needed. One time interval for profile measurement will cover the 0.1-100 ms range. In this case the beam image on the phosphor screen is observed with a digital CCD camera, providing the required exposure time 0.1-100 ms and a frame rate up to 100 fps (frames per second).

FRout: For high current synchrotrons, the beam profile evolution after injection - and therefore the transverse emittance - is of great importance to control the optimum matching conditions [2]. To evaluate the beam quadrupole moment and the resulting emittance blow-up it is sufficient to record the beam width of the first few hundred turns. A photo-diode array provides a turn-by-turn regime at ~1 mm resolution when a single beam profile is measured during ~1 μs.

RGM MODULES

E-Field: Due to the need of a horizontal and a vertical profile measurement two monitors have to be installed. Considering the different field directions of both monitors special arrangements should be made for the shielding between them. A voltage of ± 4 kV is applied to the bottom and the top sheets establishing field strength of about 0.5 kV/cm.

REPM dipole: The split-pole [3,4] and quasi sheet multipole [5] rare earth permanent magnet (REPM) systems deliver the most compact design of a multipole. When longitudinal magnet size l, is several times greater than its bore radius R_1, then magnetization spread and mechanical errors are the only sources of the field distortion. In practice ring type magnets [6] suffer higher deviations in magnetization while segmented multipoles are difficult to fabricate.

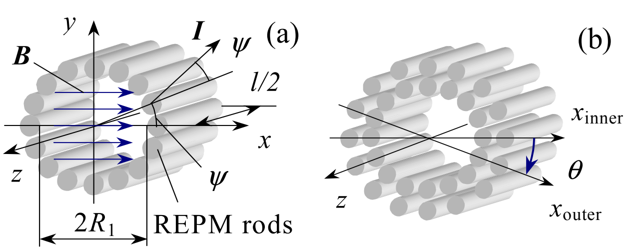

Figure 3: Rod type dipole – (a) and (b) – field compensation method in two-layer construction.

Unique advantage of rod type construction [7] provides arbitrary magnet assembly sizes due to the magnetic element unification. Since average magnetization is lower than in ideal magnet the field of a dipole with outer radius R_2 and rod magnetization I

$$B = c_f \mu_0 I \ln R_2 / R_1 \qquad (1)$$

due to the space filling factor c_f<1. The magnetic alloy of the REPM is Nd-Fe-B with remnant induction B_r = 1.2 T.

In short magnet $l \le 2R_1$ seen in Fig. 3(a) the field becomes lower because of fringe fields and field configuration differs from perfect uniform. In particular the rod dipole axis field, $B_0(z)$, given by

$$B_0(z) = \frac{c_f \mu_0 I}{4}\left[F\left(\frac{z-l/2}{R_2}\right) - F\left(\frac{z+l/2}{R_2}\right) - F\left(\frac{z-l/2}{R_1}\right) + F\left(\frac{z+l/2}{R_1}\right)\right], \qquad (2)$$

where $F(\zeta) = \zeta\left(1+\zeta^2\right)^{-1/2} + 2\ln\left(\sqrt{1+\zeta^2}+\zeta\right)$, is some lower than field eqn. (1) at the center z=0. Nevertheless the field integral is equal to the 'square wave field' eqn. (1) and the same length l.

For electron detection in RGM the 30 mm z-axis dimension of MCP defines the working region width w_z<l. Below l=100 mm the dipole outer radius shows a very rapid growth seen in diagram Fig. 4 calculated with eqn. (2) at R_1=200 mm while the REPM weight reaches minimum W=64 kg at l=176 mm (point S).

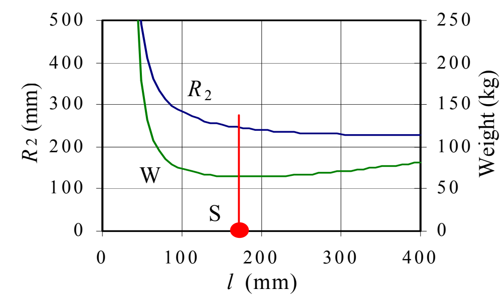

Figure 4: 0.1 T dipole outer radius and REPM weight dependencies.

The 5 % non-uniformity tolerance in the 210×160×40 mm^3 working region requires a single dipole length longer than 500 mm. Nevertheless a combination of several shorter dipole sections with different sizes reduces the full dipole length. Fig. 5(a) shows a 300 mm long Nd-Fe-B rod dipole with 200 mm long central section, having a total weight of 92 kg. Varying the central section bore radius the field curves seen in Fig. 5(b) corresponding to several y and z within working region can be fitted in 3 % accuracy range.

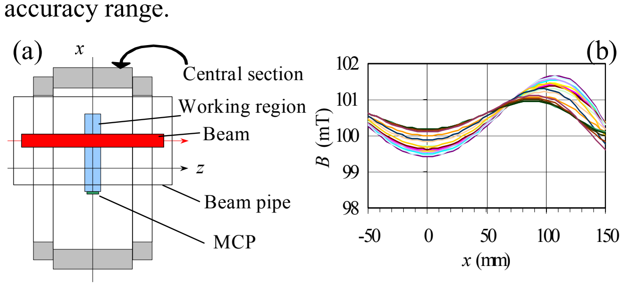

Figure 5: Three-section dipole – (a) and (b) – field.

During the vacuum bake-out the REPMs can be disassembled and removed from the beam pipe, because they cannot withstand temperature increasing up to 300°C. Due to high magnetic rigidity the dipole field is reversible so we divide the dipole into semi-cylinders.

The dipole will be made from relatively small magnetic elements assembled in two layers seen in Fig. 3(b). At a rotation angle of θ=180° the center field can be reduced to nearly zero if the layer fields equal each other [8].

The monitor *E*– and *B*–fields result in a transverse kick up to several 10 mrad. They should be compensated by the same type of field configuration.

To minimize expenses of a new monitor development we foresee a monitor design, which covers the most possible variations of main vacuum, beam and accelerator parameters. Three-dimensional scaling the magnet sizes conserves both the magnetic field value and its configuration. The working region scaling should be also involved because the necessary magnetic field uniformity is extended on whole electron trajectories up to the MCP.

MCP and phosphor screen: For the large aperture applications it is planned to use MCPs of around 100×30 mm^2 in Chevron configuration. The FRout mode makes it necessary to use a phosphor screen with a short decay time at least P47 type with a decay time of 70 ns. The amount of residual gas electrons has to be large enough for this application so a moderate pressure bump has to be applied.

Optical coupling: The specifics of this device are: low light intensity from the phosphor screen and very limited space due to the dipole volume. A movable mirror reflects the image from the phosphor screen to the CCD camera or to the photo-diodes seen in Fig. 6.

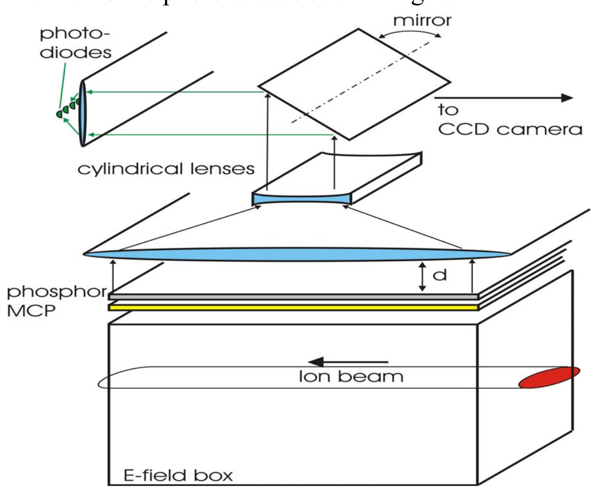

Figure 6: Basic optic scheme.

For the photo-diodes it is necessary to integrate the intensity of the light over the MCP length. This can be done by optical elements with cylindrical geometry, like parabolic mirror, cylindrical lenses, and Fresnel lens.

A special lens configuration improves the light transmission. A convex lens followed by a concave lens is mounted closer to the phosphor screen. This configuration collects a large light fraction fitting it to a smaller area. The light can be easily focused to the photo-diodes or observed by the CCD camera.

CCD camera and photo-diodes: CCD cameras are available as full-configured systems with high resolution, short exposure time and high frame rate. The fast turn-by-turn readout mode by the photo-diode array requires 0.1-1 µs sampling time and a data capacity for about 300 beam revolutions. Each photo-diode is equipped with an individual low-noise preamplifier and a variable gain amplifier to normalize the readout signal. Also a high performance digitalization system with peak performance of about 30 MSamples/s and a data storage capacity of about 20 kB/channel is needed.

CONCLUSIONS

The basic idea is the application of permanent magnets to create the required dipole field of the RGM. It offers a good homogeneity as well as a very compact design. With a proper mechanical design, i.e. a two-layer system, the magnetic field can be switched off. Two REPM dipoles can be fitted into 700 mm long free space and are removable for vacuum bake-out. We will integrate two modes of operation: a high spatial resolution mode by a CCD camera and a fast turn-by-turn mode by a photo-diode array. The monitor will be a very flexible and modular detection system, which covers a wide range of application.

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