MAGNETIC SYSTEM FOR RESIDUAL GAS MONITOR*

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Abstract

The advanced residual gas monitor requires very careful design of each structural component and special attention to match the properties of different subsystems. An important point is a proper magnetic guiding system design. As it is shown, high field uniformity, which is required for sub-mm spatial resolution, can be achieved despite the presence of the field-distorting hole for the light signal transmitting. The low energy (down to 10 MeV/u) beam disturbance compensation methods are also discussed. The ionisation process and electron dynamics simulations are used for proving this system design.

INTRODUCTION

Because preventing material melting by the large beam power, non-destructive measurement device of the beam profile is one of the most attractive beam detectors for high current synchrotrons and storage rings such as the superconducting SIS100 with $5 \cdot 10^{11}$ U^{28+} ions in primary beams at the energy of 1.5 GeV/u or $4 \cdot 10^{13}$ protons at 29 GeV and SIS300, which after further stripping accelerates heavy ions up to GeV/u. The accelerators as well as storage rings RESR, NESR, HESR and other installations are under development according to FAIR program at GSI. The beam losses are restricted on the level of only few percent in the superconducting synchrotrons; so current measurements could be provided with relative accuracy of 10^{-4}.

The Ionisation Profile Monitor (IPM) with fast readout is under collaborative development by GSI, ITEP, COSY, NPI at MSU and CRYRING laboratories [1,2]. It will cover a wide range of beam intensities and dimensions with high spatial resolution operating in turn-by-turn regime. In the fast mode of the IPM operation the beam bunch will be studied with the record speed up to 10 profiles/μs.

In IPM an electrostatic field accelerates electrons, being the products of residual gas ionisation, towards a Micro Channel Plate (MCP). At the same time magnetostatic field (parallel to electrostatic field) of the same direction keeps the most of electron trajectories within thin and straight tubes conserving the transverse coordinate of the interaction point until MCP.

Transverse *x*- and *y*-distributions of the beam intensity are determined individually in two identical measurement chambers, installed along *z*-axis by 90° azimuth angle to each other. To reduce a distortion of ions trajectories because of an influence from static electromagnet fields in the monitor the main magnets should be added by compensating magnets. Only several millimetres of the transverse ion beam shift and less than 1 mrad of the velocity refraction angle are allowable. In this paper we discuss calculation results for the monitor magnetic channel excited by Rare Earth Permanent Magnets (REPM).

OPTIMISATION TECHNIQUE

From several magnetic channel schemes considered the symmetric one, in which from both sides of each main magnet a pair of compensation magnets is installed, showed better fields at the most compact geometry. Because of rectangle shape of the electrostatic unit the main dipoles have rectangle aperture of 480×480 mm cross-section unlike circular aperture in compensation magnets.

At calculations we modified the monitor sizes to reduce the detection error of a point-like source coordinate down to 0.5-0.7 mm over the whole working region. The optimisation process is in iterative selection of the diameter, length and magnetization angles of magnet rods as well as gaps between main and corrector dipoles.

TWO-DIMENSIONAL MONITOR

All the dipoles belong to split-pole type seen in Fig. 1. However they do not generate ideal dipole fields because of their short length. Besides the main dipoles are not circular and in front of the MCPs the light windows are made 90 mm apart the channel axis in their REPM walls to observe the visual images of the beam intensity.

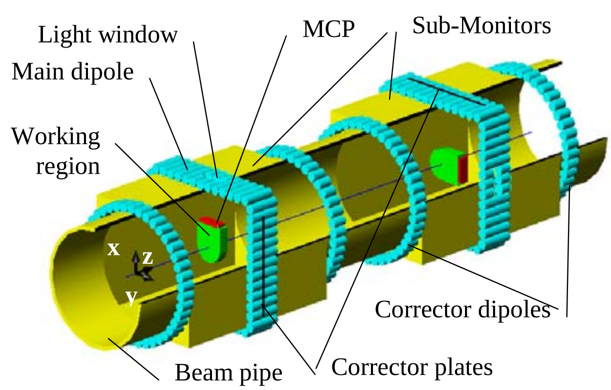

Figure 1: REPM channel of the IPM.

By iterative calculations an appropriate angular distribution of the NdFeB rods of 38 mm diameter with 1.1 T magnetisation has been found to get 30 mT steering field component (perpendicular to MCP) in both working regions. Transverse parasitic field component (sweep component) is suppressed to below 0.1 %.

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In such relatively simple design we found the geometry parameters listed in Table 1. At total mass of the channel REPMs of about 200 kg it is 2 m long that corresponds to restrictions assigned on the beam pipe for the monitor installation in synchrotrons.

Table 1: Magnetic channel geometry

Main dipole rod number	52
Corrector dipole rod number	42
Main dipole length, mm	132
Corrector dipole length, mm	57
Main dipole – corrector gap, mm	292
Gap between sub-monitors, mm	370
Channel length, mm	2030

Further decreasing a gap between main and corrector dipoles results unacceptable increasing the field non-uniformity in the working region. To compensate the main field component of a neighbour sub-monitor, which penetrates into the working region of the first one and introduce there a harmful component additional steel plates are involved in the design. They of 2×5×450 mm each are attached in the central cross-section outside rods of the main dipoles. Field distributions in both sub-monitors are identical to each other at inversion of the transverse coordinates notations.

Due to rather high number of magnetic elements in each magnet the discreteness of the magnetisation distribution plays lower role in the magnetic field non-uniformity than other factors. On the engineering stage we intend substituting in the circular dipoles two adequate layers of the REPM rods instead of involved into calculations for "switching off" the magnetic fields of correctors every time after measurement sessions. Shims technique will be used to provide the same in the main dipoles.

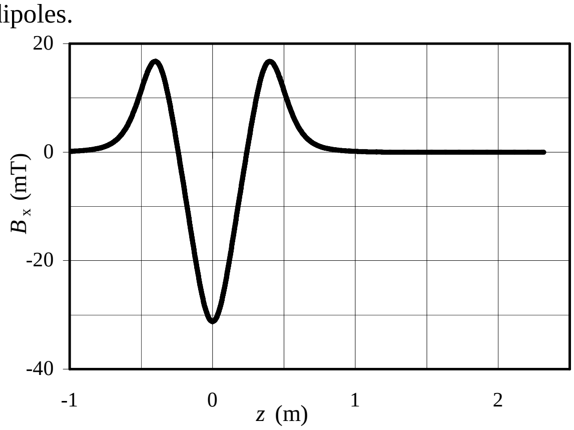

Figure 2: Longitudinal distribution of the channel field.

We use symmetric sub-monitors respect to the transverse plane passing through the centre of the main magnet. In such scheme fields of both correctors are identically distributed longitudinally. Both ion velocity refraction and beam shift could be compensated at the same field excitation. By the numerical calculations described below a kick compensation was found for every current channel modification at all optimisation steps. The final field distribution is illustrated in Fig. 2 for *x*-component of the field. The *y*-component distribution is absolutely symmetric respect to the channel centre.

ELECTRON DYNAMICS

For all optimization steps the main field distribution was numerically tested to obtain a monitor response on a point-like source of electrons generated at interactions of accelerated ions with residual gas molecules. This simulation indicates the monitor ability to separate two different points located maximally closer to each other in the interactions space and also an accuracy of the reading out their locations. The first factor is a consequence of image divergence respect to the actual object because of initial electron velocity spread while the second is a result of the field configuration imperfections at the whole electron traveling to the MCP.

We made the dynamics simulation of $N=10^4$ electrons from the working region center to the MCP. The ionization process was simulated with azimuthally uniform distribution within 360° angle while impact parameter was chosen in the range 0.1÷3.85 Å at locally uniform distribution of incident 10 MeV/u U^{72+} ions [3,4]. The right hand boundary of the range is the boundary of ionization of residual gas molecules. In our model we consider the molecular hydrogen with 15.4 eV ionization potential as predominant residual gas component. In all simulations of electron dynamics we took into account the own bunch field. Gaussian bunch parameters were: transverse width $\sigma_x = \sigma_y = 20$ mm and length $\sigma_z = 10$ m whereas ions number was 10^{10}.

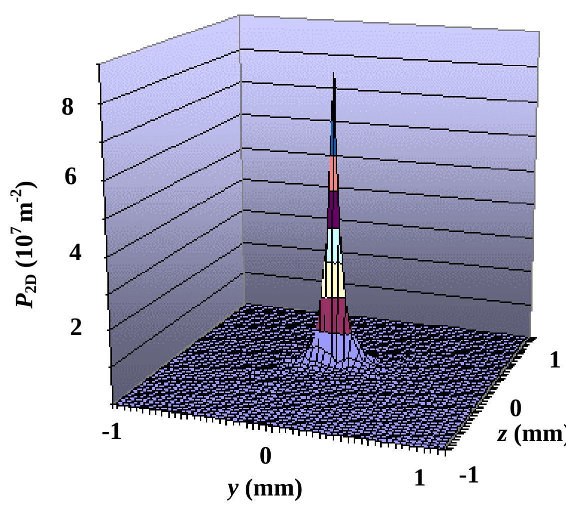

Figure 3: Electron density distribution at MCP surface.

The visual image of the point-like source, which we describe in terms of the probability $P_{2D}(y,z)=dN/(Ndydz)$, where dN – number of electrons achieved MCP within a square with dimensions dy×dz and center (y,z), looks like a very thin peak on the MCP surface in both directions seen in Fig. 3.

In our monitor the MCP's signal will be proportional to the integral $P_y(y) = \int_{-\infty}^{\infty} P_{2D}(y,z)dz$, which is onedimensional distribution function. Peak of the distribution has some small shift of -20 μm. Because of the magnetic field non-uniformity the shift between starting coordinate and peak of the distribution at MCP must depend on a starting point. We tested the field using electrons with very small energy after ionization: 0.02 eV. Such electrons get MCP near the distribution peak. It was found that shift grows to ~0.5 mm when an electron source moves closer to the working region boundary. The result shows that in sub-millimeter resolution the monitor is very sensitive to the field non-uniformity.

We describe the monitor resolution by the function $R(\lambda)=2\Delta y$, where $\lambda = \Delta N/N$, ΔN – the number of electrons that are inside the region $y_{peak}-\Delta y \le y \le y_{peak}+\Delta y$, found by integration of y-distribution: $\Delta N(\Delta y) = \int_{y_{peak}-\Delta y}^{y_{peak}+\Delta y} P_y(y)dy$.

We found that 0.5 mm spot around the peak contains 75 % particles while 1.0 mm – 90 % particles.

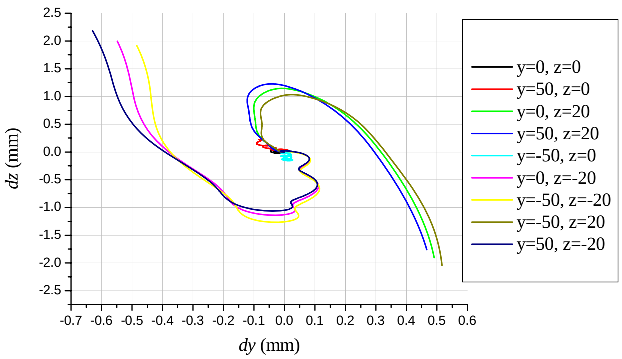

Figure 4: Electron trajectories.

Fig. 4 illustrates electron trajectories from ionisation point to MCP plane for the most remote points of interaction x_0=-50 mm and several other coordinates (y,z) specified on the diagram.

It is seen that the most of trajectories are located within ±0.1 mm vicinity around the starting point and only in the edge of the working region the accuracy of the electron detection falls because of up to 0.5 mm shift of the electron position on the MCP.

KICK COMPENSATION

Fig. 5 shows U^{72+} ion trajectories in monitor fields. We made single particle simulations for 10 MeV/u ions. At these calculations beside magnetic field described here also the electrical field of 50 kV/m static accelerator deflects ions however with much lower effect.

The own beam field plays negligibly small role in our bunch model and can be ignored. Besides we studied ion beam behaviour at different beam offsets up to 20 mm and found approximately the same results.

We can see the shift between initial and final transverse ion position is reduced down to about 0.1 mm whereas in magnets it reaches about 1 mm. Velocity inclination to z-axis after the monitor is reduced to 0.1 mrad.

Such monitor without substantial beam distortions can be successfully applied on accelerators with much lower ion energy. However it is obvious “switching off” the monitor field is desirable in the pause between beam parameters measurements.

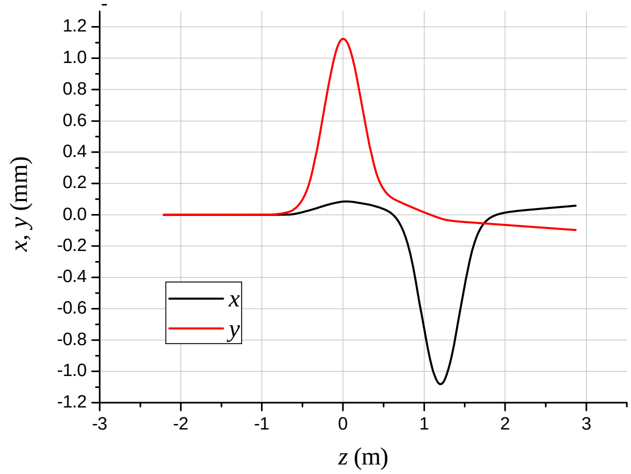

Figure 5: Ion trajectories in monitor field.

CONCLUSIONS

- The ionisation profile monitor with permanent magnets and circular corrector dipoles has advantages compared with electromagnetic one [4] that define its choice.
- The sub-millimeter resolution of the beam transverse coordinates detection can be realized.
- Ion beam transverse shift and velocity divergence after passing through the channel can be reduced at compact (2 m long) monitor dimensions making possible its using for intensive synchrotrons and storage rings in wide range of the ion energy.

ACKNOWLEDGEMENT

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