IONIZATION PROFILE MONITORS - IPM @ GSI *

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Abstract

The Ionization Profile Monitor (IPM) in the SIS18 is frequently used for machine development. The permanent availability and the elaborated software user interface make it easy and comfortable to use. Additional to the beam profile data the device records the data of synchrotron dc current, dipole ramp and accelerating rf properties. The trend curves of these data are shown correlated to the beam profile evolution for an entire synchrotron cycle from injection to extraction with 100 profiles/s. The reliable function is based on the optimized in-vacuum hardware design, and the UV-light based calibration system. The permanent availability is based on the convenient software interface using the Qt library. A new IPM generation was recently commissioned in the experimental storage ring (ESR) at GSI and another at COSY at FZ-Jülich. These monitors are enhancements of the heavy ion synchrotron (SIS18) multiwire IPM but equipped with an especially developed large area 44x94 mm^2 optical particle detector of rectangular shape that is readout by a digital camera through a viewport.

DETECTION PRINCIPLE

Beam profile measurement is an important task for accelerator optimization and in general for accelerator experiments [1]. The basic principle of an IPM is the beam ionizes the residual gas in the vacuum. An electric field is applied transverse to the beam direction to extract the ionized particles toward a position sensitive particle detector, e.g. a wire array or a phosphor. The electric field is created by high voltage electrodes. To increase the small number of ionized particles a multi channel plate (MCP) multiplier is necessary [2]. For each transverse plane of the beam a seperated IPM is installed.

SETUP

The electric field box with an aperture of 175mm x 175mm and a field strength of about 60kV/m is equipped with 12 side electrodes and mounted on a CF250 flange. It was designed with CST studio software with realistic model geometries and potentials to improve the electric field uniformity also in the fringe fields. Because of the UHV conditions in the GSI rings each high voltage electrode is supplied by an individual high voltage feedthrough. The high voltages range from -9kV to +12kV. To measure the horizontal and the vertical beam profile 2 electric field boxes are placed nearby but turned by 90 degree. The vacuum tank of the whole system is 0.6 m in beam direction

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MEASUREMENT

To measure beam profiles at low beam intensities the MCPs are operated near their high voltage limit. Because of the number of different high voltage electrodes and the sensitive MCPs the high voltage control of IPM is critical. The software interface written in Qt reduces the complexity of the control so the user just has to adust the amplification voltage of the MCPs. All other features like network connections, data analysis and storage, high voltage control, etc. are controlled automatically. Because of the non-uniform MCP amplification a calibration of the particle detector is important. The MCPs are sensitive to UV light up to 150nm wavelength. Illuminated by a deuterium lamp with uniform UV light they emit secondary electrons towards the phosphor screen.

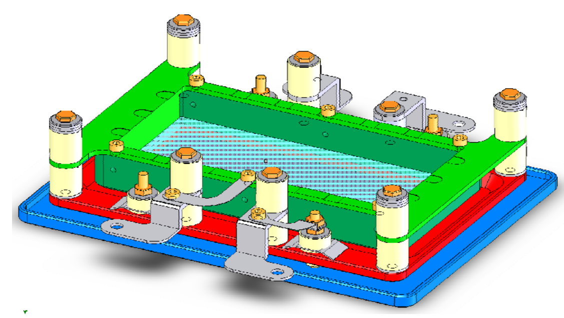

Figure 1: Particle detector, active area 44mm x 94mm.

The measured light signal represents the non uniform MCP amplification. The beam profiles are recorded with a fixed rate of 100 profiles per second from beam injection to extraction. The data are stored in ascii format to simplify the data access for experimenters. All profiles are stored in two different manners. First as original values and secondly corrected and noise reduced as clean beam profiles. The analysed data like beam width, position and profile integral value are shown over time correlated to the alternating signal of the beam dc current. This gives a quick view of beam profile evolution during the different accelerator phases like acceleration, flat top or slow extraction. The beam parameters like position and width at start of acceleration or during multiple injections are direct visible. All beam profiles are plotted as an overlay like a waterfall plot or as a collection of single profiles.

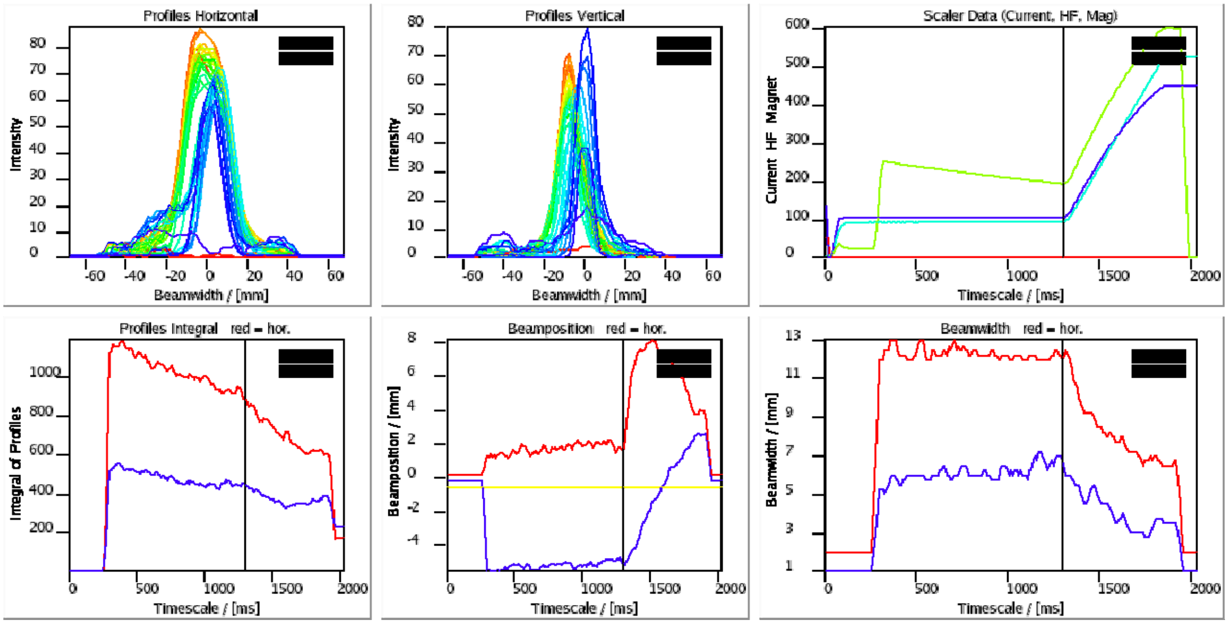

Figure 2: Beam profiles, dc current, beam position, width and integral for one full cycle of SIS18. The beam is injected after 250ms as seen in the upper right graph. One can see some beam losses up to start of acceleration at 1300ms (marker position). When the acceleration starts the beam position changes, center graph of the lower row.

OPTICAL IPM READOUT - OIPM

The conventional IPM in the heavy ion synchrotron SIS18 at GSI is equipped with a 2 stage MCP and is readout by a wire array. Because of the large wire pitch of 2.1mm the spatial profile resolution is poor. To improve the spatial resolution a new optical particle detector was developed. The new optical IPM can detect residual gas ions or electrons and is equipped with a 2 stage MCP and an upstream fast phosphor screen P47. The wavelength of the emitted light is about 400nm and the decay time is in the range of about 100ns. The beam is visualised on a large active area of 44mm x 94mm, 44mm in beam direction. To reduce the maintenance time the 4 fixing points are designed in an unmistakable way and are also the high voltage connections. Different high voltage constellations of up to 15kV for the phosphor are provided. A digital CCD camera records the images of the phosphor screen with about 200 frames per second and are readout by a frontend software designed in LabView on a Windows XP computer near the accelerator. The cameras are externally triggered to get a deterministic beam profile rate and to ensure the correct timing. The cameras are triggered by a FPGA card also controlled by LabView. The raw image data are transferred for analysis and display to a Linux computer in the electronic room. The optical IPM prototype was installed in the COSY ring in Jülich in 2009 [3]. The experimental storage ring ESR at GSI was equipped 2010 with an optical IPM of the same type like at COSY in Jülich.

PROFILE DISTORTIONS

The space charge of the beam applies an additional force to the residual gas particles after ionization. The residual gas particles are moved out of their transversal path towards the optical particle detector. This effect corrupts the measured beam image, especially the ionized particles outside the beam center are affected. The measured profile width increases for residual gas ions and decreases for residual gas electrons. The residual gas ions are less sensitive to the space charge effect than the electrons. If the particle density and charge increase the space charge effect becomes more relevant also for the residual gas ions.

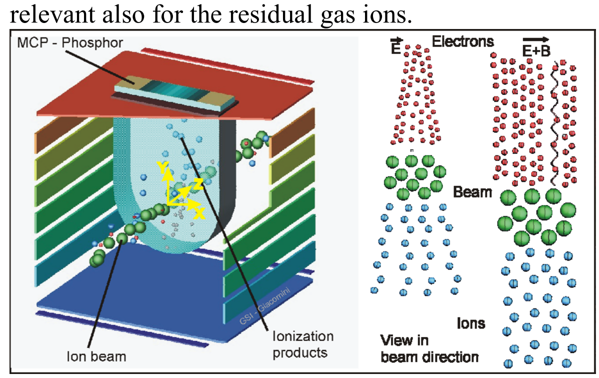

Figure 3: Residual gas particle shifts inside the electric field due to the space charge of the beam.

ELECTRON DETECTION MODE

To reduce this space charge effect and to improve the measurement quality an additional magnetic field of about 80mT can be applied in parallel to the electric field. Now, the ionized residual gas particles spiral along the magnetic field lines toward the optical particle detector. The resulting cyclotron radius is large for residual gas ions but small for residual gas electrons. When the magnetic field is applied one has to detect residual gas electrons, without magnetic field detection of residual gas ions is more reasonable. The magnetic field is applied outside the vacuum. To view the phosphor with the CCD and to calibrate the MCPs with UV light the yoke has to provide slits on both sides. The yoke with slits can be seen as 2 magnets arranged close together. To get beam profiles of both planes two optical ionization profile monitors (OIPM) are used but turned by 90 degree.

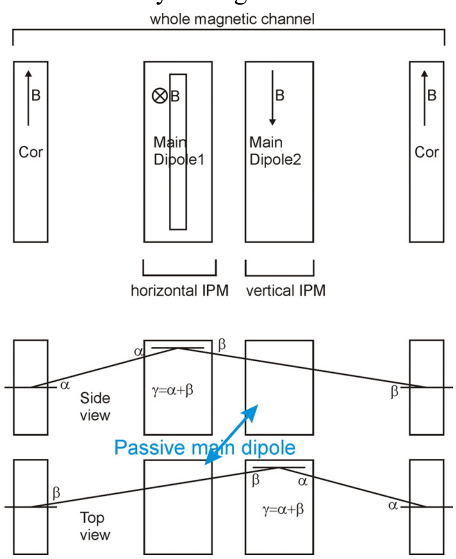

Figure 4: Magnetic channel with 2 main magnets and 2 corrector magnets. Main magnets are used alternating. Both cases are shown, horizontal (Side View) and vertical measurement (Top View) .

Therefore two magnets are needed. The large aperture of the main magnets of about 0.5m and the short length in beam direction of about 0.4m result in a large crosstalk between the 2 main magnets which are turned by 90 degree. The transverse outside dimensions of the magnets are in the range of about 1.2m in x and y direction. To increase the field uniformity the inside aperture of the yoke was reduced to a minimum. Therefore the vacuum compenents are installed in beam direction opposite to the transversal installations at IPMs without magnets. A moveable rack was designed to ensure the correct positioning of the IPM after maintenance. The lower rack is fixed on the ground while the upper rack can be moved out of the beamline.

The applied magnetic field affects not only the residual gas particles but also the beam itself which is steered out of the original beam path. To compensate for this effect 2 corrector magnets are needed. The first corrector magnet steers the beam back to its center position while the second corrector magnet steers the beam back to the original beam direction. This magnet design is very space consuming because of the size of the magnets and the minimum distances in between the magnets. To reduce the overall length to an acceptable value a design was choosen with 2 main magnets and 2 corrector magnets, as presented in figure 4 and 5. During the measurement only one main magnet per plane is used. The corrector magnets have 4 coils and can work in both planes while each of the main magnets work in 1 plane.

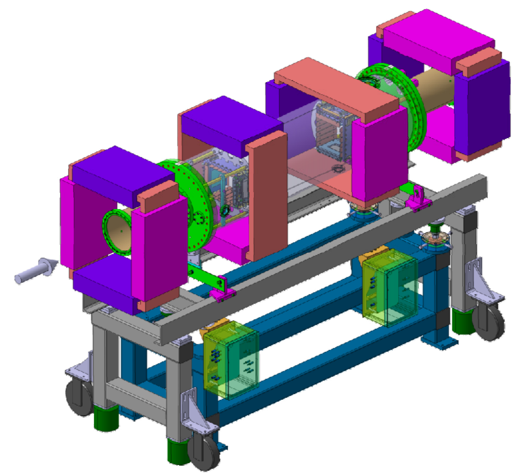

Figure 5: Design of the whole OIPM device with magnet.

For the heavy ion synchrotron SIS18 at GSI an optical IPM with magnetic field was designed. All components except the magnet were built and wait for testing and installation in the ring. This device will serve as a prototype for the OIPMs in the new FAIR facilities.

SUMMARY

After improvement of the electric field box a new optical particle detector with large active area was developed. Main features were the flexible high voltage design and fast maintenance intervals to protect the delicate MCPs of atmosphere. After comissioning of 2 IPMs at COSY and at ESR the development of the next IPM generation was started. The prototype system for all FAIR IPMs was built and will be comissioned in the next available shutdown.

REFERENCES

[1] G. Franchetti, O.Chorniy, I. Hofmann, Other, “Experiment on space charge driven nonlinear resonance crossing in an ion synchrotron”, PHYSICAL REVIEW SPECIAL TOPICS – ACCELERATORS AND BEAMS 13, 114203(2010)

[2] P.Forck, "Minimal invasive Beam Profile Monitors for high intense hadron beams", IPAC 2010, Kyoto, Japan

[3] V. Kamerdzhiev, "Beam Test of the FAIR IPM Prototype in COSY", DIPAC 2009, Basel, Switzerland