

# DEVELOPMENT OF A PERMANENT MAGNET RESIDUAL GAS PROFILE MONITOR WITH FAST READOUT\*

S. Barabin<sup>2</sup>, P. Forck<sup>1</sup>, T. Giacomini<sup>1</sup>, D. Liakin<sup>2#</sup>, V. Skachkov<sup>2</sup>, A. Vetrov<sup>3</sup>,  
<sup>1</sup> GSI, Darmstadt, Germany, <sup>2</sup> ITEP, Moscow, Russia, <sup>3</sup> MSU, Moscow, Russia

## Abstract

The beam profile measurements at modern ion synchrotrons and storage rings require high timing performances on a turn-by-turn basis. On the other hand, high spatial resolutions are very desirable for cooled beams. We are developing a residual gas monitor to cover the wide range of beam intensities and dimensions. It supplies the needed high-resolution and high-speed tools for beam profiling. The new residual gas monitor will operate on secondary electrons whose trajectories are localized within 0.1 mm filaments. The required magnetic field of 100 mT will be excited by either a permanent or an electromagnet. The high resolution mode of 0.1 mm is provided by a CCD camera with upstream MCP-phosphor screen assembly. In the fast turn-by-turn mode the beam profile will be read out with a resolution of 1 mm by a 100-channel photodiode-amplifier-digitizer, which will be explained in detail.

## INTRODUCTION

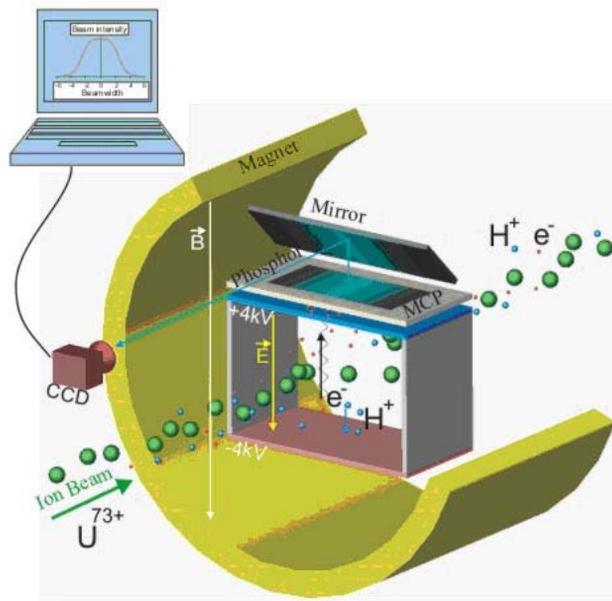


Figure 1: Advanced residual gas monitor.

The Residual Gas Monitor (RGM) provides a non destructive beam profile measurement of a circulating ion beam. Applications are the detection of transverse beam

profiles in dependence of injection matching [1], hollow beams, coupling resonances, beam cooling effects, etc. These different applications call for a detector that is capable of providing a spatial resolution down to 0.1mm for cooling and hollow beams, and a time performance up to 10 profiles per microsecond registration to determine an optimal matching condition at injection. To cover the variety of applications we are developing an RGM that unites two different profile registration mechanisms in one device, namely the high resolution readout via digital CCD camera and high speed readout by photodiodes.

The beam interacts with the residual gas within the beam line and produces residual gas ions and electrons (Fig. 1). An electrostatic field  $\mathbf{E}$  accelerates the ionization products (ions or electrons) towards a Micro Channel Plate (MCP). When the particles reach the MCP surface, secondary electrons are produced and multiplied by a factor of about  $10^6$  (Chevron configuration). The output electrons with energies of several keV hit the phosphor screen which is mounted behind the MCP. At the impact points light spots are produced with about 100 photons per each incident electron. These spots can be observed by a CCD camera, photo-diodes or other light detectors.

For precise beam observations during acceleration or cooling, a high spatial resolution down to 0.1mm is needed. The exposure time of one beam profile will cover the 0.1-10ms range. In this case the beam's profile projection image on the phosphor screen is observed with a digital CCD camera providing the required frame rate up to 100fps (frames per second). To realize the fast readout (one profile per synchrotron revolution) an array of photodiodes with a spatial resolution of 1mm and 10MHz bandwidth electronics is under development. The fast readout mode necessitates the electron rather than ion detection due to the shorter time-of-flight. To match the residual gas electrons position on the MCP to the ionization point coordinate, a magnetic field of about 100mT will be applied. This magnetic field eliminates the electron trajectory uncertainty due to initial 3D velocity distribution and reduces the space charge effect of cold or high intensity beams. For more details see [2] and [3].

## FAST READOUT ELECTRONICS

To observe a fast beam profile evolution during injection time a high bandwidth as well as low noise data acquisition electronics are required. One hundred

# liakin@itep.ru

\* work supported by INTAS

identical channels are planned to be used in the advanced RGM to reconstruct the real beam profile behaviour with high time and sufficient spatial resolution [2]. The proposed block diagram of a single digitizing channel is shown in Fig 2.

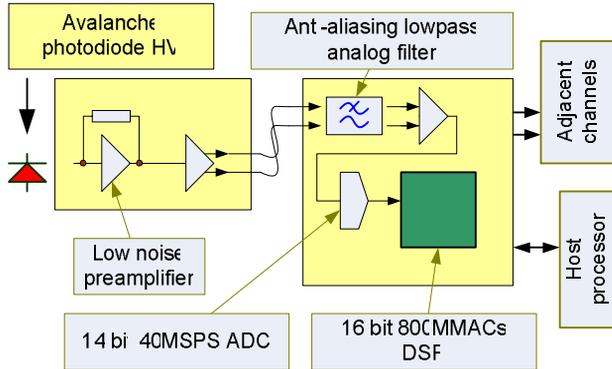


Figure 2: Single fast readout channel block diagram.

The critical elements of this data acquisition channel are the low noise preamplifier, a fast and high resolution ADC and a high performance digital processor. A 14 bit ADC AD9244 with 75dB signal-to-noise ratio provides excellent dynamic range. Therefore no additional variable gain amplifier has to be used for this schematic. A 16 bit Analog Devices BlackFin™ DSP is planned to be used for incoming data processing. Due to the digital processing, the effective bandwidth may be dynamically changed to meet the conditions of DC or wide band modes (Fig. 4). At present the printed board prototype of the digitizer is in preparation. Meanwhile the combination of the original BlackFin and AD9244 evaluation boards are used as a digitizer for the photocurrent preamplifier for testing a data evaluating algorithms.

### FAST READOUT MODES OF OPERATION

A few operation modes are foreseen for this part of RGM (see table 1). The electron counting mode is suitable for low intensity residual gas electron current. In this mode each incoming electron is detected by a separate data acquisition channel. The resulting filtering and pulse discrimination are executed digitally by the high performance DSP. Due to the matching of analogue electronics bandwidth and phosphor screen decay time, this mode has no additional missing event concerned with the electronics.

Table 1: RGM fast readout modes of operation

Mode	Time resolution	Spatial resolution
Event counting mode	$>1\mu\text{s}$	1mm
Enhanced counting	$>1\mu\text{s}$	0.3mm
Current measurement mode	$0.1\mu\text{s}$	1mm

The counting mode discrimination algorithm requires moderate signal-to-noise ratio. As an option, this mode may be enhanced for higher spatial resolution

measurement by overlaying fields of view of adjacent channels. This overlaying is provided by controlled optics defocusing. During the pulse discrimination two adjacent DSPs are able to calculate more precisely the electron position by comparing the synchronous pulses amplitudes. This mode requires better signal-to-noise ratio than the standard one. Both counting modes provide a good dynamic range at the cost of reducing the frequency bandwidth due to the averaging procedure. The current measurement mode is an alternative possibility for profile measurement which provides better frequency bandwidth limited only by phosphor decay time. The averaging of incoming electrons in this case is realised in the phosphor and in the preamplifier's filter. A higher ionized residual gas electron rate is required and therefore intensive beams or relatively high residual gas pressure are needed.

A good light transmission is mandatory to achieve sufficient signal-to-noise ratio. Figure 3 shows the basic system elements between the ionized residual gas electrons and the low noise photodiode preamplifier.

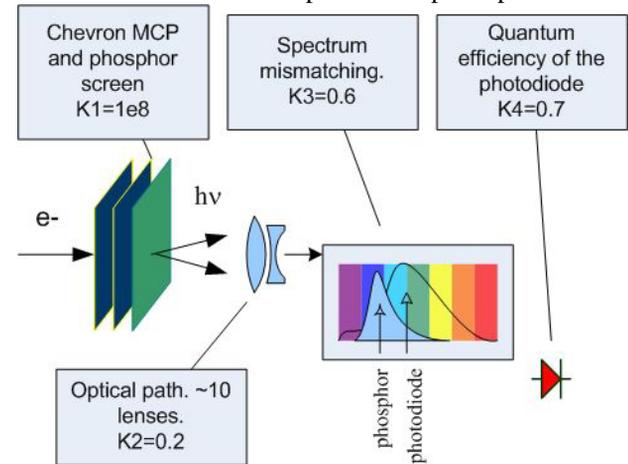


Figure 3: Transmission characteristics of the 'preelectronic' RGM stage.

The two-stage MCP combined with phosphor screen P47 can provide overall quantum efficiency up to  $10^8$  photons per incident electron. To minimize light losses the following optical system should match the Lambertian law of the angular intensity distribution of the phosphor light. Due to the limited angular aperture the fibre optic components, like tapers, fibre bundles or faceplates are not desirable in this construction. Nevertheless, the narrow space and surrounding magnet system require complex optics to use the available space for light transmission. An optic system with about 10 lenses is currently foreseen. This amount of lenses gives light intensity attenuation by factor 5.

The short wavelength Hamamatsu photodiodes produce about one electron per two photons coming from a P47 phosphor screen. The final coefficient obtained by combining those parameters will be about  $K=10^7$  photoelectrons per single incident particle, or  $K=3 \cdot 10^8$  with avalanche photodiodes. In the draft assumption of a rectangular current pulse with  $0.1\mu\text{s}$  duration, the

photodiode output pulse current is  $16\mu\text{A}$ . Usage of avalanche photodiodes increases this current up to  $400\mu\text{A}$ . This current is significant and can be easily detected.

We have tested AD8067 operational amplifier in transimpedance scheme. The overall performance is defined by the operational amplifier frequency, its noise parameters and the photodiodes junction capacitance. Thus the  $1\text{mm}^2$  active area photodiode with  $15\text{pF}$  capacitance connected to the  $4\text{k}\Omega$  AD8067 transimpedance amplifier provides the desired bandwidth of  $10\text{MHz}$ . In the same time the  $4\text{k}\Omega$  feedback resistor produces a noise current about  $2\text{pA}/\text{Hz}^{1/2}$  or  $6\text{nA}$  RMS value in the selected frequency band. This is an ideal case; in reality the equivalent input noise RMS value exceeds  $12\text{nA}$  due to the amplifier and additional resistive components noise. One can see that this noise current is significantly lower than the photocurrent for a single residual gas electron hitting the MCP with maximal gain. Therefore the fast current measurement modes as well as the enhanced counting mode with high amplitude resolution are possible.

Meanwhile we are expecting better performance with Texas Ins. OPA657 amplifier mainly due to its higher gain bandwidth product ( $1.6\text{GHz}$ ).

Another limitation factor for the fast readout mode of the RGM is MCP saturation. The recharge time of the MCP is about  $10\text{ms}$  which is too much for short time measurements. This is the reason why only the electrons stored on the external MCP surface may be used for fast processes investigation. This reserve must be spent with great caution. Without saturation the MCP is able to emit  $2\text{nC}$  output charge ( $1.25 \cdot 10^{10}$  electrons) from the  $700\text{mm}^2$  surface. One can estimate that one square millimetre of MCP with gain  $10^6$  will be saturated by less than 20 incident electrons. The MCP amplification must be reduced for the fast readout mode to increase the saturation. The compromise for fast readout event counting mode is reducing the MCP multiplication factor down to  $10^4$  – the limit due to the amplifier noise.

The current measurement mode with higher residual gas electron current will require even smaller MCP gain to avoid the MCP saturation. The limitation of the MCP surface charge requires the minimal MCP gain which is allowed by the noise of the photodiode preamplifier.

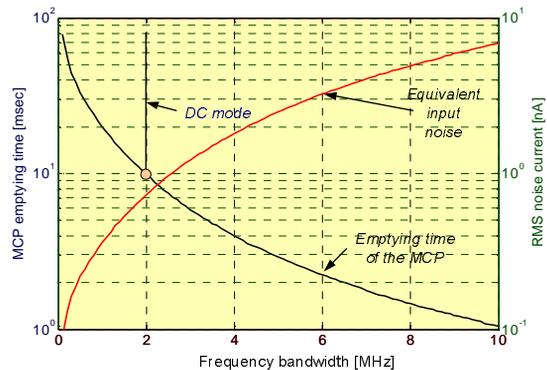


Figure 4: Expected MCP emptying time and equivalent input noise of the OPA657 avalanche photodiode preamplifier as a function of the system bandwidth.

Fig. 4 shows the limitation of the MCP's operation time in the current mode of profile measurement. The emptying time of MCP is increasing by reducing of its amplification to keep the same signal-to-noise ratio with smaller noise power. One can see that the operation with maximal bandwidth requires pulsed mode of MCP, which may be achieved by switching on and off of MCP high voltage or accelerating field of RGM. In this case the time on the figure 4 includes also the establishing time of the high voltage power supply which controls the MCP gain.

## CONCLUSION

The fast readout mode with 100 high bandwidth digitations channels is a distinctive feature of advanced RGM. The single electron counting with count rate up to  $10^7$  counts/sec per channel is possible as well as high performance continuous profile measurements. The duration of the high bandwidth measurement is limited by the accumulated MCP charge, transmission losses and the noise level of the photodiode preamplifier which determines the minimal discern current from the output surface of the MCP.

## REFERENCES

- [1] G. Ferioli, C. Fischer, I. Koopman, F. Roncarolo, "Beam Studies Made with the SPS Ionization Profile Monitor", in Proc. DIPAC-2003, p. 116, Mainz
- [2] P.Forck et al. "Advanced residual gas profile monitor for high current synchrotrons and cooler rings", In Proc. DIPAC03, p.134, Mainz.
- [3] T. Giacomini et al, "Development of a residual gas profile monitor with high resolution and fast readout", in Proc. BIW04, Knoxville, Tennessee May 3-6, 2004. <http://www.sns.gov/biw04/>