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

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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 scattered residual gas electrons whose trajectories are localized within 0.1 mm filaments by using appropriate magnetic field. 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

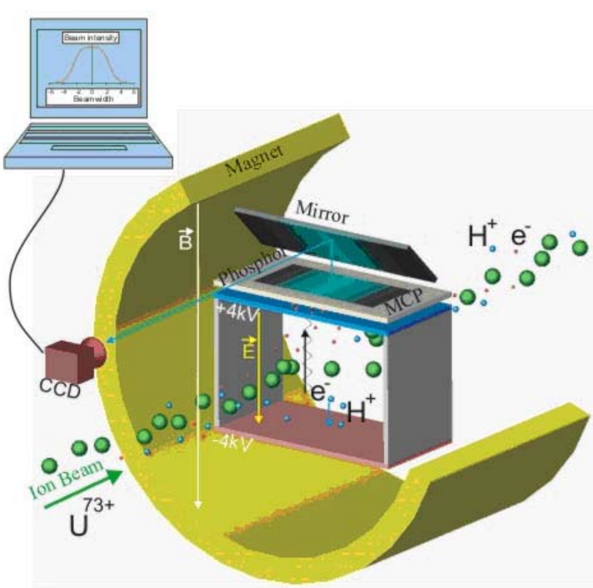

Fig. 1: Advanced residual gas monitor.

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 **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 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 block

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diagram of a single digitizing channel is shown in Fig 2.

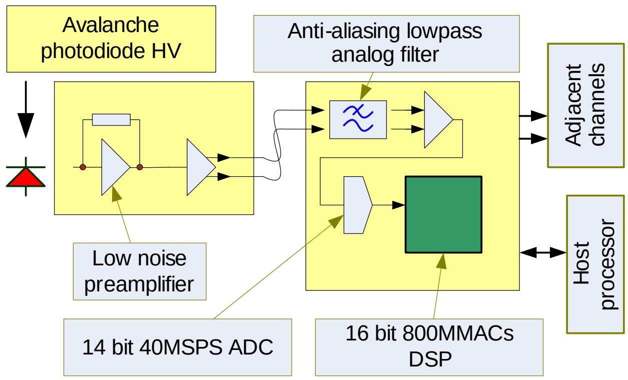

Fig. 2: Single fast readout channel block diagram.

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 will provide excellent dynamic range. Due to the digital processing, the effective bandwidth may be dynamically changed to meet the conditions of DC or wide band modes (Fig. 4).

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.

Table 1: RGM fast readout modes of operation.

Mode	**Time resolution**	**Spatial resolution**
Event counting mode	>1μs	1mm
Enhanced counting	>1μs	0.3mm
Current measurement mode	0.1μs	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 then 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.

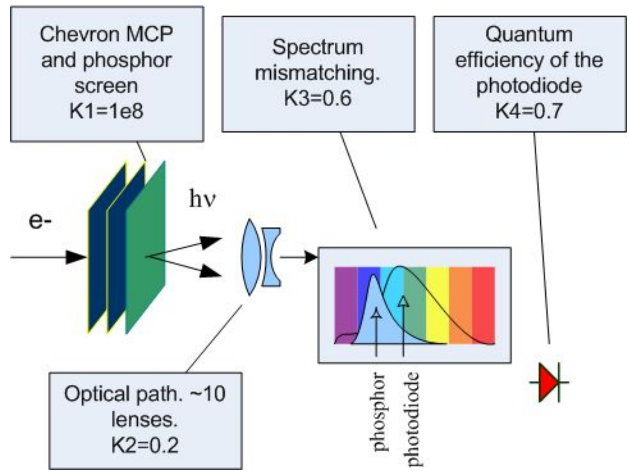

Fig. 3: Transmission characteristics of the 'preelectronic' RGM stage.

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.

In case of the maximal MCP amplification in the counting modes each incident electron can inspire 400μA of avalanche photodiode current pulses with 0.1μs time duration. 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 $1mm^2$ active area photodiode with 15pF capacitance connected to the 4kOhm AD8067 transimpedance amplifier provides the desired bandwidth of 10MHz. In the same time the 4kOhm feedback resistor produces a noise current about $2pA/Hz^{1/2}$ or 6nA RMS value in the selected frequency band. This is an ideal case; in reality the equivalent input noise RMS value exceeds 12nA 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.

Another limitation factor for the fast readout mode of the RGM is MCP saturation. The recharge time of the MCP is about 10ms 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 2nC output charge ($1.25 \cdot 10^{10}$ electrons) from the 700mm^2 surface. One can estimate that one square millimetre of MCP with gain 10^6 will be saturated by less then 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.

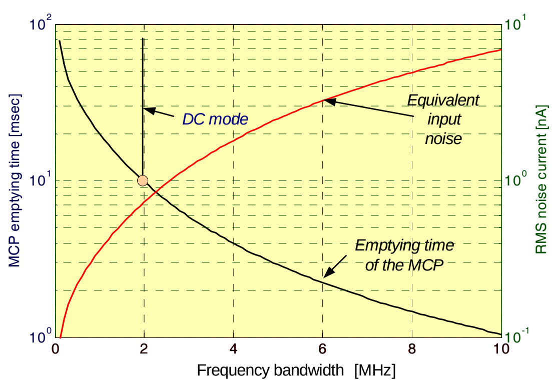

Fig. 4: Expected MCP emptying time and equivalent input noise of the OPA657 avalanche photodiode preamplifier as a function of the system bandwidth.

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.

CURRENT STATUS

A few amplifiers had been tested with avalanche photodiode to compare their parameters. A test assembly was built to check the amplifiers performance. To simulate incoming signal a light emitting diode with proper radiated light spectrum had been placed to the movable holder. A LED position could be precisely adjusted to get the possibility of fine tuning of the photodiode's incoming light intensity. The frequency response of the LED was preliminary calibrated with wideband Hamamatsu avalanche photodiode module. As a result we found that for given parameters Texas Ins. OPA657 operational amplifier showed better performance as a low noise wideband photodiode preamplifier. An achieved signal to noise ratio is enough for 500 µs of the full bandwidth continuous photocurrent measurement without saturation of the MCP.

A data acquisition module with 10MSPS and 12 bit resolution ADC was successfully tested. 40 MSPS, 14 bit module is under production.

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.

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