VISUAL MONITOR FOR NEAR-TARGET BEAM DIAGNOSTICS

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Abstract

With increasing beam powers and current densities in current neutron spallation sources one approaches materials' limits. The importance of near-target beam monitoring rises accordingly. At the Paul Scherrer Institute (PSI), the liquid metal target of MEGAPIE set especially stringent requirements for the reliable interruption of the proton beam in case of an anomaly in the incident current density distribution. A completely novel device called VIMOS based on the optical monitoring of a glowing mesh has been devised. By now, the system has been operating successfully for five years. Starting from the initial goal of reliably detecting beam anomalies in a timely manner the scope of the system has been extended to serve as a standard device for beam monitoring and fine tuning of the settings of the beam transport lines. In parallel to the expansion of the use of VIMOS over time, requirements for improving the maintainability of the system while also reducing concurrent cost have become more urgent. At the same time more quantitative data on the beam are aimed at.

INTRODUCTION

Five years of operation of VIMOS clearly produced a wealth of operational experience and also resulted in some data, which were not expected form the beginning. In the following, a few selected highlights are presented as well as their impact on the course of the further development of the system.

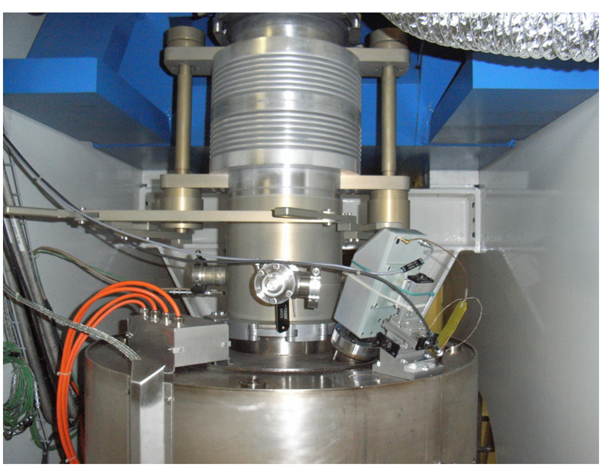

Figure 1: Camera, original installation.

VIMOS in its original configuration derived its sensitivity in part from the spectral response of the imaging tube in the used radiation resistant camera [1]. With a steep cut-off towards the infra-red, the detected signal rises steeply in case mesh-temperatures get higher and more emitted intensity is shifted to shorter wavelengths correspondingly.

INITIAL SENSITIVITY EVOLUTION

One observation at the start of the system five years ago was a significant decrease of the observed signal for identical beam conditions during the first year of operation. This had been attributed to blackening, i.e. an increase of effective emissivity, of the tungsten mesh under proton irradiation [2]. Starting with an effective emissivity of 0.3 and increasing it to 1, results in a reduction of signal in the sensitive wave band of the first VIMOS camera of 100.

Employing the same special tool as during the initial set-up, further evidence for this change in emissivity has been obtained in the meantime. A light emitting diode close to the mesh can be used for fine alignment of the camera. Whereas the image taken in 2005 (Figure 2, top) clearly shows some reflections these are absent in the corresponding image of 2009 (Figure 2, bottom).

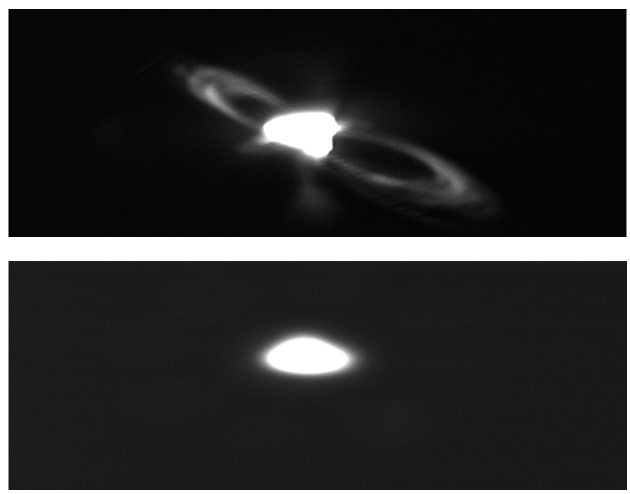

Figure 2: Set-up of the VIMOS camera by means of a special tool with a light emitting diode five years apart. Whereas the top image from the very start of operation features some reflections, nothing of this kind is visible after "seasoning" of the mesh. The absence of reflected light is consistent with the observed decrease in overall signal during the first year of irradiation.

CAMERA LIFE TIME

Initially, the tube based cameras showed very reliable and constant performance over the course of the operation periods at SINQ. During the irradiation of MEGAPIE severe degradation occurred within weeks [3]. The current amplification of some transistors inside the camera was reduced by a factor of five, which, most importantly, lead to a reduction of the usable sensitive area on the entrance window of the camera and to a shift of the image. Whereas there was no immediate loss of sensitivity with respect to the required safety function, because of easy software compensation, the expensive cameras had to be replaced at short intervals to guarantee their full functionality. An increase in the amount of fast neutrons scattered downwards from the target by a factor of two was found responsible for the damage to the cameras, most probably due to these neutrons after thermalisation [4].

A new design of the standard target in SINQ will result in similar neutron fluxes also for a solid target [5]. In order to cut down on camera wear (and maintenance cost) a radiation resistant light guide has been introduced with the aim of placing the camera four meters away at a location with much reduced radiation exposure.

During the irradiation period of 2008 no dramatic deterioration in the transmission of the light guide has been observed. The tube based camera employed during this time exhibited unchanged performance.

For the last 6 weeks of 2008 a standard CCD camera without any shielding was installed to verify the feasibility of using inexpensive semiconductor based devices in principle. This camera exhibited clearly observable degradation in the form of hot pixels, transient as well as more permanent ones, and increased noise already after short exposure. Nevertheless, it worked well over the whole remaining operation period and it delivered all the time signals which demonstrate that it could have been used for a much longer time without endangering the responsiveness of VIMOS.

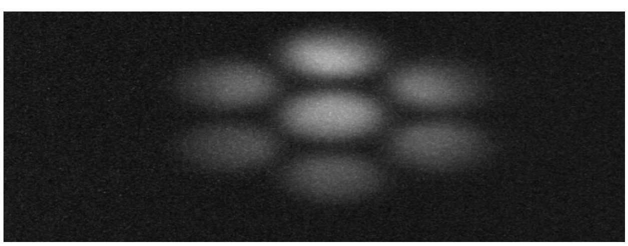

Figure 3: Image obtained through the light guide and with a CCD camera without shielding after 6 weeks of operation during nominal beam conditions at 1350 µA.

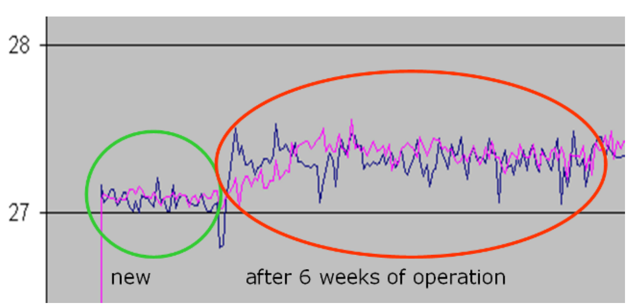

Figure 4: Representative "empty" signal from the first CCD camera, i.e. average over non-illuminated sector of frame, at the start (green circle) and at the end (red oval) of the VIMOS service period. Due to hot pixels the background level shifted just noticeable after irradiation, and fluctuations from frame to frame increased.

EXPANDED FUNCTIONALITY

Assuming that a given light guide can be used for several irradiation periods, i.e. for a minimum of two years, several improvements of the VIMOS system can be implemented:

- Use of inexpensive semiconductor based (CCD) cameras.
- Easy and quick replacement of cameras at the far end of the image guide.
- Splitting of the detected light into diverse optical paths.
- Selecting different wavelengths for better diagnostics.
- Absolute calibration of the image in terms of beam current density.

The first two bullets above were the predominant aim for short-term upgrades. If possible, the running cost of the system had to be reduced while improving the maintainability of the system. If the lifetime of the optical fibers outlasts the operational time of the tube based cameras a significant cost reduction can be achieved.

As reported above, a standard CCD camera showed satisfactory performance during a first test run at the end of 2008, even without shielding. Adding some graded shielding will definitively minimize camera degradation.

Once it has been proven that semiconductor based cameras can be employed long enough at the new remote position, additional and rather informative data can be obtained. Splitting the collected light into separate channels allows for keeping the "spectrometer-mode" sensitivity in one "alarm-signal" path while recording a less non-linear response in a second channel.

Measuring the relative signal strengths for two different wavelength-windows enables one to derive the absolute temperature of the glowing mesh rather independent of the losses in the optical transmission. Calibration in a in-active test set-up is then possible. Knowing the exact temperature of the mesh one can determine the heat deposited by the beam when passing through the mesh, and in the end obtain the current density distribution of the proton beam on the target in $\mu A/cm^2$.

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