VIMOS, NEW CAPABILITIES FOR AN OPTICAL SAFETY SYSTEM

K. Thomsen, J. Devlaminck, PSI, 5232 Villigen, Switzerland

Abstract

VIMOS is a dedicated safety system developed at the Spallation Neutron Source SINQ at the Paul Scherrer Institut, PSI, in Switzerland. VIMOS very directly monitors the correct current density distribution of the proton beam on the target by sampling the light emitted from a glowing mesh heated by the passing protons. The design has been optimized for obtaining maximum sensitivity and timely detection of beam irregularities relying on standard well-proven components. Recently it has been demonstrated that technical boundary conditions like radiation level and signal strength should allow for upgrading the system to a sensitive diagnostic device delivering quantitative and image-resolved values for the proton current density distribution on the SINQ target. By determining the temperature of the glowing mesh from the signals in two separate wavelength bands the temperature distribution over the mesh can be derived und subsequently the incident proton beam current density distribution. Work aimed at investigating the feasibility of adding these diagnostic abilities to VIMOS shows initial promising results.

VIMOS, SAFETY SYSTEM

One of the outstanding features of the SINQ neutron spallation source at PSI is its vertical insertion with the proton beam impinging on the target from directly below. Whereas this design is favourable with respect to the circulation inside a liquid metal (LM) target, it entails the severe risk of major facility damage in case of a leak. To minimize the risk of burning a hole through the liquid metal container with the beam and subsequently perforating the lower target enclosure of the MEGAPIE LM target, a new and additional safety system named VIMOS has been devised and successfully installed [1,2].

VIMOS is based on a most simple and direct approach, i.e. it monitors the glowing of a tungsten mesh inserted into the proton beam closely spaced in front of the target. This mesh is heated by the passing protons, and VIMOS watches for deviations from the expected visual signal. In case that any hot spot due to unintended beam concentration is detected, an alarm is triggered and the accelerator is switched off in less than 100 ms. In order to react most quickly to any unexpected increase of the glowing signal from the mesh, VIMOS has purposely been designed with a strongly non-linear response function [2].

VIMOS works reliable since its installation before the MEGAPIE target irradiation started and it has proven its value actually already in the commissioning phase. Now it is routinely used for beam monitoring during normal operations by the operators of the accelerator also with SINQ's standard solid state targets.

Aim of an Upgrade

In the light of the proven reliability and usefulness of VIMOS, the wish for additional capabilities of the system has emerged. One demand was to somehow calibrate the system for a display of beam current density. The other request is for enhanced sensitivity, i.e. responding also at lower current (-densities), to provide more information for set up, in particular at phases when the beam at low current is newly directed onto the SINQ target.

As the original safety goal of reacting only to hot spots imposes some limitations and inherent difficulties for obtaining more detailed diagnostics' information on beam profile during normal operations, a comprehensive upgrade of the system has been envisioned [3].

IMPLEMENTATION OF DIAGNOSTICS

One stringent boundary condition right from the start was that the safety function of VIMOS should stay untouched, new features should only come on top and as far as possible without interfering with the well-proved safety relevant installation.

Following a stepwise approach, several pre-conditions and key issues have first been identified and scrutinized before designing added diagnostic capabilities.

Enabling Conditions

Originally, VIMOS employed a radiation resistant camera, which was directly mounted in the focus of the colleting mirror and thus exposed to irradiation by back-streaming protons and high energy neutrons [4]. Epithermal neutrons in particular caused damage to the semiconductors in the camera as, after being moderated by scattering in the shielding in the surroundings, they changed the doping and thus impaired proper functioning after several months of operational exposure.

In order to increase the lifetime of the expensive cameras and also in anticipation of possible future upgrades, the camera position has been moved 3 meters further away. The light is now transmitted to the new camera position on a wall of the SINQ beam vault by means of a radiation resistant image guide [5].

With the improved possibility of packing substantial graded shielding around the sensor, the original tube-based camera has been replaced by a more standard off-the shelf CCD camera [6].

A light guide and the first shielded CDD camera have been installed in November 2008 and work since then as expected. The camera shows only acceptable damage in the form of increased noise, which does not impede the proper functioning of the system. Little and not quantified radiation damage meaning increased attenuation is seen in the image fiber.

ISBN 978-3-95450-119-9

Approach

With no way of changing any component along the signal path for the maintained safety branch of an upgraded system, the only possibility of obtaining more information was to split off part of the light from the mesh and analyse it more thoroughly than required for triggering alarms.

In order to have a signal under normal operational conditions, the glowing mesh had been designed to heat up to about 900 °C at a nominal current density maximum close to 30 μA/cm^2. Thus, ample light at infra-red wavelengths is emitted by the mesh already at lower temperatures; this might be used for increasing the overall sensitivity. For higher temperatures, the total amount of light increases steeply (T^4) and the maximum of the emission is shifted to shorter wavelengths.

As the relative contribution of visible light to the total increases with higher beam current densities it is possible to determine local mesh temperatures, and thus ultimately beam current densities, by comparing the relative signal strengths in a short versus a long wavelength band [3]. A principal sketch of the optical arrangement with separated channels is depicted in Fig. 1.

Signal-Generation, -Transfer and -Evaluation

Following the path of the light and its detection in two channels, the stations of the signal enlisted below have been identified and investigated.

- ***Glowing mesh:*** unchanged, approximately 1 per mill of the beam power is deposited; cooling happens via radiation at predominantly infra-red wavelengths
- ***Mirror:*** unchanged, almost flat reflection over the full wavelength range in question between 400 and 1100 nm (small dip at ~800 nm)
- ***Light guide:*** unchanged, determines the transmitted wavelengths as given by the doped quartz material, non-uniform transmission with a pronounced peak in attenuation around 950 nm
- ***Beamsplitter:*** newly inserted, neutral density, allows light from the fiber into the new branch for temperature determination while leaving the safety channel ending in the now qualified CCD camera (KP-M2AP) almost untouched
- ***High/Low -pass filter:*** splits short-wavelength light off, while letting the longer near-IR pass
- ***Camera for visible:*** same as in the safety channel
- ***Near IR-camera:*** very similar to the type in the other channels but with enhanced near-IR response (KP-M2RP)
- ***Image analysis software:*** to be written newly, comparing the relative strength of the signals in the two wavelength bands for current density determination and some additional new functionality

To allow for the general adaptation of the amount of light entering the fiber, grey filters can be inserted at the end of the light guide close to the mirror, which is actually also done already now.

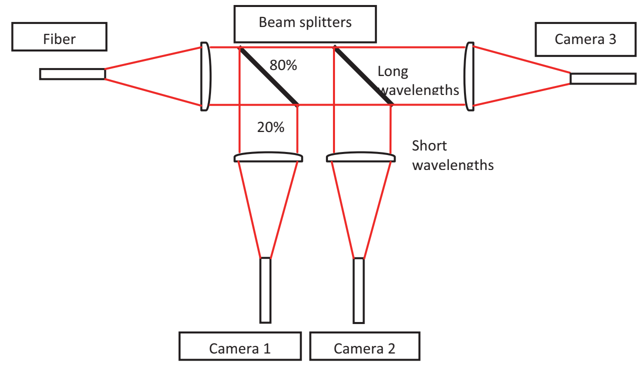

Figure 1: Principal sketch of optical arrangement with three cameras for safety (camera 1) and for local temperature / current density determination (cameras 2 and 3).

FIRST RESULTS

In a first attempt to assess the feasibility of the intended upgrade, the light signal emitted by the glowing mesh was determined and then folded with the transmissions of the individual elements along the optical path. This was done in two steps, starting with deriving the calibration of local mesh temperatures with respect to current density by means of numerical simulation, see Fig. 2.

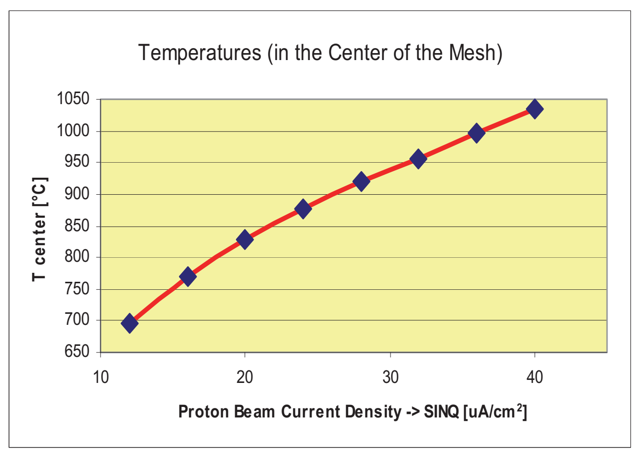

Figure 2: Over the range of usual operational beam conditions on the SINQ target the maximum mesh temperature changes in nice correspondence to the proton beam current density.

As the outcome of an initial very coarse approximation was positive, calculations have been performed taking the relative transmissions all optical components for different wavelengths into account with a binning of 20 nm.

It can be stated that the expected relative rise in the short wavelength channel is significantly larger than for the near-IR channel. Thus, temperature determination based on the ratio between the signals in both channels appears possible at a level good enough for being useful to operators, see Fig. 3.

ISBN 978-3-95450-119-9

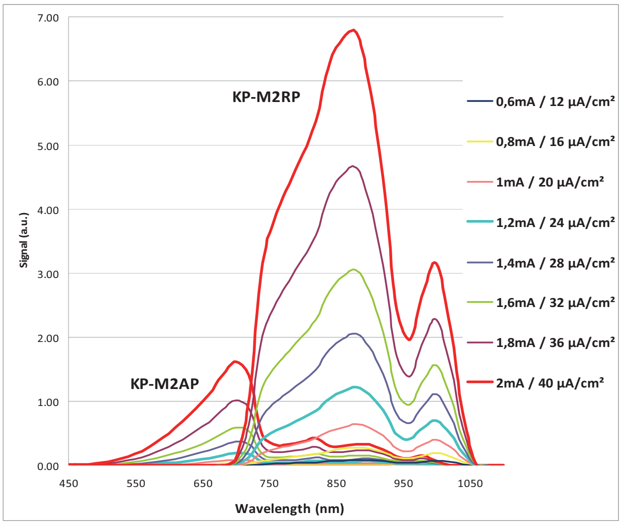

Figure 3: Selecting a beam splitter, which discriminates wavelengths at nominal 700 nm yields usable signal strengths in both channels; the signal in the visible range increases faster with beam current (density) than the signal from the near-IR.

Even in the relatively narrow window of transmission as determined by the image light guide, temperatures in the interesting range produce significant signals. The diagnostic channel thus should yield a useful diagnostics' reading, and systematic errors due the changes in signal transmission with length or irradiation appear to be of limited impact, see Fig. 4.

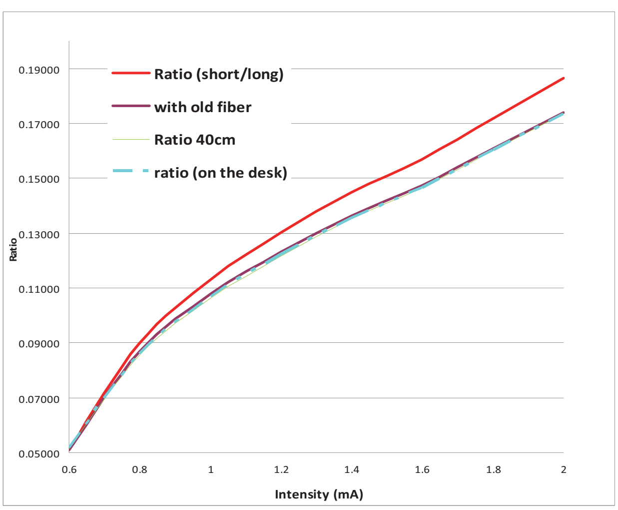

Figure 4: Simulated response ratios: short- / long-wavelength band signals as a function of total beam intensity, which is corresponding to central beam current densities as indicated in the legend of Fig. 3; fiber degradation due to exposure to irradiation can be expected to have about the same systematic effect as switching to a short fiber, as long wavelengths are attenuated relatively less in both conditions.

FIRST EXPERIMENTAL FINDINGS

Given these encouraging theoretical results concerning the feasibility and diagnostic usefulness of the intended VIMOS upgrade, an optical set-up has been built from standard components. With this, first temperatures have been determined simulating the glowing mesh by means of an ordinary incandescent light bulb and simple image analysis software, see Fig. 5.

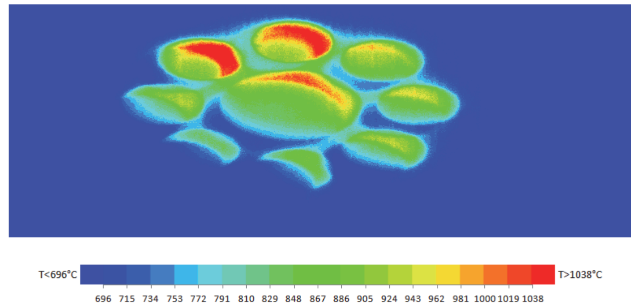

Figure 5: Using a dimmed incandescent light bulb as light source, it was possible to derive meaningful temperatures with a simple optical set-up and image analysis software.

Next Steps

Taking for granted that more thorough theoretical investigations will further confirm the here reported preliminary findings, effort will then be directed to the required dedicated software.

Just to mention one additional planned feature: by integrating the local values for the current density distribution over the whole frame, a number for the total proton beam current can be obtained. Comparing this value to the actually measured current, a measure for the plausibility / credibility can be derived and possible errors in the diagnostics' display can be detected.

Assuming steady progress, an optical assembly will be installed in the SINQ beam vault during the next service shut down at the beginning of 2013.

ACKNOWLEDGMENTS

Most valuable contributions by A. Kalt for the optical set-up are gratefully acknowledged.

REFERENCES

[1] W. Wagner, F. Gröschel, K. Thomsen, H. Heyck, Journal of Nuclear Materials 377 (2008) 12.
[2] K. Thomsen, NIMA 575 (2007) 347.
[3] K. Thomsen, "VIMOS, Beam Monitoring for SINQ", DIPAC 2009, Basel, May 2009, Proceedings, p. 206.
[4] Arcos 14c is produced by Opticon GmbH, Nobelstraβe 2, D-76275 Ettlingen.
[5] http://www.fujikura.co.uk/fibre_optics/products/speciality_fibre/figr.html
[6] http://www.hitachi-keu.com/content/industry/kameras_sw/kp_m_serie_e.htm

ISBN 978-3-95450-119-9