BEAM INDUCED FLUORESCENCE (BIF) MONITORS AS A STANDARD OPERATING TOOL

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Abstract

The Beam Induced Fluorescence (BIF) Monitor was developed as a non-intercepting optical measurement device, dedicated for transverse beam profile monitoring at high current operation at the GSI Heavy Ion Linear Accelerator. Nowadays, BIF monitors are installed at four different locations and handed over to the operating team as a standard diagnostic tool. A stable running setup and software is presented and first exemplary measurements taken during daily operation are shown.

MOTIVATION

Especially for high current operation at the GSI Heavy Ion Linear Accelerator (UNILAC) as demanded for the new Facility for Antiproton and Ion Research (FAIR) non-intercepting beam diagnostic methods are required.

The standard measurement devices at GSI used for transverse beam profile determination are Secondary Electron Emission grids (SEM). For high current UNILAC operation, the pulse duration has to be shortened to avoid damage of the intercepting tool and 5-10% of the particles are lost due to the grid interaction. The shortening of the beam pulse affects all virtual accelerators running in parallel. The BIF monitor, whose intercepting medium is only gaseous nitrogen, is destined to replace the SEM grids at high current operation.

BIF PRINCIPLE

The BIF principle is based on the observation of fluorescence photons emitted by excited nitrogen molecules. Depending on the energy loss of the interaction between ions and gas molecules, different excited states are possible, mostly emitting photons in the range of 390–470 nm.

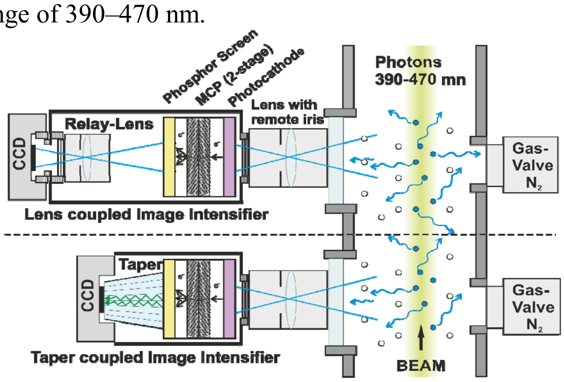

Figure 1: BIF detection principle with relay coupled (top) and taper coupled (bottom) CCD camera.

The photon yield increases proportionally to the inserted gas pressure, the number of particles in a bunch and to the square of the ion charge.

EXPERIMENTAL SETUP

For UNILAC operation, a single shot measurement at the lowest possible gas pressure is required. Hence, the optical system is optimized for single photon detection. After the first conception extensive investigations in the properties [1] and improvements of hardware and software [2, 3] were performed. The following setup was optimized for the needs at GSI UNILAC.

Image Intensified Camera System

Each monitor comprises two perpendicularly installed image intensified camera systems for horizontal and vertical beam profile determination. The Proxitronic camera system BV 2582 BX-V 100N [4] is arranged user-specific with a bialkali photocathode (quantum efficiency of 15- 20% at 390- 470 nm), a 2-stage multichannel plate (MCP) in V-stack assembly with a magnification up to 10^6 and a P46 phosphor screen with a short decay time of 300 ns and a maximum emission at 530 nm. A remote controllable voltage of up to 2 kV is applied to the MCP by a Proxitronic high voltage power supply, gated with a minimum of 100 ns. For image acquisition, a Basler 311f monochrome CCD (1/2 inch) with VGA resolution and IEEE1394 interface is used [5]. Where first a fiber-taper coupling (25:14) for maximum light transmission between the phosphor and the CCD was used, it was switched to a relay-lens coupling (magnification: 0.6) with a Schneider Componon 35/2.8 combined with an Unifoc 12 mm helical mount [6] to keep the flexibility of easy replacement of a damaged CCD camera (see Fig. 1).

Optical Setup

A special diagnostic chamber with matt finished blackened walls and antireflective-coated fused silica viewports is used for the BIF monitors. The image intensified camera systems with Pentax C1416ER lenses, fixed focal length of 16mm and remote controlled iris [7] are mounted in a working distance of 195 mm. A remote controllable iris of the lens system is an important tool to extend the dynamic range of the system and to adapt the depth of field. The iris is closed when the system is not operating to preserve the image intensifiers from undesired light exposure. The complete optical setup gives a resolution of ~4.5 pixel/mm and a depth of field of ~40 mm. For system calibration a LED target, mounted on a pneumatic drive and adjusted to beam axis is used.

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Gas Control System

Due to the linear behavior of gas pressure which correlates to the number of detected photons without changes in detected beam size and shape [8], the gas pressure turned out to be the ideal control parameter for the standard user to adjust the signal strength.

The Pfeiffer gas control system [9] consisting of a RVC300 control unit, an EVR116 needle valve and a PKR261 dual gauge (Pirani & cold cathode) regulates a local gas bump between $5 \cdot 10^{-9}$ to 1000 mbar, where for usual measurements a gas pressure of about $1\text{-}5 \cdot 10^{-6}$ mbar is applied.

Working Gas

For GSI UNILAC energies of 1.4 to 11.4 MeV/u and typical beam sizes of 5-20 mm, nitrogen turned out to be the ideal working gas for the installed monitors [8].

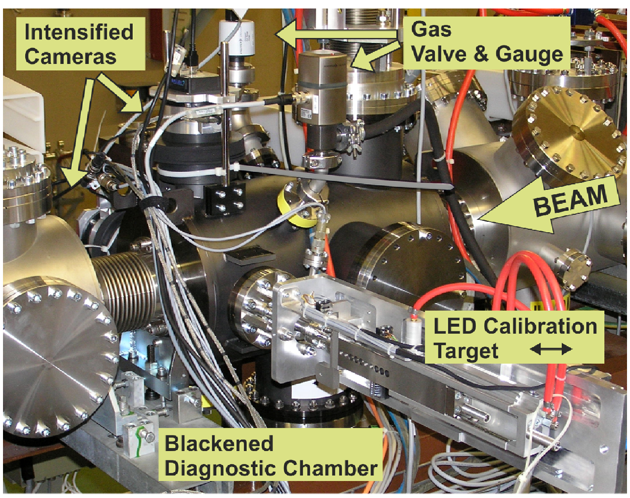

Figure 2: BIF installation at GSI UNILAC.

SYSTEM COMMUNICATION

Due to the high radiation level during beam operation, the beam line access is prohibited and the electronic devices have to be kept in a radiation safe area wherever possible (see Fig. 3). Hence, long cables and remote control options for beam line electronics are required.

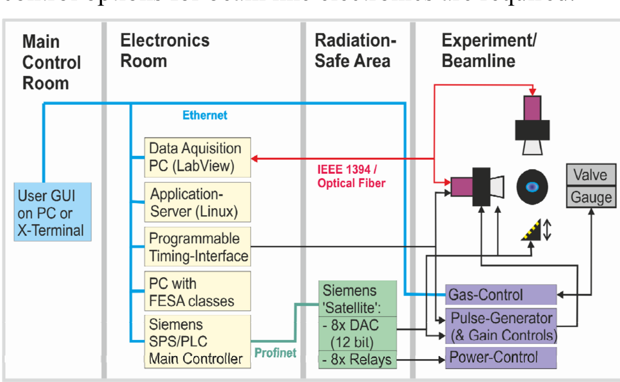

Figure 3: BIF electronic devices and communication.

Slow Controls by PLC

Slow controls like remote voltages for the iris, MCP gain, phosphor gain and the LEDs of the calibration target are applied by a Siemens PLC driven DAC (SM332: 12 bit/ 4 analogue outputs). Additionally, a relay (SM322: 8 digital outputs) is used for remote power control of all electronics near the beam line [2, 10]. A PC with FESA classes handles the PLC communication [3].

Timing Control

A custom-made programmable timing-interface is used to decode the GSI machine timing and to provide TTL signals and gates of user-defined length. To send and transmit timing signals over long distances, a custom-made TTL to RS485 (EIA 485) converter is used. The signals are transmitted differentially to minimize the influence of electrical noise.

Gas Control System

The Pfeiffer gas controller is placed near the beam line and remote controlled via Ethernet using a RS232 to Ethernet converter.

Image Data Acquisition

Due to the maximum cable length of a few meters for the IEEE1394 standard a Fiberoptic extender is used. Image data with a maximum frame rate of 60 images per second (uncompressed images, full frame) are transferred to a data acquisition PC.

SOFTWARE

A Windows PC with a LabView application is used for image acquisition and the first analysis of the image data (see Fig. 3). The custom-designed C++ program ProfileView [11] on the Linux application server receives the pre-analysed data, performs further calculations and presents the results in a graphical user interface (GUI). ProfileView also controls additional hardware devices like the timing control, the gas control and the slow controls via FESA to the PLC [3]. For operation, the GUI is shown on X-Terminals in the main control room.

ProfileView

The ProfileView Software is designed for two different applications. An easy-to-use GUI ('User Mode') is destined for the operating crew to run BIF as a standard beam profile monitor. Only the gas pressure within a limited pressure regime is a free parameter controllable by the user to adjust the light yield. All other parameters are automatically set to reasonable values. The user can observe profiles of original data as well as pre-analysed profiles with an applied moving average filter of up to three monitors (horizontal and vertical plane) at the same time on the GUI (see Fig. 4) and save the projections.

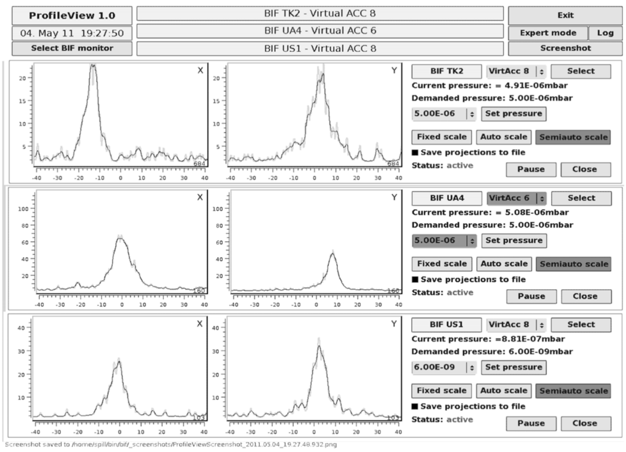

Figure 4: ProfileView GUI in ‘User Mode’.

An additional 'Expert Mode' enables experienced users to set all other parameters, like MCP gain and phosphor screen gain, aperture of the iris and the timing manually. In the Expert Mode, original images can be displayed and saved. It is used for debugging or research experiments.

COMISSIONING & USAGE

The advantages of BIF monitors are:

- A non-intercepting beam diagnostic device, in contrast to SEM grids
- No pulse shortening required for high current beams, thus the full beam pulse can be observed as well as a defined time window of minimum 100 ns
- 100 x 80 mm^2 field of view at a resolution of ~4.5 pixel/mm
- For low signal strength, images can be accumulated and smoothing or binning algorithms can be applied
- Particle losses due to the beam-gas interaction are negligible
- No charge changing processes were detected yet

Before handover to the operation crew, every BIF was extensively tested and projections were compared to the profiles simultaneously measured by a SEM grid. A good agreement between the two measurement devices is shown in Fig. 5.

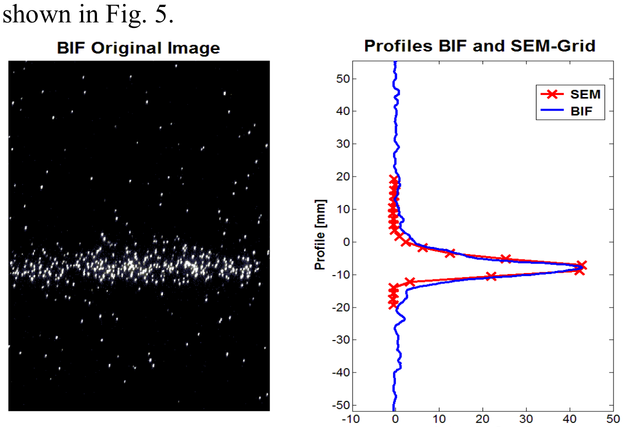

Figure 5: Single shot BIF image and profiles of BIF and SEM grid measurement, UNILAC section UA4 at 11.4 MeV/u, U 39+, $4{\cdot}10^{10}$ ppp and $5{\cdot}10^{-6}$ mbar N_2.

The signal strength and the profile quality obtained by the BIF monitor depend on many factors. Slight differences in manufacturing of the image intensified camera systems provide different dot sizes and light yields, whereas radiation or light emitted by other devices significantly increase the image background. Thus the signal has to be evaluated from case to case and adapted by choosing an appropriate nitrogen pressure. A rough estimation of beam parameters where good signals were achieved is given in Table 1. For all measurements, a local gas pressure of $5{\cdot}10^{-6}$ mbar was used. The measurements were done under user conditions and no expert optimization was performed.

Table 1: Typical Beam Parameters for Usage of BIF

Energy [MeV/u]	**Ion and Charge-state**	**Particles per Pulse**	**Example**
1.4	Ar 1+	$2{\cdot}10^{12}$	Fig. 4, bottom profile
11.4	Ar 11+	$2.8{\cdot}10^{11}$	Fig. 4, top profile
1.4	Ta 3+	$2{\cdot}10^{11}$	
1.4	U 4+	$7{\cdot}10^{11}$	
11.4	U 39+	$3.6{\cdot}10^{10}$	Fig. 4, middle profile

OUTLOOK

After the proof of functionality under daily conditions further monitors will be installed at GSI UNILAC, also in special areas e.g. at charge separation. At the new FAIR facility, several BIF monitors are foreseen in the HEBT lines.

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