Transverse Beam Measurements Using a Computer Based Image Analysis System

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Abstract

In this paper we will describe a system for the measurement of beam parameters using the light generated by a scintillating screen. Details on the architecture of the image digitizer system and analysis software will be discussed.
Preliminary measurements with heavy ion beams from the Tandem of the INFN LNS Heavy Ion Facility of Catania will be presented as a proof of the performance of the system

1. INTRODUCTION

Observation of beam profiles on fluorescent screens is perhaps the oldest and simplest accelerator diagnostic technique. With the advent of inexpensive, high quality video imaging systems and the widespread availability of powerful on-line computer systems, it has become practical to extract detailed and quantitative informations from video images in near real time [(1)].

The goal of our work has been to design a diagnostic apparatus which must fulfill the following requirements:

- it has to work with digitized images of light emission from different kind of beam interaction phenomena (luminescence, OTR, residual gas emission, etc.)
- it must be easy to configure in order to guarantee different regimes of operation
- it must be easy to insert into the computer control structure of the accelerator facility where it is in use and it must be flexible
- it must be cost effective evaluating characteristics vs. requirements
- it must be friendly both from the operator point of view and from the developer point of view
- it must be based on commercial components (hardware and software) available on the PC market.

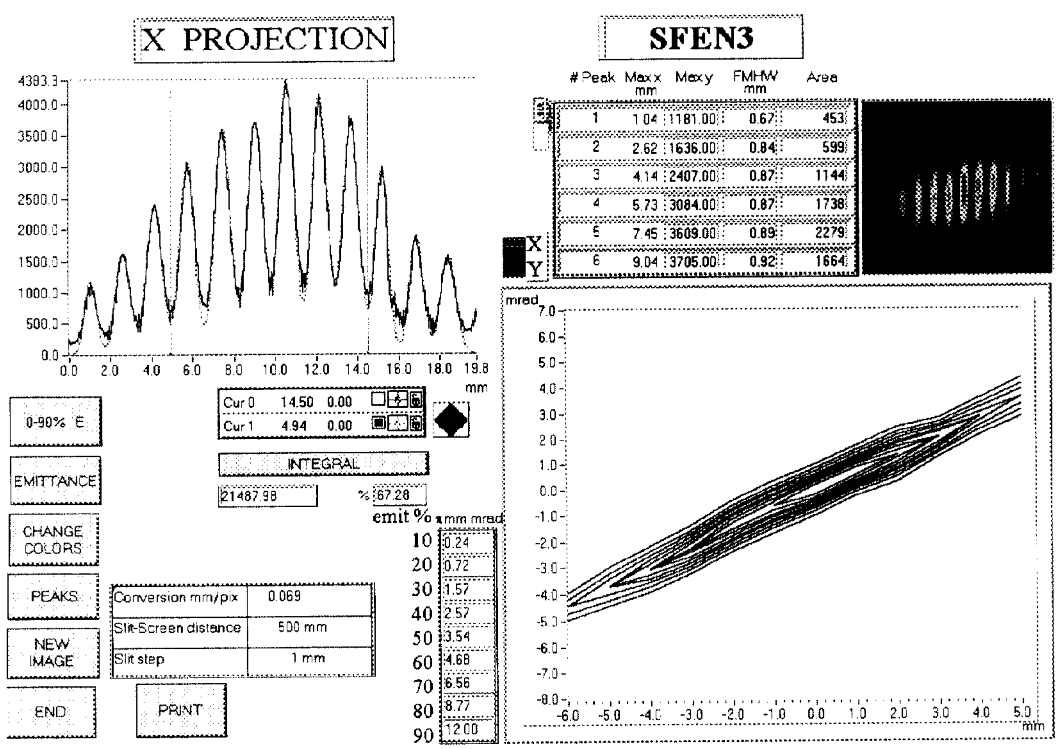

Fig. 1 Front panel layout of the analysis software

This set of requirements has been finalized to the development of a general purpose instrument which may be easily used in any kind of beam analysis structure(2).

2. BEAM IMAGE PROCESSING SYSTEM

The conceptual layout of the system is quite a conventional one, and it may be subdivided into 5 different sections : a converter of the beam into a visible image; a TV camera; an image input device; a processing device and a video output monitor.

In the following we summarize the rationale of the main choices adopted during the evolution of the project.

2.1 Converter Screens

The design and the development of the apparatus started using fluorescent materials as converter screens. This choice arises from the fact that fluorescence is a well understood phenomena which allows to work easily with different beams (protons, ions, electrons) in order to gain experience with the overall performances of the whole instrument. Moreover one may take advantage from a wide literature and from the knowledge of industrial firms on suitable materials(3).

Samples of various fluorescent materials have been examined, ranging from classical zinc sulfide to sophisticated doped alumina screens. The parameters of interest have been mainly the intensity of the light vs. beam current (to determine the dynamic range of the material) and the lifetime of the screen. Light intensity has been measured in an experimental setup where it was possible to measure at the same time the beam current by means of a Faraday cup. We used a Faraday cup with a sensitivity of 1 nA. The lifetime of the screen has been measured acquiring the light emitted at fixed time intervals, using a continuous and stable ion beam.

A first, qualitative test showed that alumina based screens provide higher sensitivity and longer lifetimes than zinc sulfide ones.

We started a deep investigation on alumina screens using two different kind of materials : an inexpensive white Al_2O_3 ceramic plate, 1 mm thick, and a more sophisticated screen of Chromium doped Alumina, 0.475 mm thick, from Morgan Matroc Limited (this material is known in the literature as Chromox 6).

Experiments have been carried out using $Oxygen^{8+}$ and $Nichel^{5+}$ beams with energy ranging from 100 kV up to 12 MV. Some measurements have been done also using a 1 mA, 5 kV electron beam.

Chromox 6 screens have proved to be more valuable both for the sensitivity and for the radiation resistance.

Beam currents as low as 1 nA at 12 MV and 100 nA at 100 kV have been well detected. With beams up to 300 nA at 12 MV no saturation effect due to the material has been measured.

As far as radiation resistance is concerned we have observed that after a period of the order of 10 minutes the response becomes asymptotic to one half of the initial value. Flux of the order of 5×10^{11} ions/(sec cm^2) have been withstood for a period of 3 hours with no further damage.

In the future we will measure bulk anodized aluminum screens which may be interesting in order to eliminate surface charge effects stemming from a buildup of charge.

2.2 TV Cameras and lenses

A low cost, 1/2 inch CCD interline camera (COHU 4910) has been used for all the experiments. Sensitivity is of the order of 1.3 lux (full video, Agc off) at full spectrum and may range up to 0.016 lux (30% video, Agc on). Spectral response is well suited to Chromox 6, showing a 50% response to 700 nm wavelength. The camera may be synchronized with the line allowing to operate with pulsed beams.

A manual zoom lens (18-108 mm, f 2.5) has been chosen as the standard optic system. Although much more expensive than a fixed lens, this device would allow a wider set of operational conditions.

As far as our experience is involved we have no experimental observation of radiation damages on the camera or on the lenses with ion beams like the ones discussed above.

2.3 Signal Digitizing

CCD signals have been processed using a frame grabber which simply takes the video signal and digitizes it. A frame grabber is well suited for the accelerator environment since it can be connected to any standard RS-170 camera and it allows a continuos observation of the beam signal while digitizing it. We have so far chosen a Data Translation (DT 2867LC) PC plug-in card with 1 Mbyte of on-board memory. This board provide four camera inputs along with external sync and trigger capabilities. Video signals are digitized using 8 bit flash ADCs, with programmable gains and offset. Input and output look up tables allow to use false colors as an aid tool in data presentations. The board requires an external RGB monitor to show live images.

This board has been chosen since it provides a quite low cost solution, still maintaining unique features as the external trigger to synchronize board operations with beam related events.

2.4 Data Processing and Operator Interface

Data processing has been splitted into two different programs working under Windows 3.1 operating system. The first program has been designed to drive the frame grabber and to provide data from acquired images in a suitable format for archiving and further analysis. Image acquisition requires careful and detailed programming of the frame grabber board. For this reason we have based our program on libraries made by Data Translation (Global Lab) which greatly simplify such a job. The main tasks performed by the program are:

- the setup of the hardware
- the geometric calibration

- the choice of live or single frame operations
- the definition of a region of interest to reduce the amount of data to handle
- choose of the storage format for data (TIFF or simply binary image dump)
- the choice to take sequence of frames, driven by hardware trigger or software flags
- the subtraction of a fixed background
- the use of simple digital filters to improve S/N ratio.

Such a program will require very small maintenance and has been written in Microsoft Visual C^{++}.

The analysis of the output provided by the above software, is one of the key elements of the whole project. In the design stage we have evaluated many different possible approaches. The leading element in the final choice has been the consideration that we have to provide both a self explanatory instrument and a simple development environment for physicist's analysis. A LabVIEW based program seems to be the right solution, providing an icon driven language and a powerful tool for mathematical analysis with a friendly interface. The program has been designed in a modular way and during the six months required for the development it has experienced 3 major releases, according to the growing of analysis capabilities (fig. 1).

In the actual version the main features of this program are the following:

- the loading of an image (we use a simple binary matrix format)
- the display of the image using false colors according to a user defined look up table
- the display of Cartesian projections
- the automatic measurements of beam position, beam FWHM, beam intensity
- the fitting of beam projections with gaussian or lorenztian curves
- the capability to analyze beam images using line curses
- the capability to measure emittance (providing a multi-slit on the beam path or multiple transverse profiles after a quadrupole)
- the comparison of experimental and theoretical data related to emittance distributions
- the automatic calculation of second order momenta of the beam distribution
- the display of emittance related data.

The two programs runs at the same time using two different windows managed by Windows 3.1. A network version of the system (using Windows for Workgroups) has been developed to allow working on 2 different PCs, dedicated respectively to image acquisition and data analysis. Data transfer over a TCP/IP network is possible by means of shareware software.

3. EXPERIMENTAL RESULTS

The system has been extensively tested both in a lab small set up (using electrons) and on the beam lines of the Tandem in Catania. Results obtained with Oxygen and Nichel beams have been extremely satisfactory.

Spatial resolution of the order of 0.07 mm/pixel has been achieved. This value is not an intrinsic limit of the system but arises from the need to have a 36 mm diameter area in the field of view for calibration.

Images due to beams of less than 1 nA (2 mm FWHM) have been easily stored and analyzed. The dynamic range of the instrument, limited by the 8 bit ADCs, has been artificially modified using external gray filters and reducing the aperture of the lenses. Beams up to 300 nA (7 mm FWHM) have been observed and the transverse profiles fit well (within a 2 % of error) with gaussian theoretical curves.

False colors, provided by output look-up table programming, have helped much in the understanding of beam current distribution in the setup of transport lines.

Light emission vs. exposure time to a continuous beam has been measured at different beam currents, showing a well predictable behavior.

Emittance measurements with the multislit method have been obtained within a 15% error. This value accounts for errors due to geometric reasons and image digitalization. The former are common to all the multislit methods, the latter are due to the imaging system resolution. The sensibility so far obtained is of the order of $3x10^{-3}$ which must be compared with $9x10^{-3}$ of a wire based method using the same field of view.

These results suggest that such a system may be routinely used by operators for the tuning of transport lines and by physicists for accurate beam measurements.

References

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