High Sensitivity Beam Intensity and Profile Monitors for the SPS Extracted Beams

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Abstract

Secondary Emission Monitors using caesium iodide coated thin aluminium foils have been installed in the SPS transfer channels to monitor the intensity of the extracted heavy ions beams. Tests have shown an increase by a factor twenty of their sensitivity with respect to bare aluminium foils. Luminescent screens viewed with TV cameras are used to monitor the position and the profiles of the extracted beams. Various luminescent screen materials have been tested. Results on chromium doped alumina, thallium doped caesium iodide and quartz are reported. A dynamic range of 10^3 in beam intensities can be achieved by using these three materials in turn in the usual three screen tanks. Intensifiers used together with CCD cameras and video frame grabbers with incorporated projection calculations are used in conjunction with these screens. Results with heavy ions in the transfer channels and with protons extracted from circulating beams in the SPS are given. Detection sensitivities down to a few tens of protons per video frame have been observed.

I. INTRODUCTION

Oxygen and sulphur ions have been accelerated in the SPS and delivered to the users of the experimental areas in the past, and the instrumentation had been adapted to this low intensity mode [1]. After the approval of the project to accelerate lead ions in the SPS complex from 1994 onwards, the instrumentation for the transfer channels was re-examined. The instruments discussed here are for intensity, position and profile measurements in the transfer lines. The intensities are measured traditionally with secondary emission foils covering the whole aperture (BSI), the position is taken from luminescent screens (BTV) and the profiles acquired with Secondary Emission Grids (BSG). The sensitivity of the BSIs had to be improved substantially. The same was done with a BSG for test purposes, but there was still the limited resolution, the risk of non uniformity from strip to strip and the inherent complexity of the monitor electronics. With the advent of high yield luminescent screens and intensified CCD cameras, it was decided to try to use also the luminescent screens for profile measurements. The output of all these monitors is proportional to the Z^2 of the ions observed.

II. HIGH SENSITIVITY INTENSITY MEASUREMENT

The usual aluminium foils used in Secondary Emission Monitors (SEM) have a yield of 5% at the SPS beam energies. It has been known for some time that this sensitivity could be increased by coating the foils with CsI or KCl. These coatings were thick ones and experienced most of the time some hygroscopic effects and sensitivity degradation with time. As the monitors had to be used over long periods, a thin coating of CsI was tested. A 500 nm thick coating was deposited at CERN on 5 μm aluminium foils with a 100 nm Al evaporated coating. It demonstrated a yield of 100% and a relatively long lifetime. When analysed on the electron microscope, the CsI appears as approximately 0.5 μm droplets covering roughly 40% of the aluminium surface: Fig. 1.

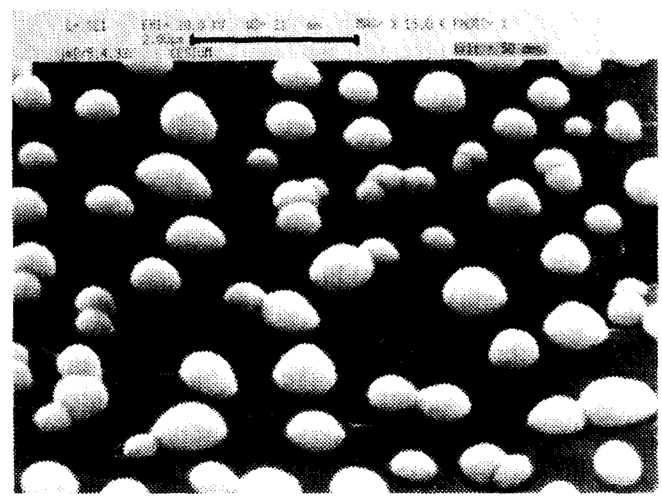

Fig.1: Electron microscope photography of a CsI coating on an aluminium foil. The reference bar at the top is 2 μm long.

Five BSI monitors were equipped with these foils for the sulphur run of 1991 and three more monitors were equipped for the 1992 run for monitoring the injection into the SPS and the ejections towards the North and West experimental areas. Together with a new high sensitivity front electronics, the system has a basic noise level of 10^5 charges with Sulphur, which is the limiting resolution. Studies were made during this period to define the sensitivity, as a function of the various beam parameters, and its variation in time. The gain factor of CsI decreases from a high value of twenty for low peak current beams down to a factor five for high peak intensity beams, the transition taking place around 1 mA peak. The foils which were not continuously submitted to high peak current proton beams of several Ampères, kept their amplification factor over the two years of experience. On the other hand, foils which had been submitted regularly to the traversal of high peak currents had their sensitivity lowered by approximately 20% from one year to the next.

III. BEAM PROFILE MONITORING

It is possible to measure beam profiles with luminescent screens. They have many advantages over SEM-Grids, i.e. high resolution with a minimum of cabling, good dynamic range, and low noise, essentially when CCD detectors can be used. The resolution is given in this case by the size of the picture elements or pixels of the chip. The CCD is a matrix of 604 x 294 pixels, 10 μm in square, made by Philips. For observing the low intensity signals associated with heavy ion operation, a DC intensifier is installed in front of the CCD camera. It has a gain which can be controlled by a low level signal, generated by a DAC under computer control and applied to the high voltage DC/DC converter. It can change the global gain from a low value of 400 up to a gain of 10^4. The Intensifier is coupled to the CCD by two lenses mounted back to back: Fig. 2. The set-up is less compact and efficient in light transmission than a fibre optic coupling, but has the advantage to be far more economical.

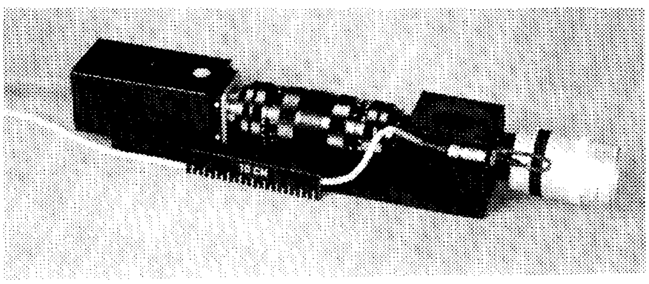

Fig. 2: Intensifier (at left) coupled by two back to back lenses to the CCD camera.

In order to use the screen information to measure beam profiles, the video signal in CCIR standard has to be digitised. As in beam monitoring the beam projections along the horizontal and vertical axis are to be used to calculate the beam emittances, a function which is not yet implemented in the commercial devices, it was decided to build a VME frame grabber module, which next to the digitisation calculates on board the two projections during two successive TV frames. The module has a windowing function, enabling to digitise and memorise a square area within the TV picture. The data reduction achieved permits to memorise several pictures and profiles until the image and profile memories are filled up, e.g. from one image of 256x256 pixels to six images of 100x100 pixels and up to 160 profiles over 100x100 pixels. This information is available for later retrieval. The digitisation is done by an 8 bit flash ADC converting at a rate of 7 MHz. A companion module allows to memorise the full TV image and to display it on the TV monitor until a reset pulse is received. This feature is interesting in the long cycles in use at the SPS. Four Intensified CCD cameras were installed for the 1991 heavy ion run. As they gave satisfactory results, five more were installed for the 1992 run.

The CCD cameras have to be replaced by tube cameras for the high intensity proton runs to avoid radiation damage.

To achieve the best sensitivity of the system, some effort was invested in the study of the luminescent screen material. Up to the heavy ion runs, three types of screen material were used: quartz for very high density beams, Cerium doped Lithium glass and Chromium doped Alumina, the light yield increasing in that order. Thallium doped Caesium Iodide crystals have interesting properties. This material has a better light yield than Al_2O_3 (Cr), is a thousand times faster which is interesting for time resolved profiles and emits light at 550 nm, in the sensitivity region of a normal CCD (450 to 1000 nm). The main disadvantage of CsI (Tl) is its softness which limits its size to a disk of 80 mm in diameter for a one millimetre thickness. The spectral emission curves for the four screens are given in Fig. 3, normalised for a 10^{13} proton beam.

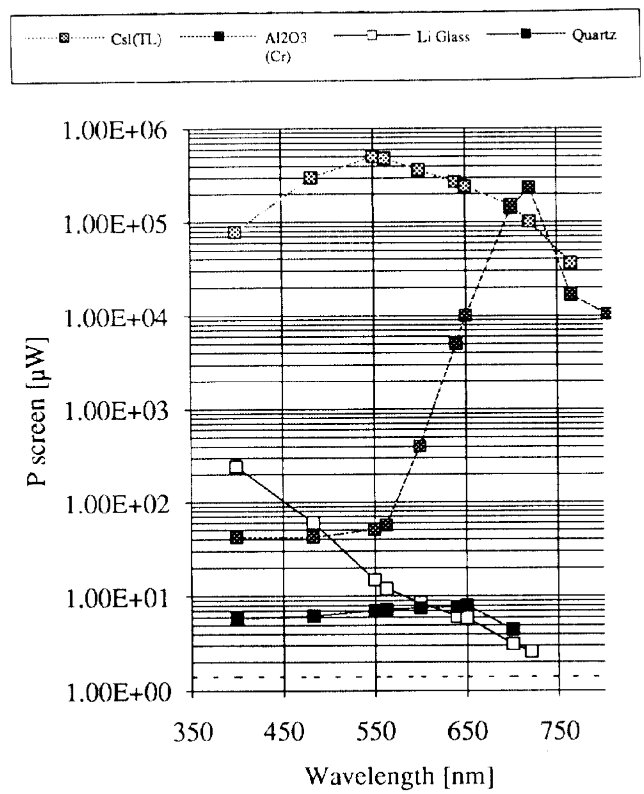

Fig. 3: Spectral emission curves of four screen materials

The lithium glass which is well adapted to TV tubes cannot be used with CCDs as it emits mainly outside the spectral sensitivity of these detectors. The properties of the three screens which are used with CCDs are collected in Table 1, where the sensitivities are given for protons beams of 2 mm diameter FWHM with a screen to CCD demagnification of 10.

Table 1: Screen material characteristics

Material	Activator	λ_c [nm]	decay	Sensitivity
Quartz	none	large	ns	$1x10^8$
Al_2O_3	Cr	700	ms	$2x10^6$
CsI	Tl	550	µs	$7x10^4$

Two Caesium Iodide screens were installed for test purposes in 1992. The results were promising and it was decided to install the previous three screen types in a maximum of monitors. The monitors have four positions, three for screens and an empty one for the free passage of beam: Fig. 4.

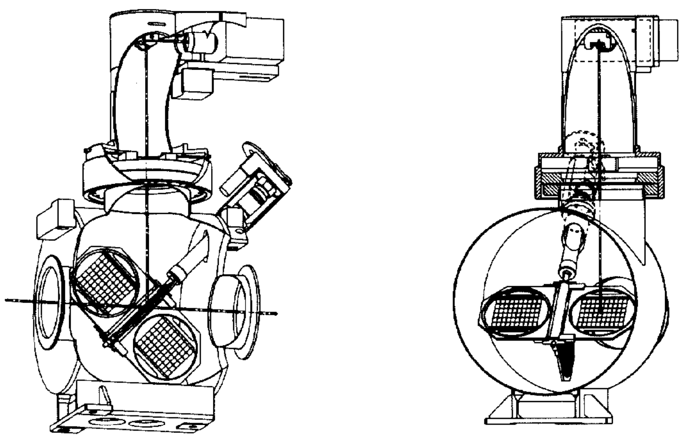

Fig. 4: Luminescent screen monitor with four positions, three for screens and one for the free passage of beam.

During the 1992 Sulphur run profiles of beams with 10^5 ions per profile were taken. A typical example is given in Fig. 5.

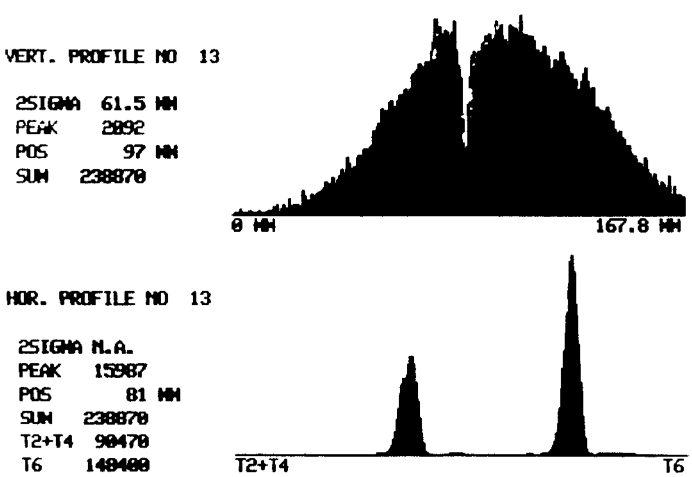

Fig. 5: Horizontal and Vertical profiles of 1.10^5 extracted Sulphur ions (in 20 ms) taken after splitter #1.

In the SPS ring, good quality profiles were also taken with the wire scanners, the signal being acquired with scintillators downstream of the wire.

IV. VERY HIGH SENSITIVITY PROFILE MONITORING.

Encouraged by the good results with heavy ions, a luminescent screen monitor was installed for the crystal extraction experiment in the SPS [2]. The monitor is comprised of a tank identical to that of Fig.4 located on the proton extraction path, under air, equipped with CsI(Tl) and Al_2O_3(Cr) screens and with the standard Intensified CCD camera of Fig.2. It permits a direct observation of the extracted beam on a TV monitor over a wide dynamic range and the digitisation of the acquired images. A lego plot of such an acquisition is given in Fig. 6.

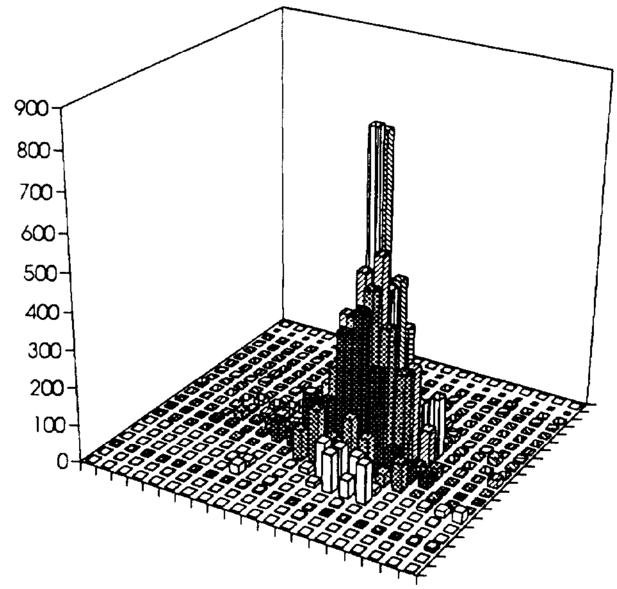

Fig. 6: Lego plot of protons extracted from the SPS by a bent crystal.

By making comparison with scintillator counters, it appears that sensitivities down to one proton per pixel can be obtained with the CsI(Tl) screen and Intensified CCD combination.

V. ACKNOWLEDGEMENTS

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[1] J. Bosser et al.: Beam Transfer Monitors for the Operation of the SPS with Oxygen, Proc. of the 1987 IEEE Part. Acc. Conf., Washington D.C.

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