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CONTROL AND MONITORING OF THE SPS PROTON AND ION EXTRACTIONS

G. Buur, G. Ferioli, J.J. Gras, R. Jung

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For the fixed target program of the SPS, protons and ions are accelerated and extracted towards seven target stations in the NORTH and WEST experimental areas. These extractions range from 10^6 Lead ions to 10^{13} protons with durations of 5 or 2.5 s and are controlled by a closed loop system. The intensity monitoring for this system is done with fast screens observed with Photo Multipliers and Secondary Emission Monitors sampled every 100 µs. Along the beam lines, the intensities of the extracted beams are monitored with fast screens at 100 ns intervals. Time and frequency domain information are extracted for diagnosis from the acquired data. A slower observation system, with a 1 ms sampling interval, is also available for assessing the evolution of the centre of charge, the intensity and the losses along the beam lines during an extraction.

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Control and Monitoring of the SPS proton and ion extractions

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Abstract

For the fixed target program of the SPS, protons and ions are accelerated and extracted towards seven target stations in the NORTH and WEST experimental areas. These extractions range from 10^6 Lead ions to 10^{13} protons with durations of 5 or 2.5 s and are controlled by a closed loop system. The intensity monitoring for this system is done with fast screens observed with Photo Multipliers and Secondary Emission Monitors sampled every 100 µs. Along the beam lines, the intensities of the extracted beams are monitored with fast screens at 100 ns intervals. Time and frequency domain information are extracted for diagnosis from the acquired data. A slower observation system, with a 1 ms sampling interval, is also available for assessing the evolution of the centre of charge, the intensity and the losses along the beam lines during an extraction.

I. INTRODUCTION

The control, monitoring and observation of the SPS extractions has been significantly improved during the 1993/94 shutdown, ready for the heavy ion beams. The instrumentation had to control the extraction to the North and West experimental areas of about 10^{13} protons over a duration of 2.5 seconds as before but it had also to be able to extract around $5x10^6$ Lead ions over a duration of 5 seconds. To control and observe these proton and ion spills, a new hardware and software system (referred to as the Servo Spill System) has been developed and was implemented for the 1994 start-up and the SEM Spill and Beam TV (BTV) Profile Systems have been improved. During the same year the new Fast Spill System was designed to allow the observation of the high frequency structure of the spill. These instruments are now fully operational and their specific functionalities and results are described in the following chapters.

II. THE SERVO SPILL SYSTEM

The main task of this instrument is to control the extraction to the North and West SPS transfer lines of a given number of protons or ions per time slot. Quadrupoles are used to bring the Qh close to a resonance which controls the horizontal beam size and thus the amount of particles extracted by the septum. The feedback information is given by a beam intensity detector located in the transfer line. During proton extractions (~5.10^{12} protons per second) the detector (BSI) measures the secondary emission signal from an Aluminium foil of 20 µm thickness [1]. During Lead ion extractions (~10^6 ions per second) the detector is a Photo Multiplier monitoring a fast Quartz screen [2]. A closed loop system compares this information to a reference value corresponding to the chosen extraction rate, processes the difference, taking into account the history of the current extraction, and controls accordingly the excitation of the quadrupole.

Simultaneously, another circuit samples and stores every 100 µs the signals coming from the detectors, the ring Beam Current Transformer (BCT) and the quadrupole power supply during the whole extraction. This data can be processed on request by the main application program running on an HP work station. It is then possible to check the quality of the spills in both extraction lines (Fig. 1), to study their frequency structure up to 5 kHz and to compare the amount of particles in the transfer lines with the evolution of the current in the SPS ring given by the ring BCT.

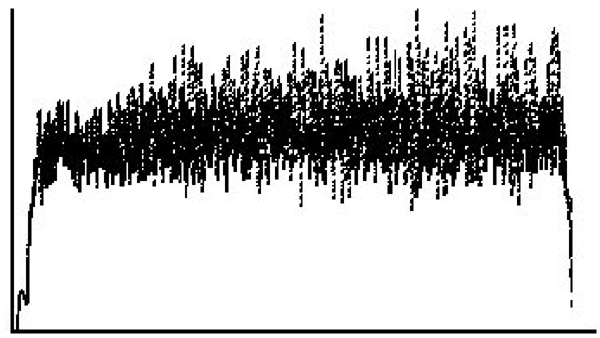

Fig. 1: Spill evolution during a proton extraction of 2.5 s.

To assess the quality of the spill the application divides the acquired spill in blocks of 100 ms and extracts from each of them the standard deviation and the Duty Factor of the spill intensity: Fig. 2. The Standard Deviation results from a normal r.m.s. calculation. The Duty Factor is computed with the following formula:

$$Df = (\sum^n x_i)^2 / (n \cdot \sum^n x_i^2)$$

where x_i is the instantaneous intensity and n the number of acquisitions. Df has values between 0 and 1 and a Duty Factor close to 1 characterises a good extraction.

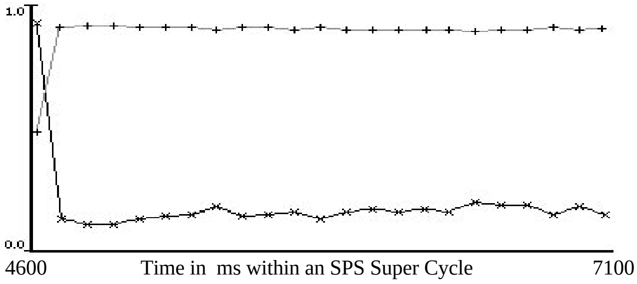

Fig. 2: Duty Factor (+) and Standard Deviation (x) evolutions of the spill intensity over 2.5 s.
N.b.: The S.D. has been normalised with the mean intensity.

III. THE FAST SPILL SYSTEM

This system has been designed for diagnostic purposes. It allows the user to monitor the intensity evolution within an SPS turn, i.e. 23 µs, and turn-by-turn during a full proton or ion extraction. This instrument receives signals from a Photo-Multiplier observing a Quartz screen and samples them every 100 ns. It is hence possible to observe the intensity evolution of the extracted beam over up to 250 SPS turns with a resolution of 230 acquisitions per turn. It uses an application program running on an HP work station. The recorded turns can be consecutive to check the turn-by-turn stability or separate to check the evolution over the whole extraction. As for the Servo Spill, a Fast Fourier Transform facility is available to analyse the frequency structure of the spill up to 5 Mhz: Fig.3.

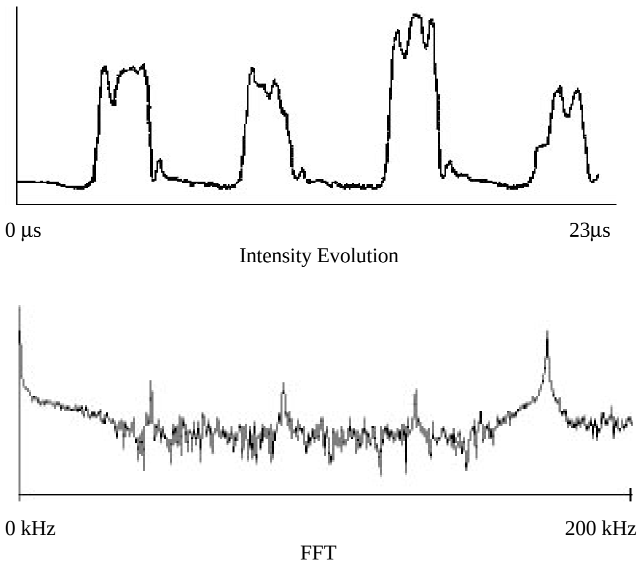

Fig. 3: Top: Temporal structure of an extracted ion beam during one SPS turn showing that the initially four injected bunches are still well separated despite the switch-off of the RF before the extraction.

Bottom: Resulting Fast Fourier Transform showing the harmonics of the revolution frequency.

Another circuit computes and stores every 23 µs the integrated intensity and the duty factor of the corresponding SPS turn. The application program provides the user with an overview of the turn-by-turn intensity and quality evolution of the spill over the whole extraction: Fig. 4.

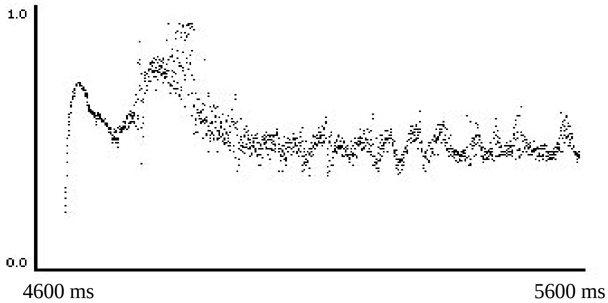

Fig. 4: Turn-by-turn duty factor evolution measured over 1 second during the start of a proton extraction.

IV. THE SEM SPILL SYSTEM

The signals from several SEMs and loss detectors have to be monitored to perform an optimum steering in the transfer lines. This information used to be displayed as raw data on a set of screens. The new SEM Spill System simultaneously collects data from these detectors and makes it available in a convenient form for on-line use. A single VME crate can handle up to 64 detectors, each channel can be amplified, sampled and stored every millisecond. This data can then be processed on an HP work station. From a BSI, one can extract the spill intensity, its duty factor and FFT. One can also extract the centre of charge evolution from a Split Foil (BSPH/V): Fig. 5, the multiplicity of a target from Target Upstream and Downstream Intensity monitors (TBIU/D) and the losses from ionisation chambers. All this information is available for further investigation and since the data were sampled simultaneously, it is possible to make correlations and to observe for example the effect of a position shift on the losses or on the multiplicity.

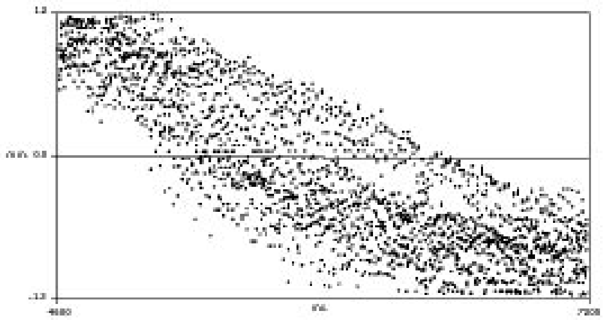

Fig. 5: Horizontal beam drift in front of a target detected by a BSPH during a proton extraction of 2.5 seconds.

V. THE BEAM TV PROFILE SYSTEM BTV

The main purpose of this system is to allow the user to fully benefit from the many screens and cameras (CCD or radiation hard tube cameras) installed in the SPS complex, especially along the transfer lines [2]. The system is able to digitise a beam image given by a camera and to display the 2-D patterns (fig. 6) and computed projections.

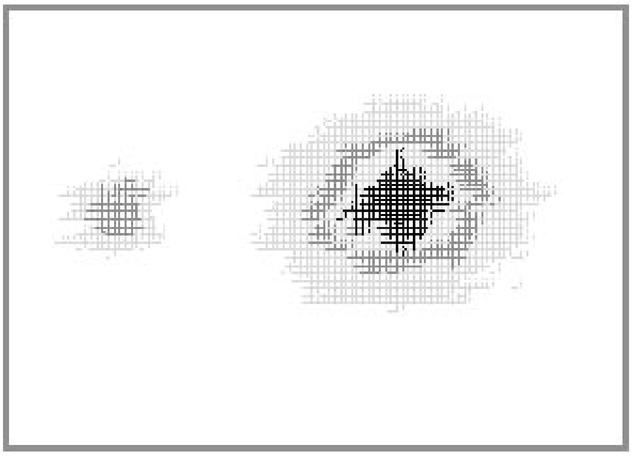

Fig. 6: 2D Image of a Lead ion beam taken after the stripper and showing on the right the expected Pb 82 beam and on the left a cluster of non fully stripped Pb 81 ions which are less deviated by the bending magnets.

The hardware is also able to extract from the camera signal a succession of horizontal and vertical profiles computed every 40 ms: Fig. 7. It is then possible to retrieve 60 sets of horizontal and vertical profiles during a proton extraction of 2.5 s. Once analysed, they provide the user with an accurate knowledge of the beam size and position evolution during the whole extraction.

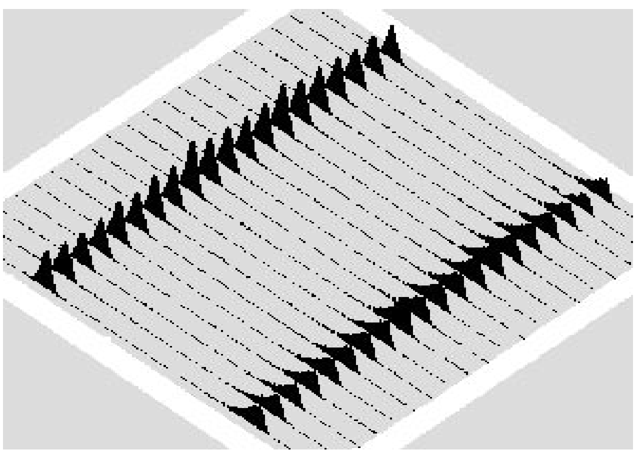

Fig. 7: Mountain range display of consecutive horizontal and vertical profiles taken every 40 ms during a proton extraction.

VI. CONCLUSION

The described instruments provide a comprehensive set of tools for extraction control, monitoring and diagnostics. They allow accurate spatial and temporal beam measurements in the transfer lines using the Fast Spill and BTV Profile monitors, and overall observations of the beams with the Servo Spill and SEM Spill Systems.

These systems are complementing each other. For instance, the Servo Spill, sampling at 100 µs a BSI, can display an apparently stable extraction, whereas the Fast Spill, sampling the light from a Quartz screen at 100 ns, can in fact uncover a very erratic extraction. The SEM Spill can warn the operator of a beam drift during the extraction, and the BTV System will show this on the television and computer displays.

This group of instruments can also be useful in other applications. The BTV Profile system can be connected to any camera and is currently being used in the SPS transfer lines and in the SPS and LEP rings to measure profiles of lepton, proton and ion beams, or the wire heating in LEP during Wire Scanner profile measurements [3]. A Fast Spill System can also be installed together with a camera and observe the same screen.

Finally, to improve the diagnostic capacity, it is possible to merge the Fast Spill and the SEM Spill Systems in order to observe the beam centre of charge, intensity and losses at a sampling rate of 100 ns, or to acquire a SEM Grid to achieve 10 MHz low resolution profile measurements.

VII. ACKNOWLEDGEMENTS

J. Provost and M. Apollonio have participated in the hardware design of the acquisition systems and J. Camas in the mechanical design and fabrication of the detectors. F. Raymond has developed the Fast Spill application program.

Their contributions are greatly appreciated and acknowledged.

VIII. REFERENCES

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