EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 1112

COOLED BEAM DIAGNOSTICS ON LEIR

G. Tranquille, C. Bal, C. Carli, M. Chanel, V. Prieto, R. Sautier, J. Tan
CERN, Geneva, Switzerland

Abstract

Electron cooling is central in the preparation of dense bunches of lead beams for the LHC. Ion beam pulses from the LINAC3 are transformed into short highbrightness bunches using multi-turn injection, cooling and accumulation in the Low Energy Ion Ring, LEIR [1]. The cooling process must therefore be continuously monitored in order to guarantee that the lead ions have the required characteristics in terms of beam size and momentum spread. In LEIR a number of systems have been developed to perform these measurements. These include Schottky diagnostics, ionisation profile monitors and scrapers. Along with their associated acquisition and analysis software packages these instruments have proved to be invaluable for the optimisation of the electron cooler.

Presented at
EPAC'08, 11th European Particle Accelerator Conference, Genoa, Italy - June 23-27, 2008

CERN,
CH-1211 Geneva 23
Switzerland

COOLED BEAM DIAGNOSTICS ON LEIR

G. Tranquille, C. Bal, C. Carli, M. Chanel, V. Prieto, R. Sautier, J. Tan, CERN, Geneva Switzerland

Abstract

Electron cooling is central in the preparation of dense bunches of lead beams for the LHC. Ion beam pulses from the LINAC3 are transformed into short high-brightness bunches using multi-turn injection, cooling and accumulation in the Low Energy Ion Ring, LEIR [1]. The cooling process must therefore be continuously monitored in order to guarantee that the lead ions have the required characteristics in terms of beam size and momentum spread. In LEIR a number of systems have been developed to perform these measurements. These include Schottky diagnostics, ionisation profile monitors and scrapers. Along with their associated acquisition and analysis software packages these instruments have proved to be invaluable for the optimisation of the electron cooler.

INTRODUCTION

To measure the performance [2] of the cooling process it is imperative to monitor a number of parameters of the circulating ion beam. The parameters of interest are i) the number of stored particles, ii) the particle momentum and momentum spread, iii) the ion beam size, and iv) the ion beam position. Furthermore the devices should be able to measure changes in these parameters with time constants smaller than the cooling times.

SCHOTTKY DIAGNOSTICS

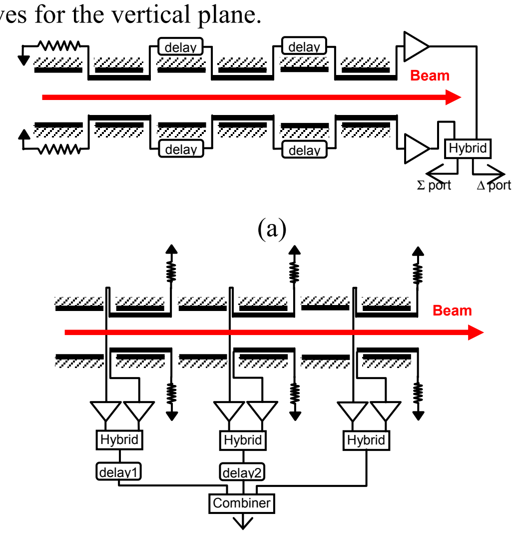
A wealth of information on the beam can be obtained from the Schottky signals of the circulating beam. In the longitudinal plane the absolute momentum of the beam can be measured in order to adjust the electron beam energy. The momentum spread of the beam at equilibrium as well as the intensity of the beam can also be obtained by analysing the frequency distribution. In the transverse plane the beam emittance and information concerning the ring optics can be extracted from the Schottky sidebands.

LEIR Schottky Pick-ups

The two systems implemented on LEIR have been inherited from the former Low Energy Antiproton Ring (LEAR). Both consist of a succession of short strip-line PUs but differ by the way the signals from the individual strip-lines are combined.

At injection energy (β = 0.0947) the strip-lines are connected in series ("travelling wave"), with appropriate electrical delays so that the currents from all electrodes are added (Figure 1(a)) giving a power signal proportional to the square of the number of electrodes. The signal is extracted at the downstream electrode, amplified and processed. There is one PU per transverse plane and the horizontal PU yields also longitudinal information.

In the second configuration (Figure 1(b)), the backward signal from each individual strip-line is directly amplified, delayed then summed using power combiners. One obtains a power signal proportional to the number of electrodes. This scheme yields a poorer signal to noise ratio than the travelling wave system but it can be applied for any particle velocity if the PU is equipped with variable delays. One PU is used for measuring signals in both longitudinal and horizontal planes, and a second one serves for the vertical plane.



(a)

(b)

Figure 1: Schottky PUs used in LEIR; (a) the "travelling wave PU" mode used at injection energy and (b) the power combiner mode for use at other energies.

The longitudinal/horizontal PU consists of 24 pairs of strip-lines and 74dB amplification is enough for beam observations. The vertical PU only has 6 pairs due to the lack of space inside the triplet and hence needs a larger amplification of 102dB.

Signal Observation and Analysis

Schottky signals are usually observed on spectrum analysers which can also be used to observe the variation of the spectral density around a given frequency as a function of time (receiver mode). In this manner the longitudinal and transverse cooling times can be estimated. To follow the complete cooling process spectrum analysers are too slow so it is necessary to down mix the signals with the use of a single sideband mixer. Followed by fast digitising and subsequent processing by a Fourier transform, a time resolution of a few milliseconds is obtainable with only a slight degradation in the signal to noise ratio. More recently, the introduction of vector signal analysers has meant that fast, high-resolution spectrum measurements, demodulation, and advanced time-domain analysis are now possible using one single instrument (Fig. 2). The data acquired by these analysers can also be post-processed by dedicated applications programs evaluating the equilibrium momentum spread as well as the longitudinal cooling time constant.

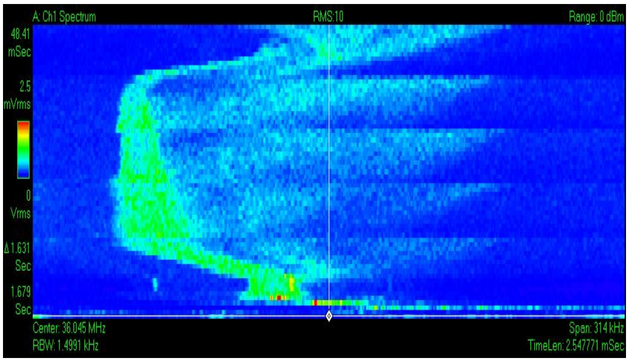


Figure 2: Longitudinal Schottky spectrum measured on the Agilent N9020A vector signal analyser at the 100th harmonic during five LEIR injection-cooling sequences.

IONISATION PROFILE MONITORS

Ionisation profile monitors (IPM) are widely used to non-destructively monitor the evolution of the beam size, the beam position in the IPM, and also the beam intensity at any given energy. The principle is to measure the profiles of electrons (or ions) created in ionising collisions between the circulating ion beam and the rest gas molecules. By applying a transverse electric field the electrons (or ions) are accelerated on to a detector, typically a micro channel plate (MCP), followed by a readout device (phosphor screen or strips).

IPM Design

A major challenge for the LEIR IPMs was their integration into the ultra high vacuum environment requiring a bakeout of the apparatus at 300ºC. The choice of materials was also critical in order to ensure that the average vacuum level in the ring (2 x 10^{-12} torr) is not perturbed by the operation of the monitors. Another constraint was the physical space allocated to the monitors, forcing us to make compromises with respect to the detector dimensions and also to pay careful attention to the readout.

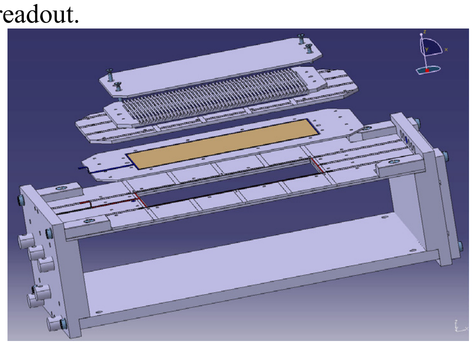


Figure 3: Drawing of the horizontal IPM.

The detectors (Fig. 3) are essentially of the same design for the horizontal and the vertical profile measurements, differing only in their physical dimensions and the resolution of the readout. The two electrodes creating the electric field are made of 316LN stainless steel and are separated from each other by two 1 cm thick aluminium oxide (AL_2O_3) blocks. The top electrode has a rectangular area corresponding to the size of the MCP (80 mm x 30 mm) cut away in its centre.

The MCP is supported in a Vespel sandwich on top of which is placed the signal readout. The readout consists of AISI 304 stainless steel tubes of 0.8 mm diameter placed on a grooved Vespel plate. 50 tubes spaced at 1.5 mm make up the horizontal readout whereas in the vertical plane 80 tubes with a 1 mm spacing was used. The total thickness of the MCP support and the readout is 4 mm. A thin kapton wire is pinched to the end of each tube and carries the charge deposited on the readout to UHV flange mounted sub-D connectors. Connection to the readout integrators is made by a flat ribbon cable.

Device Control and Data Acquisition

The control and data acquisition of the IPMs is handled by the ADwinPro system. The ADwin hardware consists of a dedicated real-time processor, fast analogue and digital inputs and outputs and an ethernet link to the local area network. Low priority tasks perform the control of the 8 high voltage power supplies needed to polarise the electrodes and the MCPs. An externally triggered high priority application takes care of acquiring the 130 data channels with the necessary time resolution. Typically, horizontal and vertical profiles are acquired every 20 ms.

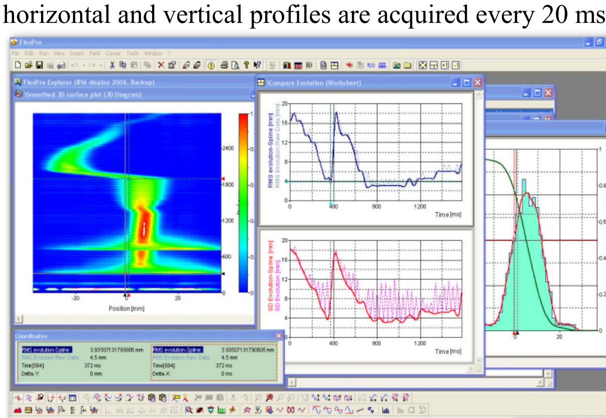


Figure 4: FlexPro IPM data analysis interface.

The R-C integrator chips are controlled by two Agilent 33220A waveform generators providing the integration and hold windows. The analogue to digital conversion of the signals is made via 14 bit ADC modules of the ADwin system requiring 770 µs to acquire all 130 channels.

The acquired data is stored in the local memory of the ADwin system and can be transferred to any data analysis program on the computers of the local area network. In our case we used an application written in TestPoint running on a windows based PC. The application provides the means to visualise the individual profiles and to store all the data to file for post analysis.

A more detailed analysis of the cooled beam profiles can be made using the FlexPro (Fig. 4) data analysis package. This package can display the data in a variety of ways enabling us to extract all the necessary information concerning the cooling/stacking process and the characteristics of the ion beam.

BEAM SCRAPERS

Horizontal and vertical scrapers, coupled to the beam intensity measurement, are used for amplitude distribution measurements giving a (destructive) measurement of the circulating beam emittance. They will also be used for calibration of other systems and in particular the Schottky signals enabling the beam emittance to be directly extracted from the analysis of the sidebands.

The scrapers have been refurbished from LEAR with particular attention paid to their UHV compatibility. Each blade of the horizontal scraper is moved linearly by means of a stepping motor. A resolver has been coupled to the motor axis in order to measure its position. The maximum displacement of 70 mm per blade results in a total aperture of 140 mm. The vertical blades make a pivoting movement using the same linear drive system as the horizontal scraper. The blades do not move exactly parallel to the beam and a small angular error is induced (Fig. 5). As the pivoting point lies closer to the blades than to the drive system, the total displacement for each blade is 45 mm giving a vertical aperture of 60 mm.

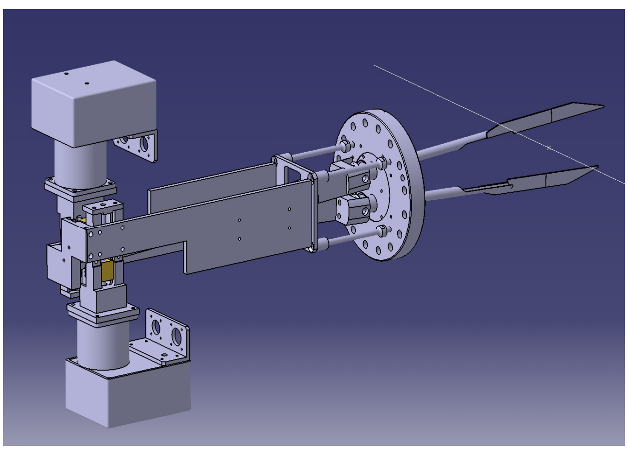


Figure 5: Mechanical drawing of the vertical scraper.

OTHER DIAGNOSTICS TOOLS

Electron and Ion Beam Alignment

The 2 existing LEAR pick-up stations (H+V) in the cooling section have been reused for the measurement of the electron and ion beam trajectories. They are made of metal-coated ceramic tubes onto which electrodes are formed. The PUs are integrated into the LEIR closed orbit measurement system which is able to measure the ion beam orbit "on request" on a flattop.

The measurement of the electron beam trajectory is performed by the direct modulation of the electron intensity by a high frequency sine wave applied on the grid electrode. The sum and difference signals from the two position pick-ups installed in the cooling section are then acquired via an oscilloscope (Fig. 6). Calibration coefficients and offsets are then applied to obtain the electron beam position. With the 22 correction coils, the electron beam position and angle are adjusted such that the alignment with the circulating ion beam is optimum.

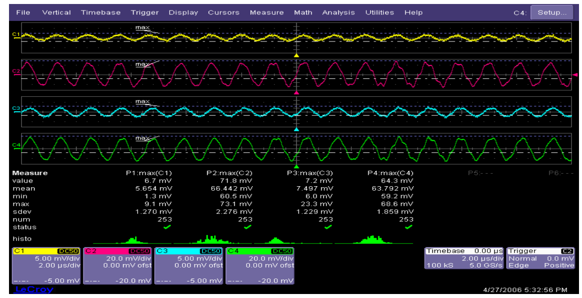


Figure 6: Difference and sum pick-up signals from an intensity modulated electron beam.

Measurement of the Beam Lifetime

The circulating beam current is measured using the DC current transformer (DCCT). New magnetic shielding has been designed and the water cooling system, used during the bake-out, renovated. A new front-end electronics has been adapted to the existing transformer, and a ß normaliser, based on the 0.1 Gauss B train counting, has been implemented to deal with the large relativistic ß range (0.09 to 0.37 for Pb^{54+} operation, and up to 0.61 for later operation with lighter ions).

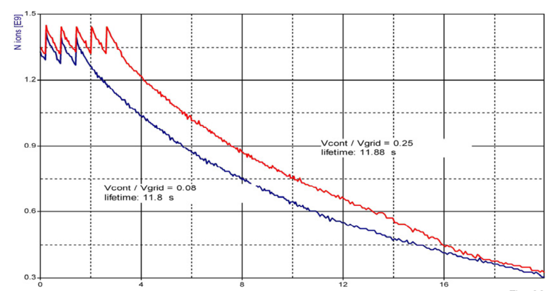


Figure 7: Example of a beam lifetime measurement.

For the evaluation of the beam lifetime, the current transformer signal is acquired by a 14 bit ADC of the ADwin system and then processed with FlexPro (Fig. 7). The acquired signal is smoothed and a decay curve is fitted from which the lifetime is estimated.

CONCLUSIONS

The diagnostics systems for monitoring the performance of the LEIR electron cooler have been fully commissioned and are used routinely to optimise the cooling/stacking process and to measure the ion beam characteristics before the transfer to the LHC. For the future, the analysis programs need to be ported to the main control system, avoiding the need to remotely connect to the devices (spectrum/signal analysers, ADwin DAQ system) via a PC.

REFERENCES

[1] C. Carli, "Commissioning and Performance of LEIR", COOL07, Bad Kreuznach, September 2007, THM1I01, p. 134.

[2] G. Tranquille, "Electron Cooling Experiments at LEIR", these proceedings.