A Single Pulse Beam Emittance Measurement for the CERN Heavy Ion Linac.

M. Crescenti, U. Raich
CERN-PS
CH-1211 Geneva 23

Abstract

A new device for transverse emittance measurement has been installed in the 4.2 MeV/u filter region of the CERN Heavy Ion Linac (Linac 3). It allows to obtain pulse-to-pulse (every 1.2 sec) visualisation of the Linac 3 beam parameters in order to tune the machine and to match the beam for injection into the first circular accelerator, the PS Booster.

The system is based on the "multi-slit" technique similar to the well-known "pepper pot" method.

A plate with a series of horizontal or vertical slits is placed in the beam, defining positions in the phase plane. Particles pass through the slits and drift to a scintillator screen where they produce light. The screen is looked at by an externally triggered high resolution CCD camera. For each slit position the light intensity distribution, in the limit of infinitesimal slit aperture, is proportional to the angle distribution of the particles and therefore, provides the angular distribution in the phase plane. The video signal from the camera is digitised and the result stored in a 512 x 512 x 8 frame store.

An application program visualising slit images (raw data) as well as the calculated emittance ellipses has been developed. This program also delivers numerical values for the rms-emittance and the Twiss parameters.

The paper discusses the method, the prototype realisation, the data treatment and first experimental results obtained during the running-in of Linac 3.

1. Introduction

The construction and assembly of a new injector for heavy ion physics at CERN has been completed during 1994 [1]. It consists of an ECR ion source producing a $Pb27^+$ beam. These ions are accelerated through an RFQ and an interdigital-H Linac. The beam is stripped and the charge state of $Pb53^+$ selected in a filter line[3] following the Linac (Fig.1).

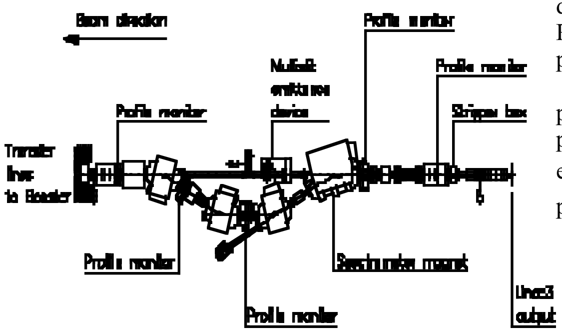


Fig.1 Beam measurement devices in filter line.

Theoretical values for accelerator output parameters are [4]: pulse width of 400 µs with a repetition frequency of 1.2 s, nominal current of $Pb27^+$ 65 µA, (20% of which is converted into $Pb53^+$), which gives $6x10^9$ particles of $Pb27^+$ per pulse. Transverse emittances are about 0.8 π mm mrad normalised.

In the context of this project, our task was to develop a device for measuring transverse emittances at each pulse, giving the possibility to check the pulse to pulse stability of the accelerator.

2. The multislit method

A plate with 10 slits is inserted in the beam at the measurement position, and particles passing through the slits are detected by a scintillator screen placed 600 mm after the plate. The image on the screen is read into a 512 x 512 pixel array by a single-shot CCD camera synchronised with the beam. Each pixel is digitised by an 8 bit ADC (256 intensity levels), and stored in a frame grabber. The plate and the scintillator screen are tilted at 45° to allow camera visualisation(Fig.2).

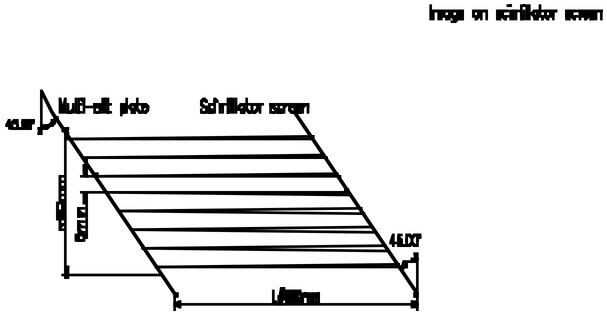


Fig.2 The method.

X or Y intensity profiles are calculated and displayed in a 512 channel projection graph (Fig.3). Phase plane reconstruction is based on these projections.

Each peak in this graph is associated with a slit position and therefore with a position in the phase plane. The width of these lines determines the angular extension (e.g. α_1-α_2 in Fig.4) for the corresponding position.

Fig.3 Projections giving x and y intensity profiles.

Different choices of the central peak do not influence emittance calculations, but care must be taken to avoid overlapping of light spots on the screen.

3. The prototype realisation

3.1 The multi-slit

The multislit is a stainless steel plate 5 mm thick, with a series of parallel slits. The number of slits can be 11, 17 or 21. The slit acceptance is ±30 mrad. Each slit is 0.3 mm in width. The finite slit dimension limits the precision in position and gives a fixed over-estimation in angle of less than 0.5 mrad.

The distance between the slits limits the maximal beam angles that can be measured. In order to be ready to measure beams of different emittances, we prepared 3 different kinds of plates, with a distance between slits of 6, 4 or 3 mm. Most of the time we used the 6 mm plate that allows the measurement of beams of max. ±5 mrad (Fig.4).

If the camera captures the whole scintillator screen on the CCD array, angular resolution is better than 0.2 mrad (and in this case the precision in angle is 4%).

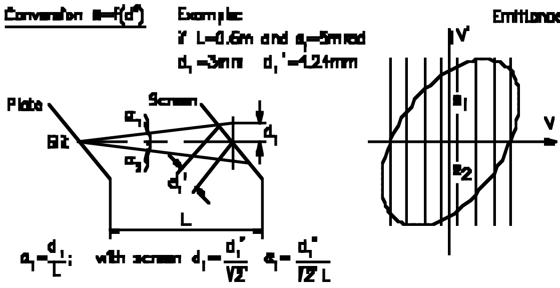


Fig.4 Some details of slits and phase plane reconstruction.

3.2 The scintillator screen

The main problem to overcome was to find a scintillator screen suitable for low intensity and low energy lead ions (compared to protons). Two different 60 x 60 x 1 mm fluorescent screens have been used: Cromox type 6 [5] (~700 nm emission wavelength, 3 ms fluorescence decay time) and the CsI thallium doped type (~500 nm emission wavelength, 0.5µs fluorescence decay time). Tests showed that the Cromox screen was more suitable for our purposes, since less subject to saturation at beam intensity levels encountered (Fig.5)

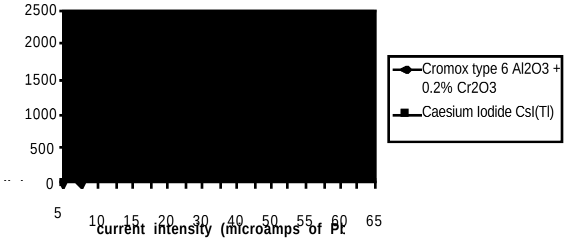


Fig.5 Light intensity output vs. beam intensity for

3.3 The CCD camera

Identical vertical and horizontal resolutions are needed, without rotating the camera. We chose a full-frame non-interlaced CCD camera, with 15 µm x 15 µm square pixels and analogue video output. The number of active pixels is 512 x 512 and the CCD array dimension is 7.7 mm x 7.7 mm.

An adjustable active low TTL pulse is needed to define the CCDs integration time (during which image acquisition is done). The camera accepts pulse lengths from a minimum of 150 µs to a maximum of 1s (due to CCD thermal noise). The image readout takes 33 ms.

3.4 The frame grabber

We chose a commercial frame grabber with a modular structure, consisting of a mother board and two plug-in daughter modules. The mother board contains 3 memory blocks of 1024 x 512 bytes each for storage of the video frames. The two daughter modules are the acquisition module (8 bits ADC resolution), and the display module, regenerating the video signal from the digitised data. The board works on the VME bus, and can be configured to accept synchronisation pulses and data from non-standard video cameras. In particular, the image acquisition can be externally triggered.

In our configuration the camera is used as master and the board as slave. Three signals are needed to synchronise image acquisition: pixel clock, line blank and vertical blank.

3.5 Timing

A programmable Camac module gives precise timing to the system. It receives a trigger pulse from the accelerator timing system, the valid beam signal (VB0), and drives the camera strobe and the trigger to software real-time task. The camera strobe pulse can be delayed, to allow displacement along the beam pulse.

In most of our measurements we use short camera strobe times (max. 300 µs) to avoid CCD saturation (Fig. 6), and a delay of 200 µs with respect to VB0.

3 ms 150 µs

Fig.6 CCD saturation with 3 ms strobe time (compared to 150 µs).

3.6 Optical and mechanical aspects

The scintillator screen is mounted in a standard CERN/PS vacuum tank. Since these tanks are not explicitly designed for emittance measurements, the camera could not be placed perpendicular to the screen, resulting in problems of perspective and depth of field. Two MgF_2 mirrors facing each other inserted in the vacuum tank by means of a newly designed mechanical support solved the problems.

4. Controls

4.1 Hardware

The detector is remotely controlled through the

M68040-based microcomputer (Device Stub Controller), running the LynxOS real-time operating system, controls the access to frame grabber memory via the VME bus. At operator level, an X-Windows application program runs on UNIX workstations. Workstations are linked to the DSC via ethernet (TCP/IP protocol)(Fig.7).

4.2 Software

A real-time task extracts the image from the frame grabber (raw data) and calculates intensity profiles (projection data).

To make image acquisition at 1 Hz rate possible, only one pixel every four is transferred, and then replicated in raw data. Full precision still remains in intensity profiles.

The application program allows to display pulse-to-pulse the raw image on the scintillator screen (without the slit plate this allows beam spot measurements), the projections onto the horizontal and vertical axis, the emittance ellipse and the intensity vs. emittance curve. In addition numerical values for the emittance and the Twiss parameters are calculated.

Calibration marks on the screen are used to find the mm/pixel and mrad/pixel scaling factors and the centre position.

Data can be saved and retrieved from files (file mode).

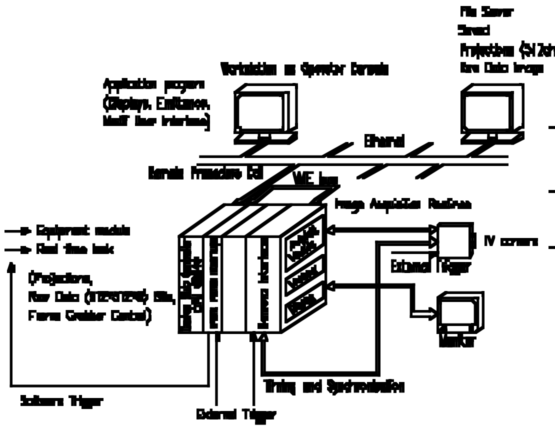


Fig.7 Controls system architecture.

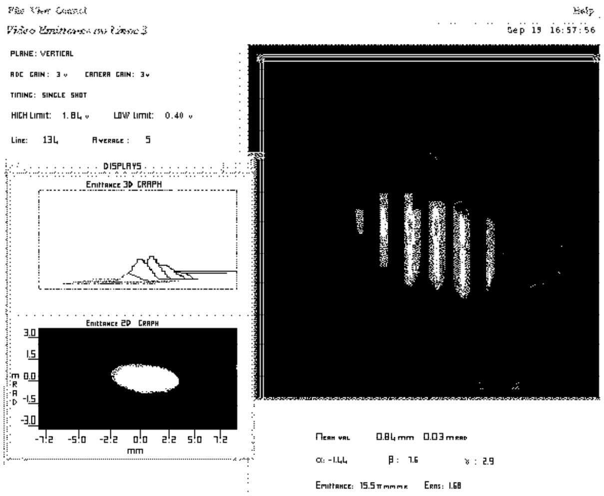
5. Measurements

Linac 3 running-in gave us the possibility to test our detector at different energies (2.5 keV/u after the ECR source, 250 keV/u after the RFQ) in a temporary measurement line. In both cases we mainly used the detector as a profile monitor. TRACE 3D[6] simulations showed a good agreement with measurements. The results were useful for the beam matching at the input of the Linac.

In its final place, the detector is situated about 7 m after the accelerator output (Fig.1) with 8 optical elements (2 triplets and 2 steering dipoles) in-between, so only indirect measurements of the Linac 3 output beam are possible.

TRACE 3D has been used to calculate beam transport in both directions. In order to fully exploit the multi-slit and minimise over-estimation errors, particular optics have been chosen, to obtain on the screen the highest possible number of peaks with the

Fig. 8 gives an example of a real-time measurement and display.



Sep 19 16:57:56

PLANE: VERTICAL

ADC GAIN: 3 v CAMERA GAIN: 3 v

TIMING: SINGLE SHOT

HIGH Limit: 1.84 v LOW Limit: 0.40 v

Line: 134 Average: 5

Mean val 0.84 mm 0.03 mrad

α: -1.44 β: 7.6 γ: 2.9

Emittance: 15.5 π mm mr Erms: 1.68

Fig.8 Screen dump of the application program.

First measurements have been dedicated to debug instrumentation and establish ADC and camera gains, camera strobe time, calibration values, and screen linearity. Every valid measurement at the slit plate position has been traced back to compare the results at the accelerator output.

After the first debugging phase, when emittances were about twice those expected, we obtained values (4 rms) of 9.5 to 11π mm mrad unnormalised (see Table 1).

4.2 MeV/u	emittance mm mrad norm. $4\pi e_{rms}\beta\gamma$	α	β mm/mrad
horizontal plane	0.91	-1.9	1.4
vertical plane	0.94	-0.3	2.0

Table 1 Measured Linac output values.

The reproducibility in the Twiss parameters at the accelerator output is within 5-10%.

6. Conclusion

The detector showed its usefulness during beam matching to the first circular machine, the PS Booster, and its results in transverse emittance measurements were confirmed by the emittance measurement line before injection into the Booster.

Several measurements and refinements are still going on to check and improve the performance of the device.

7. Acknowledgements

We want to thank our colleagues in HI, BD and CO groups of PS division and the vacuum team of AT division for the encouragement and help given to the achievement of this work.

We appreciated Drs. L. Debois, S. Deshpande and S. Bose, who worked in different periods on the application software.

Many thanks to D.J.Warner, H.Haseroth, H.Koziol and D.Möhl, who revised the manuscript.

Special thanks are due to P. Têtu, who gave us the basic idea and to W. Pirkl who was always present with strong support and useful suggestions during the critical debugging phase of the detector.

References:

[1] H. Haseroth, "The CERN Heavy Ion Facility", CERN/PS 94/27 (HI).

[2] D.J. Warner for the Linac 3 Running-In Team, The Heavy Ion Linac for the CERN Lead Ion Facility, Tsukuba ‘94 Linac conference.

[3] P. Têtu, Linac à Plomb: zone de mesure, filtrage, transfert à 4.2 MeV/u, CERN PS/HI Note 90-03.

[4] N. Angert, M.P. Bourgarel, E. Brouzet, R. Cappi, D. Dekkers, J. Evans, G. Gelato, H. Haseroth, C.E. Hill, G. Hutter, J. Knott, H. Kugler, A. Lombardi, H. Lustig, E. Malwitz, F. Nitsch, G. Parisi, A. Pisent, U. Raich, U. Ratzinger, L. Riccati, A. Schempp, K. Schindl, H. Schönauer, P. Têtu, H.H. Umstaetter, M. van Rooij, D. Warner (Ed.), M .Weiss,."CERN Heavy Ion Facility Design Report", CERN 93-01.

[5] C.D. Johnson, "The development and use of alumina ceramic fluorescent screens", CERN/PS/90-42(AR).

[6] K.R. Crandall, TRACE-3D Documentation, Los Alamos Accelerator Code Group, LA-UR-904146.