

SHEET ELECTRON PROBE FOR BEAM TOMOGRAPHY*

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Abstract

An electron beam probe has been successfully used for determining accelerated particle density distributions. However, the apparatus used for this diagnostic had a large size and complex design which limit the broad use of this diagnostic for tomography of accelerated bunches. We propose a new approach to electron beam tomography: we will generate a pulsed sheet of electrons. As the ion beam bunches pass through the sheet, they cause distortions in the distribution of sheet electrons arriving at luminescent screen with CCD device on the other side of the beam that are interpreted to give a continuous measurement of the beam profile. The apparatus to generate the sheet beam is a strip cathode, which, compared to the scanning electron beam probe, is smaller, has simpler design and less expensive manufacturing, has better magnetic shielding, has higher sensitivity, higher resolution, has better accuracy of measurement and better time resolution. With this device it is possible to develop almost ideal tomography diagnostics of bunches in linear accelerators and in circular accelerators and storage rings.

INTRODUCTION

Advanced beam diagnostics are essential for high performance accelerator beam production and for reliable accelerators operation. It is important to have non-invasive diagnostics which can be used continuously with intense beams of accelerated particles. Non-invasive determination of accelerated particle distributions is the most difficult task of bunch diagnostics. Recently, a pencil electron beam probe was successfully used for determination of accelerated particle density distributions. However, the apparatus used for this is large and complex, which complicates the broad use of this technique for tomography of accelerated bunches.

In the novel device to be described in this report, a simple, strip cathode provides a sheet beam probe for tomography instead of a scanning pencil beam that was used in previous electron probe bunch profile monitors. The apparatus with the strip cathode is smaller, has simpler design and less expensive manufacturing, has better magnetic shielding, has higher sensitivity, higher resolution, has better accuracy of measurement and better time resolution. With this device it is possible to develop almost ideal tomography diagnostics of bunches in linear accelerators and in circular accelerators and storage rings.

Beam profile determination for high intensity accelerators implies the use of non-destructive methods. The basic physics and recent technical realizations of important non-intercepting profile diagnostics are summarized in Ref. [1].

Ionization Profile Monitors (IPM) and Beam Induced Fluorescence Monitors (BIFM), developed and first used with intense proton beams by Dudnikov *et al.* [2-5], are now routinely used in all proton and ion accelerators. Recent developments of IPM are presented in [1, 6]. Transverse electron beam scanners (TEBS) were realized recently for use in the SNS storage ring by Aleksandrov *et al.* [7-9]. Laser beam scanners are used at H⁻ Linacs, Optical Transition Radiation screens, and Synchrotron Radiation Monitors for relativistic beams. Non-destructive transverse profile measurements are preferred not only for single-path diagnostics at different locations in a transfer line, but also to enable time resolved observations of a stored beam within a synchrotron. A more practical, however essential, reason for minimal invasive diagnostics is the large beam power available at modern hadron accelerators, which excludes the usage of intercepting methods like scintillation screens, SEM-grids or wire scanners due to the risk of melting when irradiated by the total beam intensity. Various methods are realized to determine the profile properties of typical widths $\sigma = 0.1$ to 10 mm of not necessarily Gaussian shapes. In most synchrotrons and storage rings the transverse profile of the circulating beam is monitored via detecting the ionization products from the collision of hadrons with residual gas by an Ionization Profile Monitor (IPM). These are relatively complex and expensive: the IPM system for the Tevatron cost ~ 0.3 M\$.

ADVANCED SHEET ELECTRON PROBE BEAM PROFILE MONITOR

The advanced sheet electron probe beam profile monitor (SEPBPM) with the strip cathode is proposed as shown in Fig. 1.

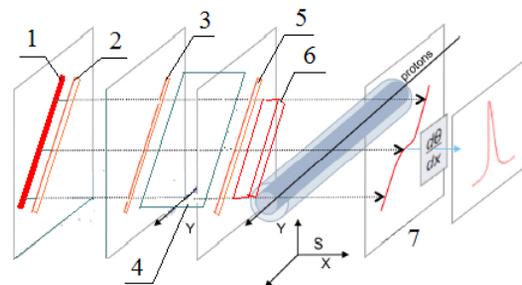


Figure 1: Sheet Electron Probe Beam profile monitor with a strip cathode: 1 - strip cathode; 2 - anode; 3 - first slit of collimator; 4 - deflecting plate; 5 - second slit of collimator; 6 - sheet slice of electron beam probe; 7 - luminescent screen.

The strip cathode (1) is used with extractor (2) for the slice (6) of sheet electron probe formation. The sheet electron probe is formed by collimator with two slits (3) and (5). The short slice of sheet electron probe (6) is

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formed by deflection of sheet electron probe through slit (5) by a pulsed voltage on deflecting plates (4). Electrons of the electron probe slice after deflection by electric field of the proton bunch is visualized on the luminescent screen (7) and fixed by fast CCD camera for further processing by corresponding software discussed above.

This version of the SEPBP is smaller, easier in fabrication, operation and magnetic shielding. Several similar systems can be integrated for production of the tomographic 3-D image of proton bunches. The proposed tomographic system is more compact, easier to operate and less expensive than residual gas ionization profile monitor (IPM) discussed above.

A simplified diagram of SEPBP is shown in Fig. 2.

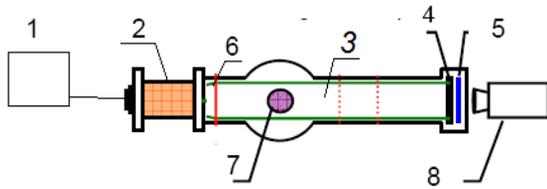


Figure 2: A simplified diagram of SEPBP: 1 - high voltage pulser; 2 - high voltage insulator of electron gun; 3 - sheet slice of electron probe; 4 - MCP; 5 - luminescent screen; 6 - sheet electron source; 7 - proton/ion bunch; 8 - CCD camera.

A slice of the sheet electron beam (3) is formed by the sheet electron source (6) and crosses the bunch (7). Sheet electrons are deflected by electric and magnetic fields of the bunch (7). This deflection is sensed by the position of the electron images on the luminescent screen (5) and recorded by the CCD camera (8). Electron multiplication with a microchannel plate (MCP) (4) can be used for synchronization and for brightness amplification. A pulsed high voltage (~ 50 kV) power supply (1) is used for electron beam acceleration (extraction). Electron source with cathode (1) is supported by high voltage insulator (2). An isometric view of diagnostic system is shown in Fig. 3 below.

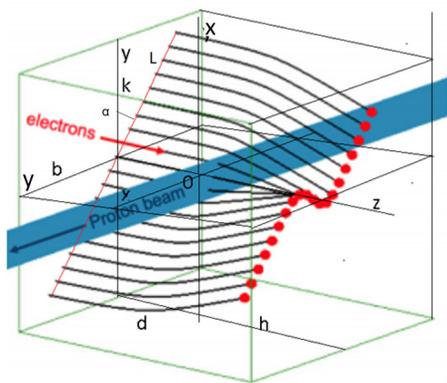


Figure 3: Isometric view of modification of strip e-beam profile monitor with a slice of the sheet electron probe.

SIMULATION PROBE BEAM DEFLECTION BY PROTON BUNCH

A computer program for simulation probe beam deflection by proton bunch has been developed. Examples of simulations are presented in Figs. 4 and 5. In Fig. 4 is shown a simulations of deformation sheet electron probe beam with energy 30 keV by proton bunch with $\gamma = 10$ and different proton numbers.

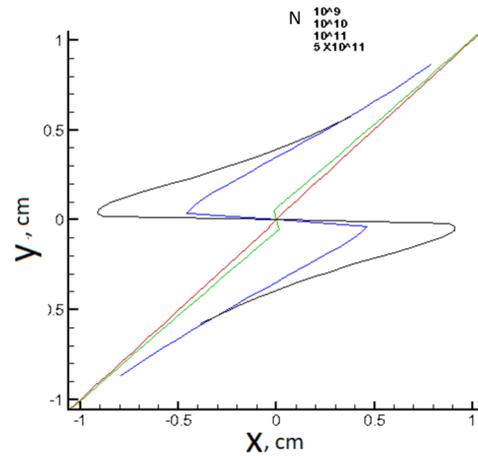


Figure 4: Simulations of deformation sheet electron probe beam by proton bunch.

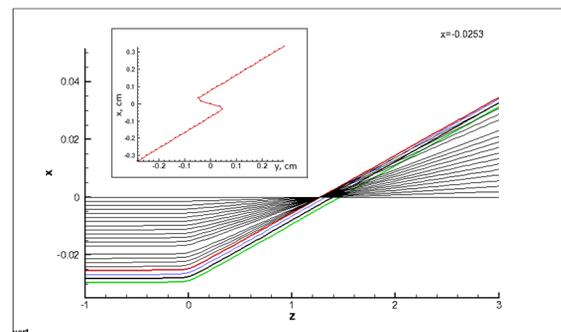


Figure 5: Trajectories of deflection sheet electron probe beam by proton bunch.

Trajectories of deflection sheet electron probe beam of 30 keV by proton bunch with $\gamma = 10$ and number of proton $N = 2 \cdot 10^{11}$ is shown in Fig. 5. A proton trajectories crossing the proton bunch is focused in one point. Proton density in bunch is described by formula

$$\rho(x, y, z) = eN (\exp(-x^2/a^2 - y^2/b^2 - z^2/c^2)) / 84abc(\pi)^{3/2},$$

where $a = 0.02$ cm, $b = 6$ cm, $c = 0,001$ cm. A screen for sheet electron beam visualization is located in distance $h = 4$ cm from centre of bunch. Electrons passing proton bunch outside is deflected divergent. Figure 6 shows the simulation of sheet electron beam trajectories deflected by proton bunch.

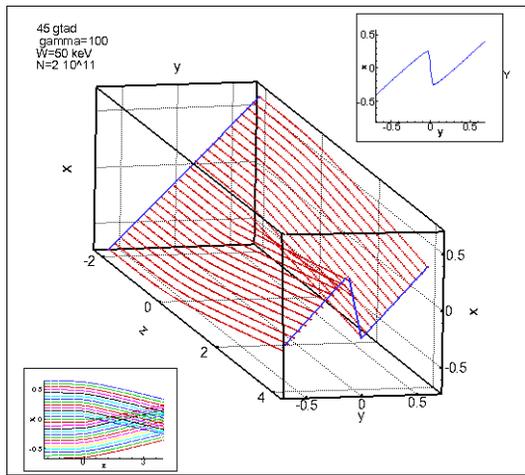


Figure 6: Simulation of sheet electron beam trajectories deflected by proton bunch.

ELECTRON GUN

For this generation of a Sheet Electron Probe Beam it is possible to use electron gun shown in Fig. 7. Electron gun consists of machinable ceramic (MACOR) disc with diameter of 10 cm and thickness of 15 mm (1), two current leads welded to current leads (2), extractor electrode (3) with aperture 1x10 mm, accelerating electrode (5) with aperture 1x10 mm, four ceramic support roads (6), flange (7), compression flange (8), compression ceramic (9). Sheet electron Probe Beam (10) is emitted by IrCe emitter (4) and accelerated by extraction electrode (3) and accelerating electrode (5). High voltage -100 kV is applied to emitter. Pulsed extraction voltage ~ 3 kV is applied to the extraction electrode and extract sheet electron beam. Electron beam is passed proton bunch and is deflected by electric and magnetic field of bunches and registered by luminescent screen with pulsed microchannel plate for choosing exposition. The life-time of IrCe cathode is up to 40,000 hours while generating current density of 15-17 A/cm² [10].

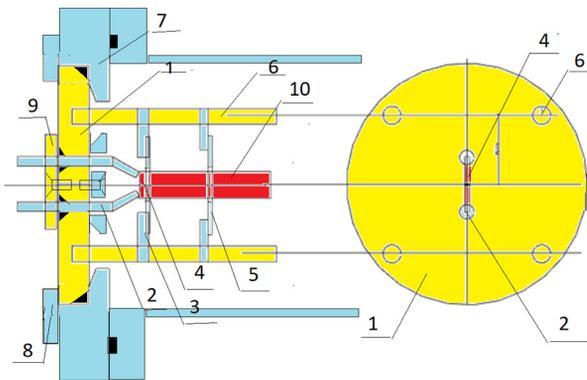


Figure 7: Design of electron gun for production of Sheet electron Probe Beam: 1 - ceramic disc, 2 - current leads, 3 - extractor electrode, 4 - IrCe emitter of electron, 5 - accelerating electrode, 6 - ceramic support roads, 7 - flange, 8 - compression flange, 9 - compression ceramic, 10 - sheet electron Probe Beam.

PUBLIC BENEFITS

The proposed electron probe tomography system with the strip cathode should be the most advanced system for detailed diagnostics of accelerated beams. It can be used in all advanced accelerators and storage rings such as SNS, Tevatron, RHIC, LHC, ISIS, KEK and many others. Serial production of these diagnostics will improve operation and lower costs of these accelerators and for some new multi-billion dollars facilities.

REFERENCES

- [1] P. Forck, "Minimal Invasive Beam Profile Monitors for High Intense Hadron Beams", in *Proc. 1st Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, May 2010, paper TUZMH01, pp. 1261-1265.
- [2] V. Dudnikov, "The intense proton beam accumulation in storage ring by charge-exchange injection method", Ph.D. thesis, INP, Novosibirsk, Russia, 1966.
- [3] G. Budker, G. Dimov, and V. Dudnikov, "Experiments on production of intense proton beam by charge exchange injection method", in *Proc. of the Int. Symposium on Electron and Positron Storage Rings*, Saclay, France, 1966, paper VIII-6-1.
- [4] G. I. Budker, G. I. Dimov, and V. G. Dudnikov, "Experiments on producing intensive proton beams by means of the method of charge-exchange injection", *Soviet Atomic Energy*, vol. 22, no. 5, pp. 441-448, May 1967.
- [5] V. Dudnikov, "Some Features of Transverse Instability of Partly Compensated Proton Beams", in *Proc. 19th Particle Accelerator Conf. (PAC'01)*, Chicago, IL, USA, Jun. 2001, paper TPPH094, pp. 1892-1894.
- [6] G. Dimov and V. Dudnikov, "Determination of circulating proton current and current density distribution (residual gas ionization profile monitor)", *Instrum. Experimental Techniques*, vol. 5, p. 15, 1967.
- [7] C. Fischer *et al.*, "Beam Studies Made With The SPS Ionization Profile Monitor", in *Proc. 6th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (DIPAC'03)*, Mainz, Germany, May 2003, paper PM11, pp. 116-118.
- [8] C. Fischer *et al.*, "Design and tests of a new rest gas ionisation profile monitor installed in the SPS as a prototype for the LHC", in *Proc. 11th Beam Instrumentation Workshop (BIW'04)*, Knoxville, USA, May 2004, pp. 133-140. doi:10.1063/1.1831140
- [9] A. V. Aleksandrov *et al.*, "Feasibility Study of Using an Electron Beam for Profile Measurements in the SNS Accumulator Ring", in *Proc. 21st Particle Accelerator Conf. (PAC'05)*, Knoxville, TN, USA, May 2005, paper RPAT039, pp. 2586-2588.
- [10] G. I. Kuznetsov, "IrCe cathodes for EBIS", *Journal of Physics: Conference Series*, vol. 2, pp. 35-41, 2004. doi:10.1088/1742-6596/2/1/005