ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-TUPA04

SHEET ELECTRON PROBE FOR BEAM TOMOGRAPHY*

Vadim Dudnikov†, M. A. C. Cummings, Muons, Inc. Batavia, IL, USA
Galina Dudnikova, UMD, Collège Park, MD, USA

Abstract

An electron beam probe has been successfully used for determination of 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 noninvasive 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 [1]. Ionization Profile Monitors (IPM) and Beam Induced Fluorescence Monitors (BIFM), developed and first used with intense proton beams by Dudnikov [2-8], are now routinely used in all proton and ion accelerators. Recent developments of IPM are presented in [1, 7, 8]. Transverse electron beam scanners (TEBS) were realized recently for use in the SNS storage ring by Aleksandrov et al. [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 σ = 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 ~$0.3M.

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.

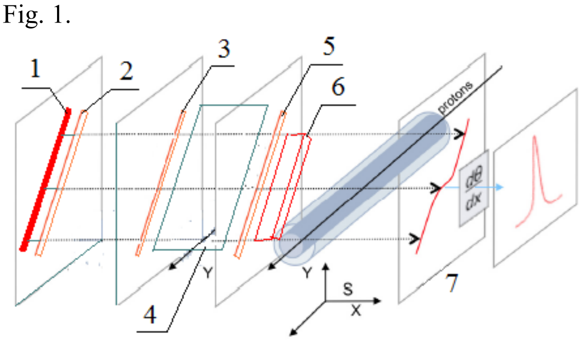

Figure 1: Sheet Electron probe beam profile monitor with a strip cathode: 1- strip cathode; 2- anode; 3- first slit of collimator; 4- deflecting plate; 5- second slit of collimator; 6- sheet slice of electron beam probe; 7- luminescent screen.

* Work supported by DOE Grant DE-SC0021581
† vadim@muonsinc.com

ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-TUPA04

The slice (6) of sheet electron probe formation utilizes the strip cathode (1) with extractor (2). The sheet electron probe is formed by collimator with two slits (3) and (5). The short slid of sheet electron probe (6) is formed by deflection of sheet electron probe through slit (5) by a pulsed voltage on deflecting plates (4). Electrons of electron probe slid after deflection by electric field of 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 SEPBPM is smaller, easy for 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 SEPBPM is shown in Fig. 2.

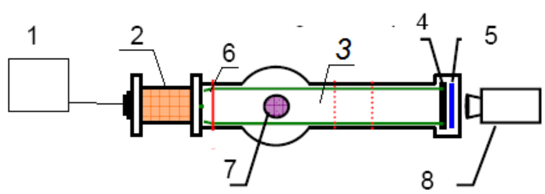

Figure 2: A simplified diagram of SEPBPM:1- high voltage pulser; 2- high voltage insulator of electron gun; 3- sheet slice of electron probe; 4- MCP; 5- luminescent screen; 6- sheet electron source (items 1 through 5 of Fig. 1); 7-proton/ion bunch; 8- CCD camera.

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). An isometric view of diagnostic system is shown in Fig. 3 below.

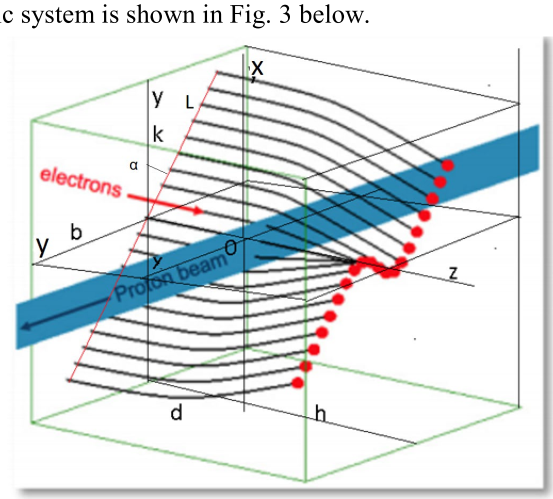

Figure 3: Isometric view of Modification of strip e-beam profile monitor with a slice of the sheet electron probe.

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).

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 γ=10 and different proton numbers.

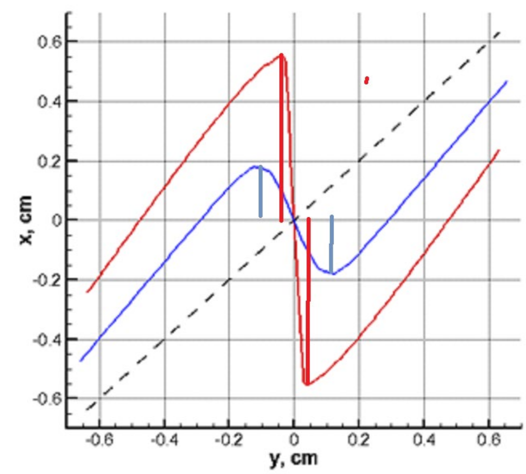

Figure 4: Tracks of deflected electron beam on the luminescent screen for RUN1-red, RUN2-blue. Dashed line is trace of non-deflected electron beam. Distance between max and min of blue curves Δy=0.24 cm is related to horizontal dimension of proton bunch. The nmplitude of deflection Δx=0.36 cm is proportional to the number of protons, γ-factor of proton bunch, and inversely pro-portional of electron beam energy.

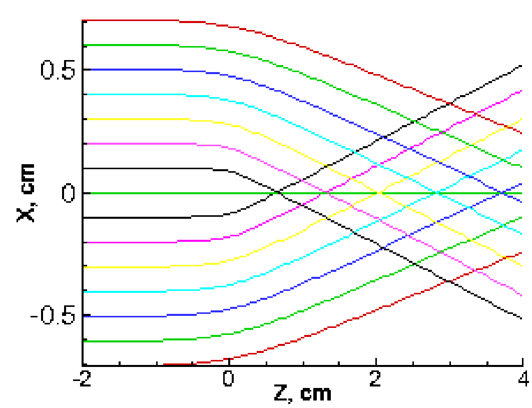

Figure 5: Trajectories of deflection shit electron probe beam by proton bunch.

ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-TUPA04

Figure 5 shows trajectories of deflection of the sheet electron probe beam of 30 keV by proton bunch with γ=10 and number of proton N=2 10^{11}. 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 at a 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.

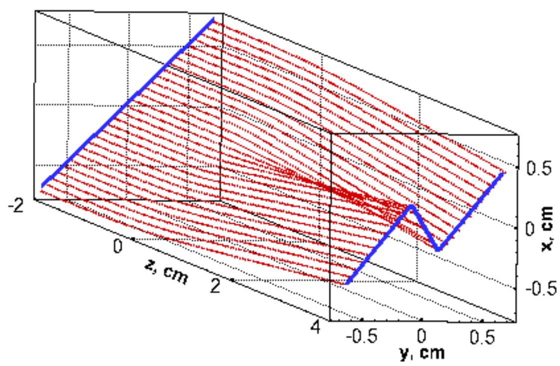

Figure 6: Simulation of sheet electron beam trajectories deflected by proton bunch.

ELECTRON GUN

For the generation of a sheet electron Probe Beam it is possible to use electron gun shown in Fig. 7. The electron gun consists of machinable ceramic (MACOR) disc with diameter of 10 cm and thickness of 15 mm, two current leads 2 for emitter heating, IrCe emitter of electron 1x10 mm 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 Beam10 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 bunces and registered by luminescent scrin 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/cm^2 [10].

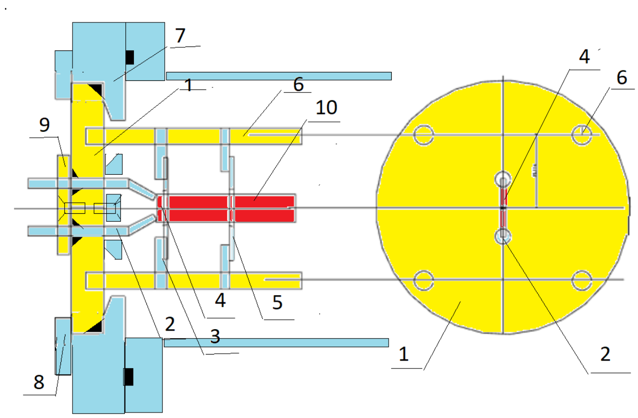

Figure 7: Design of electron gun for production of Sheet electron Probe Beam:1-ceramic disc, 2-current leads, 3-extractor electrode, 4- IrCe emitter of electron , 5-accelerating electrode, 6-ceramic support roads, 7-flange, 8-compression flange, 9-compression ceramic, 10-sheet electron Probe Beam.

REFERENCES

[1] P. Forck, "Minimal Invasive Beam Profile Monitors for High Intense Hadron Beams", in *Proc. 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, Novosibirsk INP, 1966;

[3] G. Budker, G. Dimov, and V. Dudnikov, "Experiments on producing intensive proton beams by means of the method of charge-exchange injection", in *Proc. of the International Symposium on Electron and Positron Storage Rings*, Saclay, France, no. VIII-6-1, 1966.

[4] G. Budker, G. Dimov, and V. Dudnikov, "Experiments on producing intensive proton beams by means of the method of charge-exchange injection", *Sov. Atomic. Energy*, vol. 22, pp. 441-448, 1967. doi:10.1007/BF01175205

[5] V. Dudnikov, "Some Features of Transverse Instability of Partly Compensated Proton Beams", in *Proc. 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. Exp. Tech.*, vol. 5, no. 15, 1967.

[7] G. Ferioli, C. Fischer, J. Koopman, and F. Roncarolo Geneva, "Beam Studies Made With The SPS Ionization Profile Monitor", in *Proc. 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", *AIP Conf. Proc.*, vol. 732, p. 133, 2004. 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. PAC'05*, Knoxville, TN, USA, May 2005, paper RPAT039, pp. 2586-2588.

[10] G. I. Kuznetsov, "IrCe cathodes for EBIS", *J. Phys.: Conf. Ser.*, vol. 2, pp. 35-41, 2004. doi:10.1088/1742-6596/2/1/005