RIBBON ELECTRON BEAM SOURCE FOR BUNCHED BEAM PROFILE MONITOR AND TOMOGRAPHY

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Abstract

Ribbon electron beam source with a strip cathode has been designed, fabricated and tested. Image of the ribbon electron beam with width up to 15 cm has been registered on the luminescent screen. This ribbon beam can be used for the large proton bunch profile monitoring in the Spallation Neutron Source (SNS) proton storage ring. Advanced beam diagnostics are essential for high performance accelerator beam production and for reliable accelerator operation. It is important to have non-invasive diagnostics which can be used continuously with intense beams of accelerated particles.

INTRODUCTION

Beam profile determination at high intensity ion accelerators requires the use of non-destructive methods. The basic physics and recent technical realizations of important non-intercepting profile diagnostics are summarized in Ref. [1]. Transverse electron beam scanners were realized recently for use in the SNS storage ring by Aleksandrov et al. [2, 3].

In the electron beam profile monitor (EBPM) developed at the SNS, a transverse beam profile is reconstructed from the deflection of electrons crossing the proton or ion beam after being influenced by the beam's space charge, as schematically shown in Fig. 1 [1]. A pencil electron probe is formed by an electron gun and scanned through the proton beam by the electric field of deflectors as in an oscilloscope tube. The position of the scanning electron probe after crossing the proton beam is visualized by a fluorescent screen and the image is captured by a camera for further processing. Assuming the electron beam has a much lower diameter than the proton or ion beam and the scan duration is much shorter than the ion bunch passage, the space charge field can be treated as constant. The beam profile can be reconstructed from the electron beam trace using the mathematical formalism given in Ref. [2].This method was considered for high energy synchrotrons and recently commissioned at the SNS [3]. A significant part of the scanner hardware is used for the extension of the scanning e-beam. Large quadrupole magnets also complicate the magnetic shielding of this version of scanner. For these reasons, electron beam profile monitors (EBPM) with electron beams formed by the deflection of pencil e-beams can be long, and fairly complex. Potentially more practical e-beam profile monitors that are more suitable for proton beam tomography can be developed using a strip cathode for formation of a ribbon beam as discussed below [4]. The analysis of the data for beam bunch transverse profiles for the system that we are proposing will be very similar to what has been developed for the EBPM as described below.

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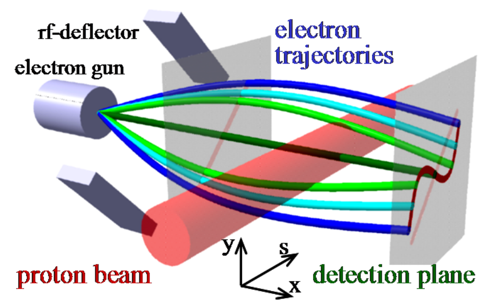

Figure 1: Schematic of an electron scanner for the vertical beam profile [1].

RIBBON ELECTRON BEAM PROFILE MONITOR (REBPM)

The ribbon electron probe beam profile monitor (REBPM) using a strip cathode is proposed as shown in Fig. 2. The electron ribbon (6) is generated by the strip cathode (1) with extractor (2). The transverse dimensions of the ribbon are defined by the collimator with two slits (3) and (5). The width or duration of the ribbon electron probe (6) is formed by the deflection of the ribbon electron beam across slit (5) by a pulsed voltage on the deflecting plates (4). Electrons of the ribbon electron probe after deflection by electric field of the proton bunch are visualized on the luminescent screen (7) and recorded by a fast CCD camera for further processing by the corresponding software discussed above.

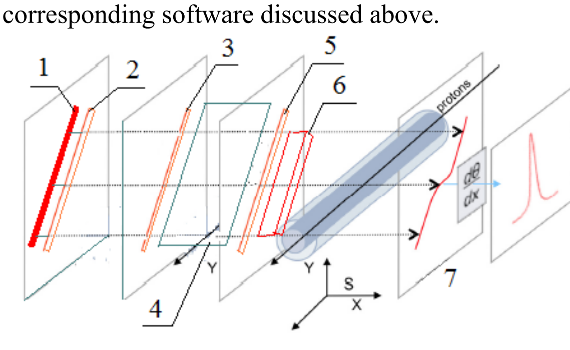

Figure 2: Electron probe beam profile monitor with a strip cathode.

The mechanical design of the system is shown in Fig. 3, the 3D models of the of the strip cathode electron gun with insulators and support insulators are shown in Figs. 4-6.

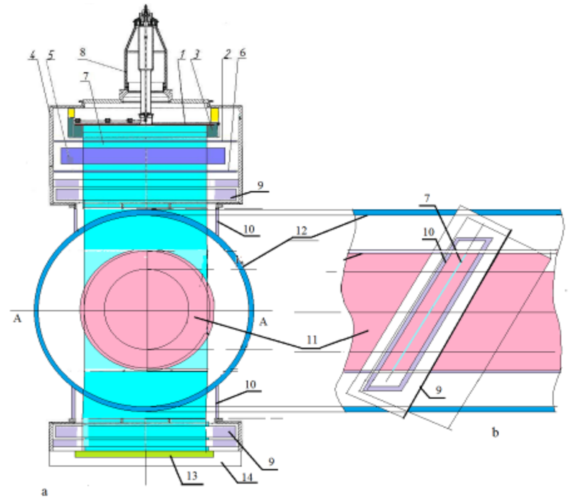

Figure 3: Mechanical design of the RBPM. a-cross-section in the plane of the ribbon electron beam; b- view of cross section in plane A-A. 1-strip cathode; 2-anode with slit; 3-extraction electrode with a slit; 4-vacuum vessel; 5-deflection plates; 6-beam forming electrode with collimating slit; 7-ribbon electron beam (up to 15 cm wide); 8-high voltage insulator; 9-slit valves for proton tube vacuum insulation (need slit ~50x180 mm^2); 10-electron beam vacuum chamber joined with proton vacuum tube 12; 11-proton bunch; 12-proton storage ring vacuum tube (OD=254 mm, ID=248 mm); 13-luminescent screen for electron beam observation; 14-vacuum window.

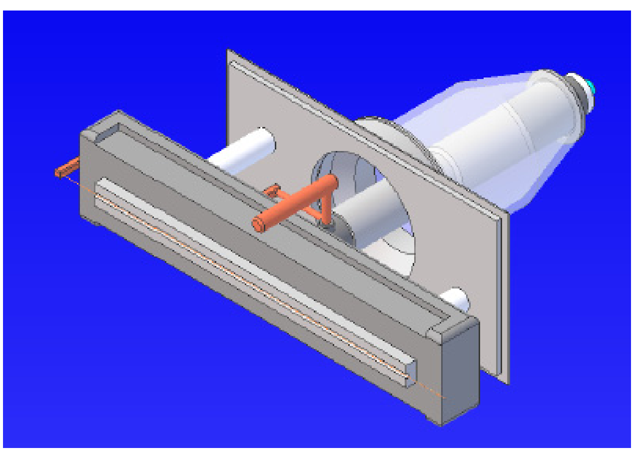

Figure 4: Design of Ribbon strip cathode electron gun.

Ribbon electron beam formation was optimized using the computer simulation code PBGUNS. The study below shows the optimization to reduce the electron beam divergence in the plane orthogonal to the ribbon. This is necessary to keep the image of the ribbon focused on the phosphor screen. The cross section of the electron gun for ribbon beam production is shown in Fig. 7. The scale of this drawing is 1 mm per division. The simulation grid step-size near the emitter can be up to 16 times smaller than the regular grid and the emission area can be simulated with high accuracy in an acceptable simulation time. The extracted electrons escape from the gun through a slit with width h=1 mm.

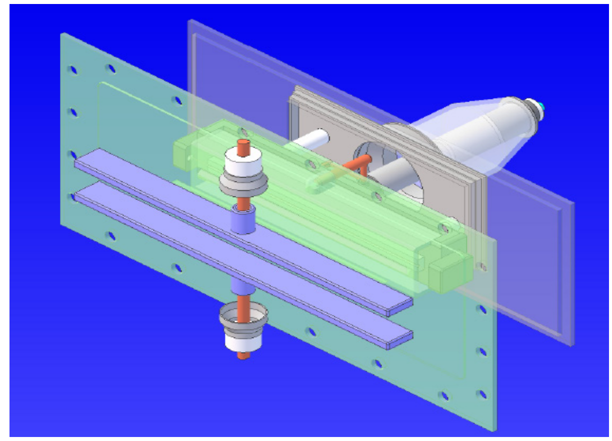

Figure 5: 3D design of RB electron gun with extraction electrode, accelerating anode, and deflection plates.

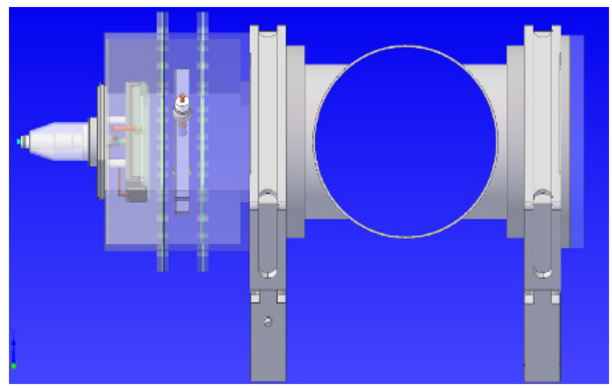

Figure 6: Adaptation of RB e-gun on the vacuum tube of the proton storage ring with vacuum valves.

The escaping electrons are accelerated by an anode (4) with voltage Ua= 100 kV located at coordinate Z_4=8 mm. Deflecting plates (5) with coordinates between Z4=9 mm and Z_5=13 mm are located between the anode (4) and electrode (6) with coordinate Z_6=14 mm. The ribbon electron beam can be deflected by the transverse electric field created between these plates and can be focused by electric fields near ends of these plates. This simulation was made with the potential of deflecting plates Ud=95 kV, which corresponds to the focusing voltage of a cylindrical (one dimensional) Einzel lens Uf=-5 kV.

The simulation was conducted with a space charge current limitation and with emission current limitation at the level of Je=100 mA/cm^2 ~ 1.5 mA per cm of the cathode filament (the simulation used a 1 m long filament). As can be seen from Fig. 7 the emitted flux of electrons is very divergent because of the cylindrical emission surface. The extraction electrode (first anode) intercepts a linear current density J1~0.23 mA/cm and J2~0.08 mA/cm is emitted from the gun. The central part of the beam has a regular divergence of α=40 mr/mm which must be compensated by additional focusing. This additional focusing was provided by the Einzel lens made by the fields between the deflection plates and the collimating slits.

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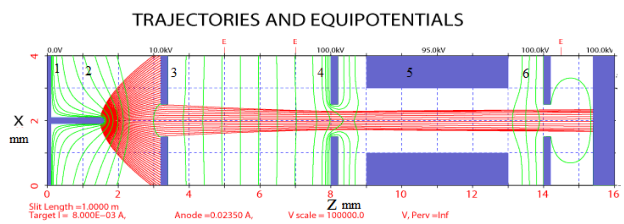

Figure 7: Edge view of the strip cathode electron gun showing the simulation of ribbon electron beam extraction, acceleration, and focusing by the deflector plates (extraction voltage Uex=10 kV, accelerating voltage Ua=100 kV, focusing voltage on the deflector system is Uf=-5 kV). Red lines are electron trajectories, green lines are equipotentials. The scale is 1 mm/division. The flat electrode (1) at Z_1=0 mm has zero potential, the same as the cylindrical emitter (2) with radius r=0.05 mm, located at coordinate Z_2=1.5 mm from the flat electrode. The electrons are extracted from the cylindrical emitter (2) by extraction electrode (3) located at coordinate Z_3=3.2 mm with potential Uex=+10 kV relative to the emitter.

A strip cathode with strong filament tension have been built and tested (see Fig. 8). The filament (1), (0.11 mm diameter thorium doped tungsten) has been attached to insulated holders (3) by spark welding with nickel foil interface and has been kept straight by a system of springs. The right holder is fixed on insulator 8. The left holder (3) can slide along a rod (4). Two direction plates with a glassy carbon inserts (5) can keep the left holder from rotating. The spring (6) can press the left holder to the left direction to keep the filament (1) straight. The filament (1) is positioned along the slit (2) of extractor (9). The anode (10) is used for further electron beam acceleration. The cathode is assembled on the base plate (7).

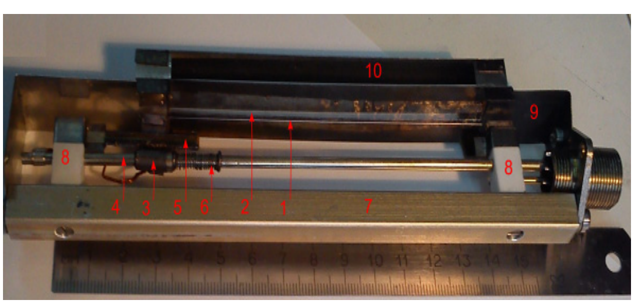

Figure 8: Design of a strip cathode gun with a tension by a spring. 1-filament thorium doped tungsten; 2-slit of extractor electrode; 3-cathode holder, sliding along support rod (4); 4- support rod; 5-plates for direction a cathode holder with a glassy carbon sliders; 6-spring 7-insulated base plate; 8- high voltage insulators;

The image of the ribbon beam from the e-beam gun prototype hitting the phosphor screen is shown in Fig. 9. The filament was heated by current Ih=1 A. The electron beam was extracted from the filament by pulsed extraction voltage Ue~ 1kV with the pulse duration T=1 µS and repetition up to f=10 Hz transmitted through an insulating transformer.

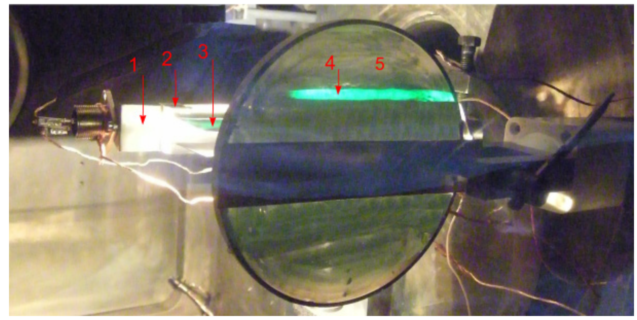

Figure 9: Ribbon electron beam on the luminescent screen deflected by deflection plates. 1-extractor electrode; 2-anode; 3-deflecting plates; 4-image of the ribbon electron beam on the screen; 5-luminescent screen. Diameter of luminescent screen is 110 mm, the shielding plate width is 25 mm.

The green line (4) on the screen (5) in Fig. 9 is an image of deflected ribbon electron beam. In this experiment, the beam line image was ~3 mm wide because the beam focusing by the deflecting plate electrostatic lens, as described in the section above on computer simulations, was not used. The beam trace visible on the screen can be seen and registered after one pulse.

With the electron beam energy increased to 100 keV, the luminescent screen trace can be seen with lower beam current. More-efficient luminescent screens with metallization will be used for the regular RBPM developed in Phase II. Increased accelerating voltage and fine focusing by the deflecting plates will produce a finely focused ribbon beam with thickness less than 1 mm, which is enough for good RBPM accuracy.

REFERENCES

[1] Peter Forck, "Minimal Invasive Beam Profile Monitors for High Intense Hadron Beams", IPAC 2010, Kyoto, Japan, 2010.
[2] A. Aleksandrov et al, "Feasibility Study of Using an Electron Beam for Profile Measurements in the SNS Accumulator Ring", PAC 2005, p. 2586-2588.
[3] W. Blokland, et al., "Electron Scanner for SNS Ring Profile Measurements", Proceedings of DIPAC09, TUOA03, Basel, Switzerland, 2009.
[4] V. Dudnikov and A. Aleksandrov, Rep. IPAC 2012, New Orleans, USA, 2012.