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A DIAGNOSTICS BOX FOR THE LINEAR ACCELERATOR OF INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES (IPM)

Sh. Sanaye Hajari†, S. Ahmadiannamin, M. Bahrami, H. Behnamian, S. Kasaei, H. Shaker, School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
F. Ghasemi, Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran

Abstract

The IPM linac is an 8 MeV (up gradable to 11 MeV) electron linear accelerator under development at Institute for Research in Fundamental Sciences, Tehran, Iran. The design and construction of the linac is nearly finished and it is in the commissioning stage. The commissioning is planned in several phase of different energy ranging from 50 keV to 8 MeV. At each phase, appropriate diagnostics is required in order to investigate the linac performance. A diagnostics box including a scintillator view screen, a dipole magnet, and a focusing solenoid is designed to diagnose the beam longitudinal and transverse parameters in wide range of energy. These parameters are the beam transverse profile, size, position, emittance and the energy spectrum.

INTRODUCTION

The IPM linac is an electron linear accelerator with an energy and current up to 8 MeV and 10 mA, respectively. The machine is developed at the Institute for Research in Fundamental Sciences, Tehran, Iran. Labled as Iran's first linear accelerator project, nearly all the components of the linac is designed and constructed within the country, in particular, the RF amplifier system (klystron and its modulator), RF cavities, magnets and beam diagnostics systems. The main aim of this research project is to provide the scientific foundations for the future accelerator projects at IPM.

The linac consists of a thermionic electron gun followed by a pre-buncher, a travelling wave (TW) tapered phase velocity buncher and two constant impedance TW accelerating tube (see Fig.1). The TW tubes are connected together via appropriate flanges and fed with a 2 MW RF power. The tubes are embedded in solenoidal magnetic fields for the focusing. The beam energy at the end of electron gun, TW buncher, first and second tube is 50 keV, 1.4 MeV, 4.8 MeV and 8 MeV, respectively. The design of the different parts of the linac is described in [1-3] and the construction process in [4-6]. The beam parameters at the end of linac are listed in Table 1.

The construction of the linac is nearly finished and it is in the commissioning stage. The commissioning is foreseen in phases of different energies – up to the end of prebuncher, TW buncher, first and second accelerating tubes. At each phase appropriate beam diagnostics is demanded in order to investigate the linac performance. The parameters to be measured are the beam current, the transverse beam profile, size, divergence, emittance and the energy spectrum. In order to diagnose the mentioned parameter in a relatively large range of energy a flexible diagnostics system is required. For this purpose, according to Fig. 2 a diagnostics box has been designed based on a focusing solenoid and a dipole magnet followed by a movable scintillator view screen. Such an integrated diagnostics box is capable to measure the beam transverse parameters and the energy spectrum of the beam via the beam profile measurement when the dipole magnet is off and on, respectively. At each phase of the commissioning, the diagnostics box will be installed at the end of the structure. In the next sections we first describe the beam profile monitor system then we will present how the beam transverse parameters and its energy spectrum can be extracted from the transverse profile. Special attention has been paid to the resolution of the measurement. For each parameter the resolution of the measurement has been calculated and the corresponding diagnostics system has been designed with the aim of providing the best resolution in the whole range of the energy of interest.

Table 1: Beam Parameters at the End of the Linac

Parameter	Value
Beam energy	8 MeV
Beam current (peak)	10 mA
Rms energy spread	0.23 MeV
Rms bunch length	2.3 mm
Normalised emittance	3.8 mm-mrad

BEAM PROFILE MONITOR SYSTEM

The view screen consists of a 3 cm × 3 cm YAG:Ce scintillator of 30 μm thickness on an aluminium substrate. The substrate ensures the heat and charge transfer. The substrate as well can be connected to an electronics readout system to be used as a Faraday cup for the beam current measurement. The scintillator view screen should be placed at a 45 degree angle and the visible photons are detected with an optical system consists of an aluminium mirror, an achromatic lens and a CCD camera.

† sanayehajari@ipm.ir

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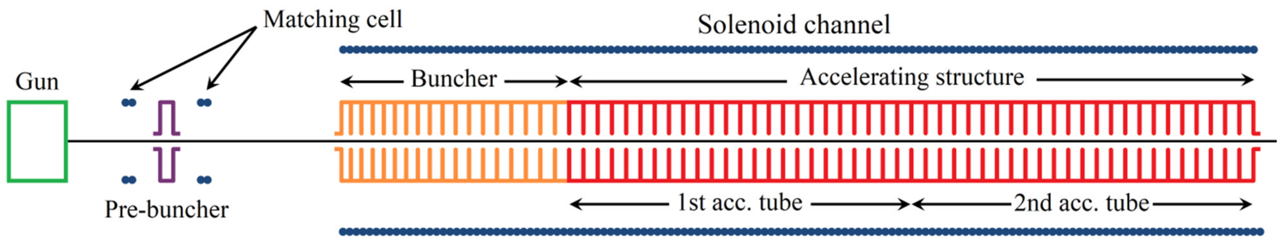

Figure 1: General layout of the ipm linac.

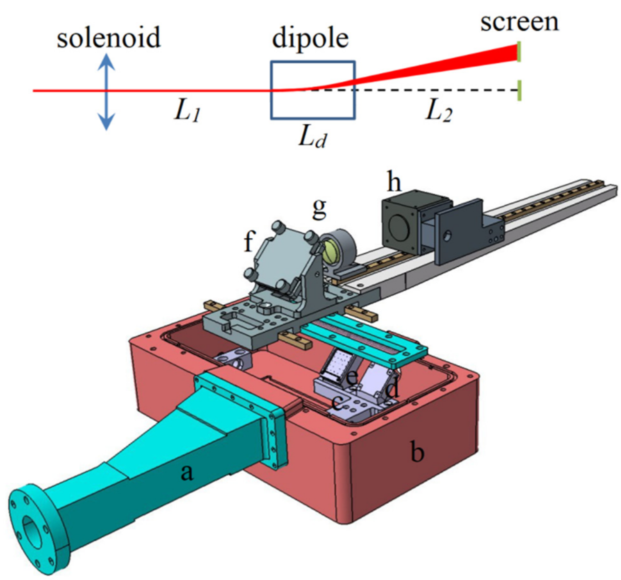

Figure 2: General layout of the diagnostics box (top) and mechanical design of the view screen holder and the optical system (bottom). Details are the dipole magnet position (a), vacuum chamber (b), movable scintillator holder (c), scintillator target (d), calibration target (e), aluminium mirror (f), achromatic lens (g) and the CCD camera (h).

Both the optical system and the scintillator view screen limit the resolution of beam profile measurement. A tilted view screen at 45 degree angle puts a limit on the resolution which can be estimated to be in the order of the illuminated thickness of the scintillator [7]. Multiple scattering of the electrons in the scintillator as well limits the view screen resolution. The resolution limit associated with this effect is estimated by Geant4 simulation [8] of particle trajectories in the scintillator material (see Fig. 3). In each case the question is how large the area of scintillator will be illuminated for an ideal point-like beam. The worst resolution of the scintillator itself in our case will be 30 μm. Several effects limit the optical system resolution. Among these are the camera pixel size and noise, spherical and achromatic aberration of the lens, diffraction and Scheimpflug effect. The optical system has been designed to provide resolution below 100 μm.

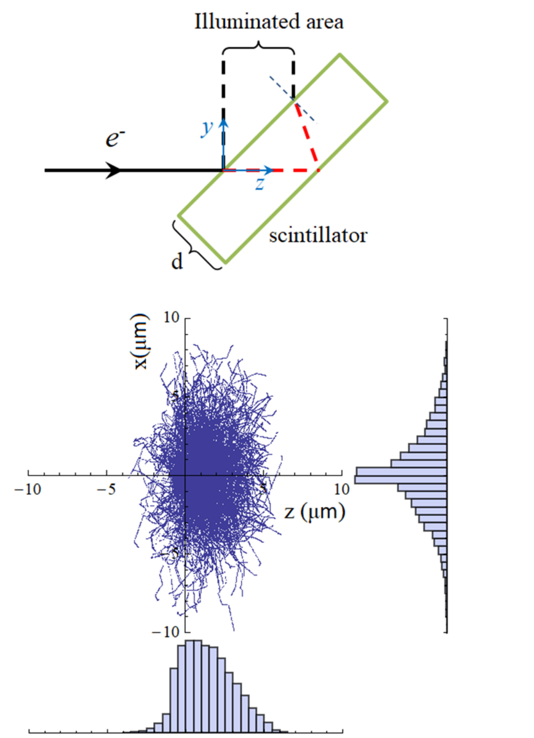

Figure 3: Resolution limiting mechanism due to tilted scintillator (up) and multiple scattering (bottom). The multiple scattering has been simulated by Geant4 for a point like beam of 50 keV energy.

MEASUREMENT OF THE BEAM TRANSVERSE PARAMETERS

The transverse beam parameters – size, divergence and emittance – can be measured using the solenoid scan process [9]. In this method according to Fig. 4, several beam sizes are measured for different solenoid focusing around the minimum beam size at the screen.

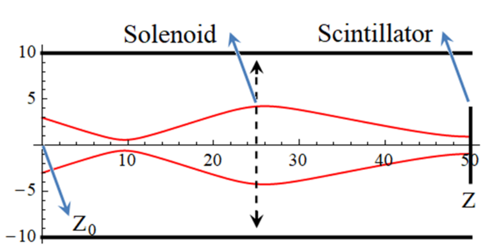

Figure 4: Solenoid scan process experimental setup.

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The transverse beam parameters then can be calculated using the following formula and the least square fit method [10],

$$a^2 = M_{11}{}^2 a_0^2 + 2M_{11}M_{12}a_0 a_0' + M_{12}{}^2\left(\frac{\varepsilon^2}{a_0^2} + a_0'^2\right). \quad (1)$$

Here M_{ij} is the transfer matrix elements, a the rms beam size at the screen, ε the geometric emittance, a_0 and a_0' the beam size and its derivative (beam divergence) at an arbitrary origin before the solenoid. In order to determine the three unknown parameters a_0, a_0' and ε at least three measurement is required, however, more measurements provides a better accuracy. The least square fit method in addition to the unknown parameters determined the error propagation as well. Therefore, for a known resolution of beam profile measurement the relative error in other beam transverse parameters can be calculated. In our system in worst case the relative error in the emittance will be less than 20%.

ENERGY SPECTROSCOPY

After measuring the beam transverse parameters the dipole magnet can be turned on to measure the energy spectrum of the beam. Here the view screen will move transversely in order to measure the beam profile. The beam position and its horizontal size will be associated to the beam energy and its spread. Figure 5 shows an example of the beam cross section at the view screen when the dipole is off and on.

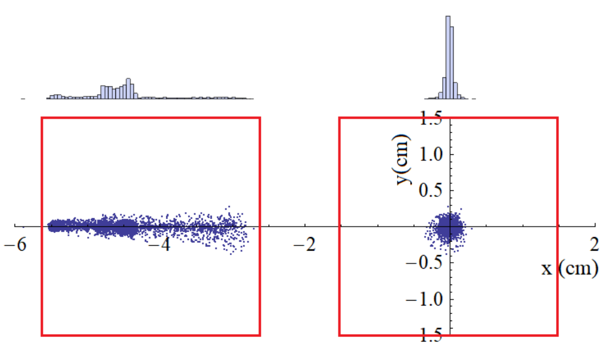

Figure 5: Beam cross section at the view screen when the dipole is off and on.

The main resolution limiting effects here are the betatron motion of the particles. It can be shown that relative error in the relative energy spread, δ, is given as [11]

$$\frac{\sigma_\delta}{\delta} = \frac{a_{off}}{a_{on}} \quad (2)$$

a_{off} and a_{on} are the horizontal beam size when the dipole is off and on, respectively. Therefore, in order to improve the resolution, the beam should be focused well at the screen when the dipole is off. This indicates the role of the focusing solenoid in the spectroscopy.

The movable view screen providing a variable bending angle ensures high resolution energy spectroscopy in a wide range of energy.

CONCLUSION

A diagnostics box has been designed in order to measure the beam parameters in a wide range of energy (from 50 keV to 8 MeV). When the dipole magnet is off the transverse parameters are measured with the solenoid scan process. Then the dipole is turned on in order to perform the energy spectroscopy. The resolution in the measurement of all parameters has been calculated. The diagnostics box provides good resolution in the whole energy range of interest.

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