LOW INTENSITY ELECTRON BEAM CONTROLLING AND MONITORING

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Abstract

To calibrate a cosmic-ray detector, a low beam current accelerator has been built to generate ultralow intensity electron beams at Institute of High Energy Physics (IHEP). The minimum beam charge obtained was estimated to be about one electron/pulse. Beam commissioning has been carried out. The key technologies for achieving such low intensity electron beams are to control the beam using 8 movable slits and to measure the intensity of the beam using 9 movable current monitors based on scintillator. In this paper, principal of operation, instrumentation and programming of the movable slits and movable current monitors are discussed. Some results of beam commissioning are also presented.

INTRODUCTION

A small electron LINAC was designed and installed at IHEP. The ultimate goal of the accelerator is to obtain a quasi-single electron beam of a certain energy for the cosmic-ray detector calibration. The electron LINAC consists of a weak current electron gun, a RF chopper, two accelerator tunes, eight movable slits, nine sets of low energy pulsed electron beam intensity monitor and other necessary systems. It can generate 0.1~50MeV electron beams. These beams are sent to the target chamber by the bending magnets. The schematic diagram of the LINAC is shown in Fig. 1.

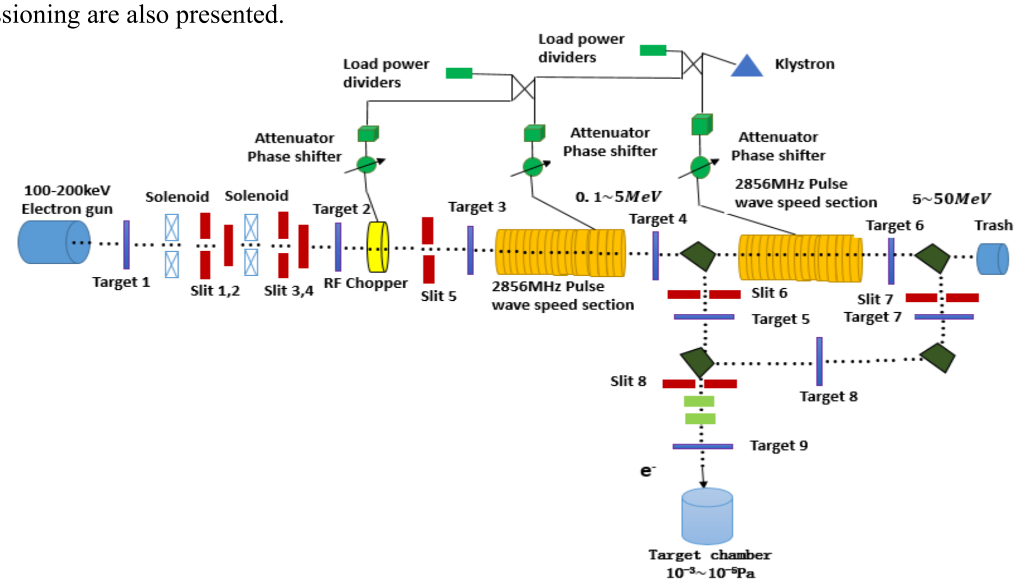

Figure 1: Accelerator device layout.

A beam micropulse of an ordinary electron LINAC has more than 10^6 electrons [1]. For the study on the calibration of cosmic-ray detectors such a beam is too intense. It is necessary to have a single-electron pulsed beam. However, when the beam intensity is ultralow, the normal current measurement methods are no longer applicable. Therefore, in order to reduce the number of electron in each pulse from 10^6 to single, eight movable slits are installed to control the electron beam and nine detectors based on plastic scintillator and photoelectric multiplier tube (PMT) are developed to monitor the 100Hz pulsed beam intensity. In this paper, principal of operation, instrumentation and programming of the movable slits and movable current monitors are discussed. Some results of beam commissioning are also presented.

INSTRUMENTATION

Movable Slits

In order to step by step decrease the beam intensity, 8 movable slits are installed along the accelerator. These slits include both horizontal and vertical slits. Each slit can decrease the electron beam intensity to 1/20. Each slit has two stoppers. Every stopper is moved by step motor. Motion Controller NI PXI-7334 is used to control the motor. In order to precisely control the beam intensity, the position resolution of the stopper can reach less than 5 μm.

1µm position resolution Sino grating ruler KA-500 is used to measure the position of the stopper. Signal Acquiring cards NI PXI-6602 are used to read the data from grating-rule. To effectively block the electron beams and avoid other unwanted effects, tungsten is chosen as the material of the stopper [2]. Figure 2 shows the overview of one movable slit.

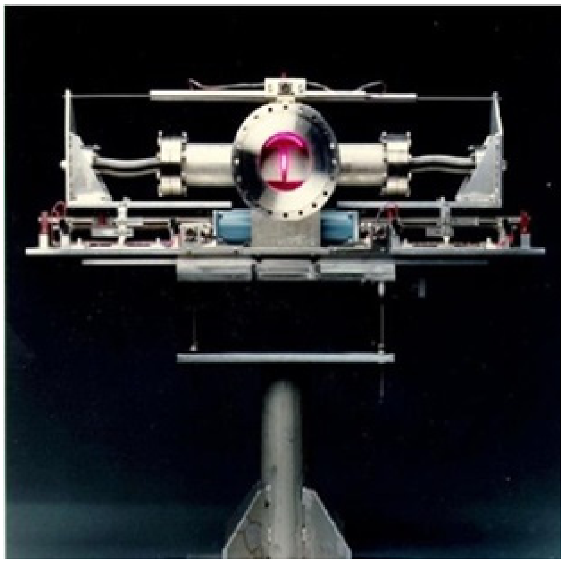

Figure 2: Overview of one movable slit.

Beam Intensity Monitors

Nine monitors based on plastic scintillator and PMT are used to measure ultra-low electron beam intensity. These monitors can detect single electron. The energy loss (dE/dx) of the electrons crossing the scintillator is proportional to the number of electrons. So the intensity of converted flicker light can be used to deduce the electron beam energy loss and the number of electrons in a bunch. In order to produce photon coupled to the PMT as many as possible, we combined the light guide and the plastic scintillator probe as a unit, and then coupled to the surface of the PMT through the silicone oil (Fig. 3).

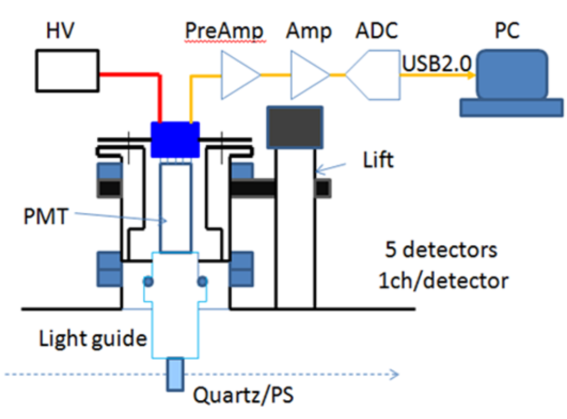

Figure 3: The schematic of weak current monitors.

The monitor can be pushed into the tube for beam intensity measurement and pulled out from the vacuum pipe to let the beam passing through.

BEAM MODULATION

Currently, nine detectors and target lift mechanism have been installed in the accelerator beam line. Detectors are located at different positions on the beam line. All signals are connected to the Waveform Sampling and Reading Unit (DT5742) via a 15m long cable, so that various noise sources on the beam line can have a serious impact on the detector. By shielding and grounding, etc., the noise can be reduced to a certain level.

Calibration Result

Before the scintillators are used to measure the beam intensity, calibration needs to be done by radioactive source. Here β source ^{207}Bi is used to calibration the monitor. Figure 4 shows the statistical result, we can see 1369keV correspond to 976 keV (we know the energy of beta beam of ^{207}Bi is 976 keV), so there is a coefficient of 976/1369. Deposition energy and electron number of the beam can be calculated by formula:

$$N_m = \triangle E/\delta E_e = 0.976 * (P/P0)/Ee$$

Respectively, N_m is the number of electrons measured by probe, δ is light collection efficiency, △E is total deposition energy and E_e is incident electron energy, i.e., beam energy.

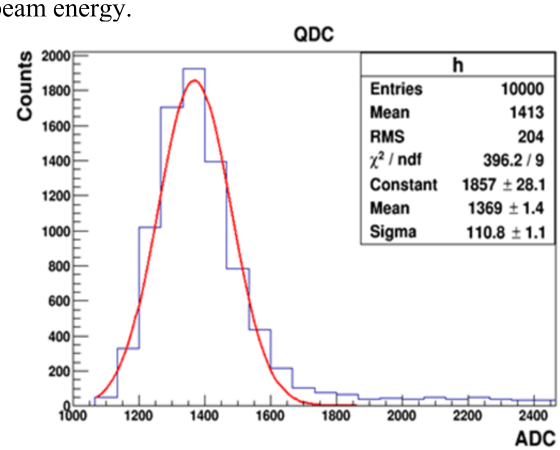

Figure 4: Test energy spectrum of Bi^{207}.

Initial Beam Commissioning Result

During the initial beam commissioning, the vacuum and noise are in the normal range. With high pressure 185kV of electron gun, filament current 1.65A, and gate voltage 50V, all nine beam monitors have detected beam signals.

Different from our expectation, the electron beam out of the electron gun is deflected upward and the beam spot is relatively scattered. We installed a focusing magnet and a syndrome in front of the detector 1.Then the beam spot focused slowly after detector 1 until detector 3. And it starts to disperse after reaching the accelerating tube (Figure 5).

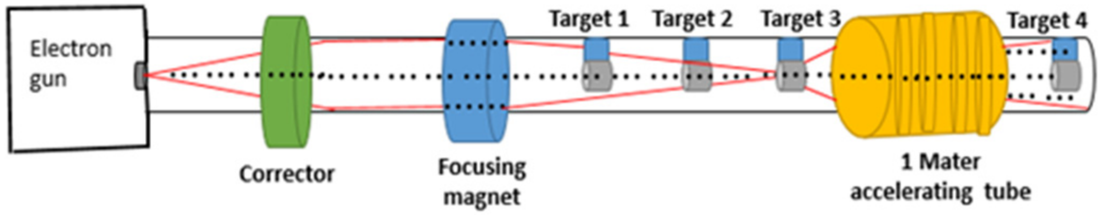

Figure 5: Schematic diagram of actual beam photometry.

Figure 6 shows the results of the beam modulation. The number of detected electrons at detectors 1~4 is Nbeam1 =4275, Nbeam2 = 6025, Nbeam3=7855, Nbeam4 = 1945, respectively, which is consistent with the actual beam metering guess.

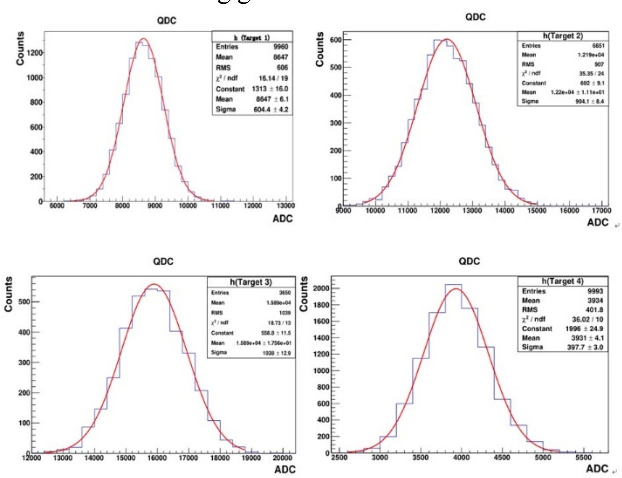

Figure 6: The results of detector 1, 2, 3 and 4.

Slit Experiment

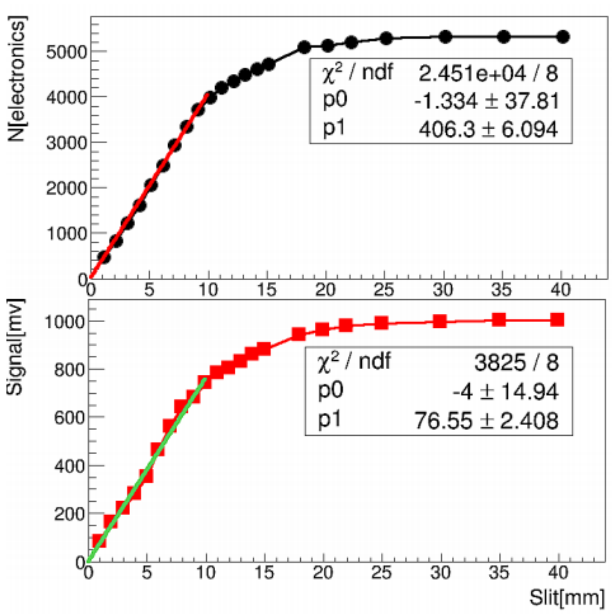

Figure 7: Electron number on detector 3 with the slit 5 changes.

The quasi-single electron in the accelerator beam pulse needs to be obtained by movable slit mechanism. Each movable slit can reduce the beam intensity to one-twentieth of the original. In our experiment, when movable slit 5 was fully opened, signal detected by detector 3 was 1000 mv. Then slit 5 was completely closed, and open 1mm every time, gradually increased. The number of electrons corresponding to slit position is calculated and shown in Fig.7. The electron number detected by detector 3 are gradually increased as the slit 5 is opened. Within the range of 10 mm, the number of electrons are almost linear with the distance of movable slit 5. The results of the slit experiment show that movable slits play an effective role on beam commissioning.

CONCLUSION

Beam intensity monitors based on plastic scintillator and PMT have been successfully applied to the low energy electron beam. 8 movable slits are also used to control the electron beam successfully. Some preliminary results of beam commissioning have been shown. Compared with other commonly beam intensity measurement methods, these beam detectors have higher sensitivity and better detection efficiency. The beam commissioning is still in progress. More further study needs to be done.

REFERENCES

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[2] J.H. Yue *et.al.* "The Measurement and Controlling System of the Beam Current for Weak Current Accelerator", WEPG33, Proceedings of IBIC2016 Barcelona, Spain, 2016