MEASURING AND CHARACTERIZING BEAM ENERGY OF A COMPACT MEDICAL LINEAR ACCELERATOR*

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Abstract

Beam energy is an important parameter of linear accelerator. Compact linacs for medical and industrial applications are usually not equipped with beam monitors. The commonly used methods are “half value layer” (HVL) in industrial and “Percentage Depth Dose” (PDD) in medical to evaluate the beam energy of linac. However, these methods are not easily and accurately carried out, the HVL method needs big and heavy steel plates to prevent scattering x ray beams and PDD method need standard beam position and expensive 3D water tank to measure the beam energy. Most importantly, those methods cannot measure electron beam energy, but the photon distribution generated through Bremsstrahlung. This article introduced a method to measure and characterize the average electron beam energy when hitting the target by combining the external measurements and simulation beam profile results under different deflection magnetic field generated by steering coils. This method not only gives confidence in developing and operating the medical equipment but also reveals relation between beam energy and RF power settings. In addition, this paper provides energy and dose output variation across the RF pulse. This data provides guidance for proper setting of gun pulse width and timing.

INTRODUCTION

Unlike accelerators in physics laboratories which are facilitated with various kinds of beam monitors, medical and industrial linacs are sealed with permanent target and RF cavities together directly without monitors[1-3]. While these monitors are not necessary during typical operation for those applications, it is very difficult to characterize the beam performance during research and development. The measurable output from the linacs is typically the photons generated by Bremsstrahlung, which has a broad spectrum and strongly depending on target structure. In case of troubleshooting, it is difficult to find out if the linac is delivering electron beam properly. This article introduced a method for measuring electron beam energy of compact linac that has no internal monitors. In addition, because the medical and industrial linacs are operating with pulsed RF power and e-gun pulse, the relative timing between the pulses affects the output energy and dose rate as well. This article also presented these variations using short gun emission pulse with different injection timing.

METHOD

As typical accelerator beam energy measurement, steering magnetic field is applied to the beam line after acceleration, and the beam energy can be found from the displacement. However, in the compact linac case, there is not room between linac output and target for such measurement. The steering field can only be applied in the upstream part of the linac during beams acceleration. The electrons after the steering are subject to strong RF fields, that changes electrons’ energy and transverse momentum significantly. The displacement cannot be simply calculated. In this paper, we combine linac beam simulation and beam spot centre shifting measurement to determine the electron beam energy.

A pair of steering coils are installed on the linac, close to the e-gun. The beam spot profile is measured with a scanning slit device[4-5]. The measured profiles with different steering current settings are shown in Fig. 1.

The profile data is fitted with dual-Gaussian function which is typically observed in this kind of linac[4]. To determine the beam center, we take the center of the narrow Gaussian. (More discussions regarding the two Gaussians, please refer to another paper in this conference.) The beam center shift vs steering current is obtained, and the steering rate is calculated, as plotted in Fig. 2(a).

Above procedure is repeated with varying RF power (HV applied to magnetron), which changes e-beam energy. The steering rate with various RF power is shown in Fig. 3(a).

The same process is applied to simulation data. The beam spot center shift with various steering current is plotted in Fig. 2(b), which is used to obtain steering rate with various average electron beam energies. Therefore, we obtained the relation of steering rate vs e-beam energy, as plotted in Fig. 4. The data are fitted with a quadratic curve. The measurement data points are overlaid on the curve with equal steering rate. This yields the relationship between beam energy and RF power setting (Mod_HV). Figure 5 shows the relation. From this plot, one can find out the electron beam energy once RF power is set.

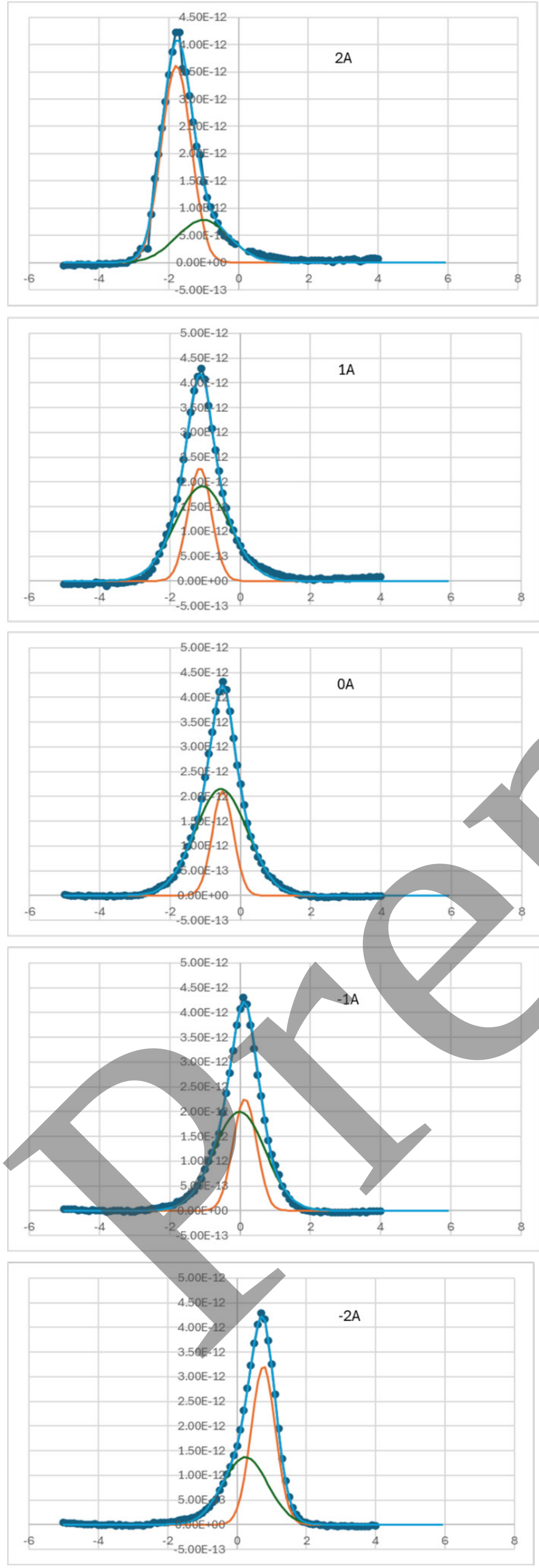
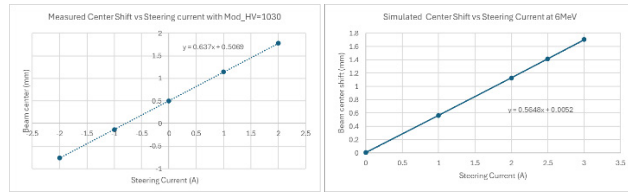
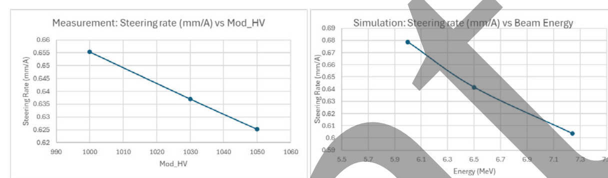


Figure 1: Beam profiles with various steering currents.



(a) (b)

Figure 2: Beam spot center positions versus steering current. (a) Measured; (b) Simulation



(a) (b)

Figure 3: Steering rate versus (a) magnetron modulator high voltage in measurement and (b) beam energy in simulation.

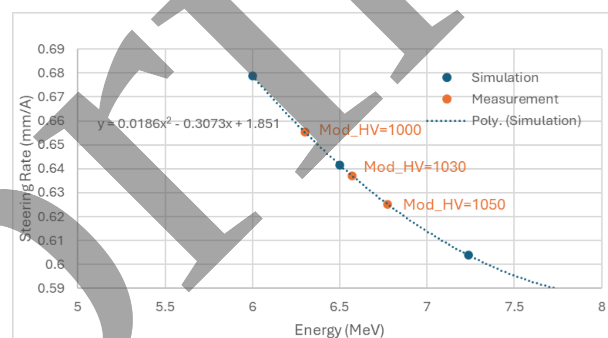


Figure 4: By combing the measurement data and simulation data with equalling steering rate, the electron beam energy is related to the linac power setting.

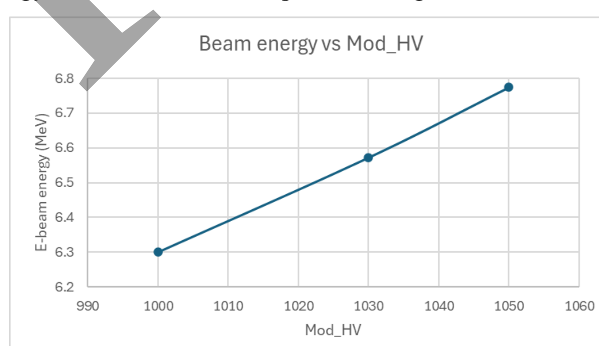


Figure 5: Linac power setting vs electron beam energy.

TIMING EFFECTS ON ENERGY AND DOSE RATE

In addition, the beam energy and dose output of the electron beam are characterized across the RF pulse, to guide the proper setup of the system. In medical radiation generation, the dose output is measured by dose rate at the Dmax position in the water, while the beam energy is measured by the ratio of the dose rate at 10cm water depth and the maximum dose rate (D10/Dmax). These are important parameters to characterize the radiation therapy machines.

So, they can be used to evaluate if the radiation beam is generated properly.

A short gun pulse (0.3 µs) is used to probe the RF pulse by varying the delay time. We start the gun pulse when the RF energy starts to fill the cavities, where the reflection is at its minimum. Then the gun emission pulse timing increases step-by-step, with 0.3 µs per step, until the RF pulse falls. The pulse timing relation is shown in Fig. 6. The dose rate and relative energy (D10/Dmax) are measured at each step. The results are plotted in Fig. 7. Each data point is corresponding to the probing gun pulse in Fig. 6.

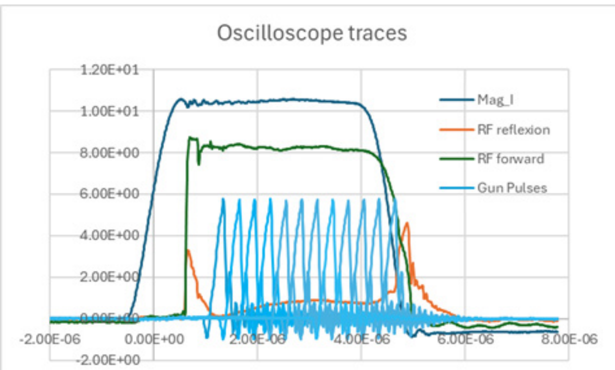


Figure 6: The series of probing gun pulse timing vs RF pulse.

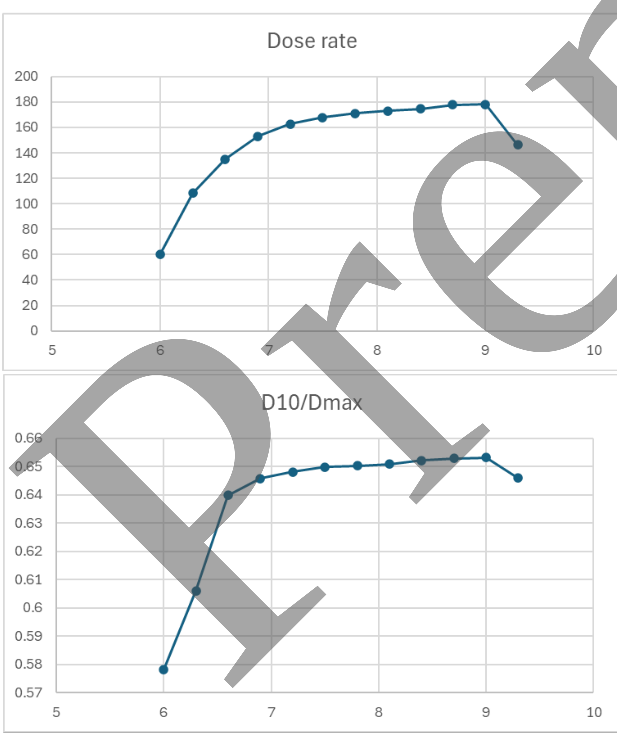


Figure 7. The dose rate and energy output vs gun pulse sequence with timing variation.

In certain application, particularly in medical, proper energy level is desired. This data is a guide to set the gun pulse within the flat range to achieve best beam quality.

CONCLUSION

This paper presents a method for measuring the electron beam energy of a compact linear accelerator (linac) without relying on beam monitors. This approach provides guidance for the proper setup of such linacs. Additionally, we report the variation in beam energy relative to the timing between the RF pulse and the gun pulse, which serves as a useful reference for system configuration.

REFERENCES

[1] S. H. Lee, *et al*, “X-band Linac for a 6 MeV dual-head radiation therapy gantry” *Nucl. Instrum. Methods Phys. Res. A,* vol. 852, pp. 40-45, Apr. 2017. doi: 10.1016/j.nima.2016.11.034

[2] S. V. Kutsaev, *et al*, “Linear accelerator for security, industrial and medical applications with rapid beam parameter variation”, *Int. J. Radiat. Phys. Chem.*, vol. 183, p. 109398, Jun. 2021. doi: 10.1016/j.radphyschem.2021.109398

[3] X. Yu, H. Tao, Z. Zhao *et al.*, “Design, Fabrication, and Testing of an S-Band 2.5-MeV Linear Accelerator for Irradiation Applications”, IEEE Transactions on Nuclear Science, 73[2026-03-23]. doi:10.1109/TNS.2025.3635208

[4] Q. Chen *et al*, “A slit method to determine the focal spot size and shape of TomoTherapy system”, *Med. Phys.* 38(6), p. 2841, Jun. 2011.

[5] F. Li, G. Zhong, H. Yu, *et al*, ”Measuring Size and Stability of Focal Spot for Linear Accelerator in Industrial CT by Slit Translation Scanning Method”, *IEEE Trans. Instrum. Meas.*, vol. 73, pp. 1–7, 2024. doi:10.1109/tim.2024.3406806