DUAL BEAM DYNAMIC MODES IN A COMPACT STANDING WAVE LINEAR ACCELERATOR

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Abstract

It has been commonly observed that the beam spot profile of compact standing wave linacs have a dual Gaussian distribution. Further study of this paper shows that the two Gaussian distributions are generated by different acceleration processes and beam dynamics. Simulation data analysis concludes that the particles in the two Gaussian distributions are strongly dependent on their initial phases. Experiment results have demonstrated the two Gaussian distributions responded differently to steering magnetic field.

INTRODUCTION

Compact standing wave linac is widely used in radiation therapy equipment. In this industry, it has been common knowledge that the beam spot is typically showing a dual-Gaussian distribution [1-2], rather than a single Gaussian type that most accelerator beam features. It is desire to have a further understanding how the dual Gaussian profile is generated, which is potentially helpful to optimize beam dynamics design, improving characteristics such as spot size and energy spread.

OBSERVATION

A 6 MeV standing wave linac is designed and developed by Chengdu Elekom Vacuum Electron Technology Co. Ltd for RefleXion Medical Inc. The beam spot profile on the target is measured at RefleXion with scanning-slit apparatus. The measured results can be fitted fairly well of summation of two Gaussian functions – one narrow and one wide. In addition, we observed that the two Gaussian distributions respond to steering field, which is generated by a pair of coils mounted on the gun side of the linac, differently!

Figure 1 shows the measured beam profiles with various steering currents. Each profile is fitted with sum of two independent Gauss functions. It is quite visible as the steering current increases; the two Gaussian distribution centres no longer have the same displacements. The narrow Gauss moves more than the wider Gauss. In addition, the size of the two distributions also varies, with the wider Gauss shrinks.

Figure 2 plots the center shifting of the two distributions, versus steering current. The narrow Gauss tends to respond linearly with steering current, while the wider Gauss responds rather nonlinear.

This observation indicates that the electrons in these two Gaussians possess different beam dynamics.

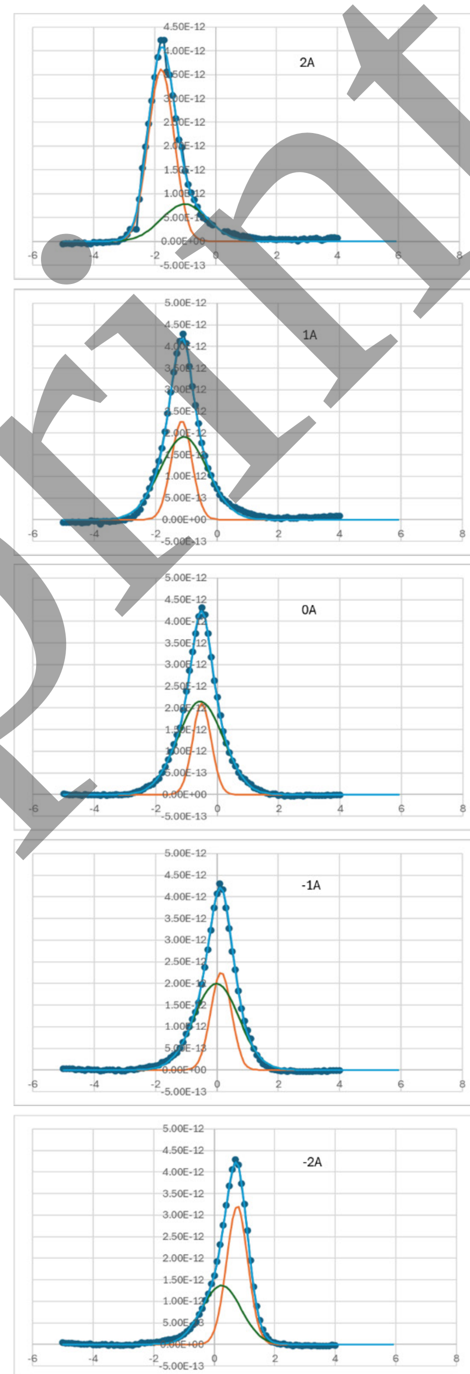


Figure 1: Measured beam profiles and Gauss fittings with varying steering currents.

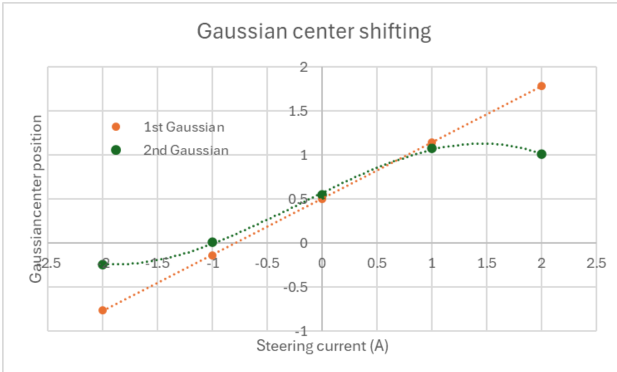


Figure 2: Distribution centre shifting vs steering current.

SIMULATION AND ANALYSIS

To understand the different dynamics of the two beams, simulation is performed with General Particle Tracer (GPT) [3]. Total of 99,177 particles are emitted from the electron gun, and 45,638 reached the target. The particles ended on the target also feature the dual-Gaussian distribution (Fig. 3).

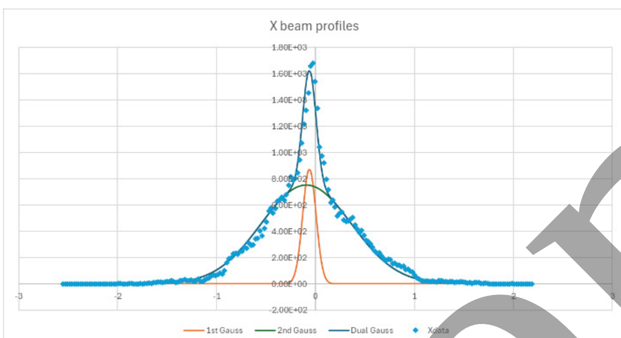


Figure 3: Simulated electron profile fitted with the sum of two Gaussian functions.

Similar to experimental measurements, the simulation also shows the two Gauss distributions response to steering current differently: the narrow one is rather linear and wider one is non-linear, as shown in Figure 4.

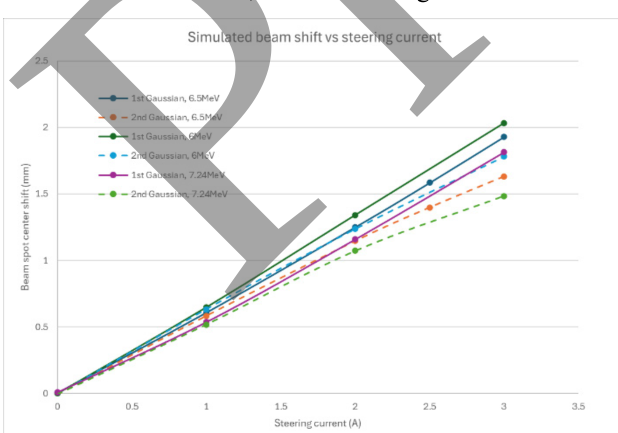
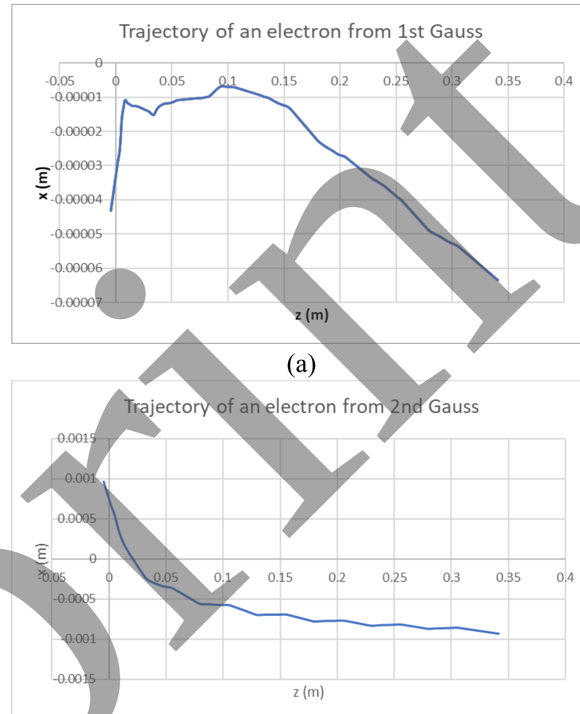


Figure 4: Gauss distribution centres displacement versus steering current by simulation.

To understand the electron behaviour of the two distributions, the trajectories of two individual electrons, each from one of the distributions, are plotted in Figure 5. The one from the narrow distribution, as shown in Fig 5(a), is strongly impacted by the transverse focusing of the bunching cavities. The electron from the wider distribution, on the other hand, is almost not influenced by transverse focusing, behaved as direct projection from the e-gun. The reason that its trajectory appears logarithmic is due to the acceleration, which is well understood [4].



(b)

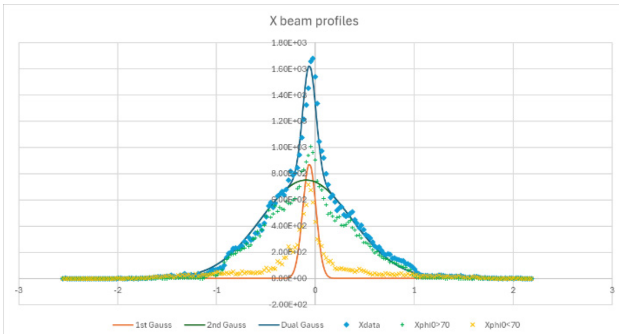
Figure 5: Typical single electron trajectory from narrow (a) and wide (b) distribution.

DISCUSSIONS

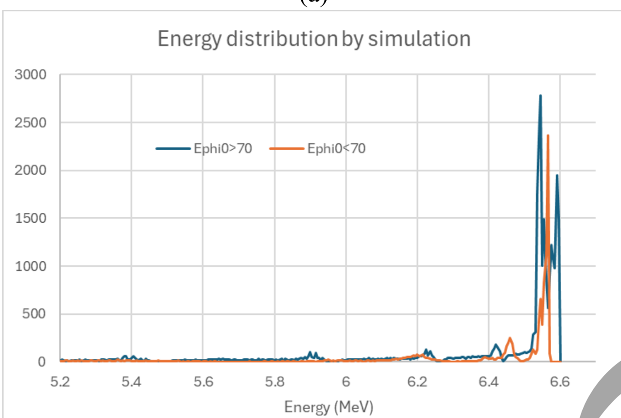
Both simulation and measurement demonstrated that the electron beam through a compact standing wave linac include two modes of beam dynamics. One is a well-focused beam, and the other is projected from e-gun through the accelerating tube with minimum focusing.

It is conceivable that there might be a phase space "bucket" which distinguish the electrons inside and outside to be trapped in the different modes. The separation based on the particles' initial RF phase explored. Simulation shows that electrons that reached to the target have initial RF phase between 12.2 ° – 233.5 °. Data shows that the narrow Gauss consists most low initial RF phase electrons while the wide Gauss consists of higher ones. For example, the distribution of electrons with initial RF phase below 70° and higher than 70° are plotted in Figure 6(a) respectively. It can be seen that these distributions of the two groups resemble the two individual Gaussian functions well.

Further looking at the energy distributions of the two groups of electrons, as plotted in Figure 6 (b), one can see the narrow Gauss group also has a sharper energy distribution, indicating better longitudinal focusing as well as transverse.



(a)



(b)

Figure 6: (a) Distributions of electrons with initial RF phase below and beyond 70° are plotted against the total electrons distribution, with Gaussian function fit; (b) Energy distribution of the above two groups of electrons.

By careful examine Figure 6 (a), it is visible that the two distributions separated by initial RF phase are not completely represent the two Gaussian functions. Each one has small amount from the other mode. More investigations will be needed.

CONCLUSION

The study of a compact 6 MeV standing wave linac has revealed that the electron beam accelerates through the cavities under two different beam dynamics modes. One part of the electrons is strongly focused by the RF field transversely and longitudinally. The other part is essentially projected from the e-gun and accelerated. The phenomenon is observed as two Gaussian beam profiles and confirmed in simulation and experiment studies.

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