INITIAL OPERATION OF THE UCLA PLANE WAVE TRANSFORMER (PWT) LINAC

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Abstract

We report on the initial operation of a novel compact rf linac — the plane wave transformer (PWT). The PWT is a 42 cm long, 8 cell standing-wave structure, operated at S-band, in a π−mode. We present the properties of this linac at rf power levels from 4 MW to 8 MW and beam energy from 7 MeV to 10 MeV, measured initially using both dark current and photo-electrons. Some technical issues associated with the operation are discussed. Future improvements of the PWT, using a modified design, are also studied.

I. INTRODUCTION

The UCLA rf linac system is designed to provide a high brightness electron beam for physical experiments, such as free electron lasers, plasma focusing and plasma acceleration [1]. It uses a laser-illuminated photocathode rf gun as an injector. The rf linac accelerates the electrons to an energy ranging from 10 to 20 MeV with a high beam quality. To this end, a compact, high gradient and high brightness rf linac structure is needed to achieve our goals. Therefore, the plane wave transformer (PWT) [2] linac, which promises high impedance, high efficiency, low cost, is used in our system.

Since it was first proposed in 1960s [3], the PWT linac structure, named in 1980s [2], had not been under much studies. The PWT is a standing-wave linac, excited in the π−mode. It consists of a cylinder cavity, loaded with disks. The disks are separated from the cylindrical tank and supported by several metal stems parallel to the axis. This structure has features such as operation at TM_{02n} mode (where n is the number of disks), the simplicity in fabrication, and the strong coupling between cells. The PWT structure supports both a longitudinal acceleration field and a TEM-like plane wave between the tank and the disk array. The plane-wave provides the coupling between the individual cells. In this sense, this structure transforms a plane-wave into a longitudinal acceleration electric field. This unique feature makes the PWT structure have advantages of high shunt impedance and low fabrication tolerance. It also has the potentials of compactness, high brightness, high efficiency and low cost. These properties will make the PWT linac a very promising candidate to be widely used in experimental labs and industry communities.

Since the PWT operates on a high order TM_{02} mode, it raises concern on its mode structures and frequency separation of the operation mode from other different modes. It is probable that other undesired modes would be excited by either the rf coupler or the elctron beam. Besides, for operation in the π−mode, a linac structure is sensitive to defects in the manufacture and beam loading. Therefore, the actual application of this structure, if any, to particle accelerators will demonstrate its feasibility to become a promising candidate in the rf linac family.

We started the rf high power conditioning of the PWT late last year. The preliminary results are very encouraging. In this paper, we describe the mechanical design of the linac. We report the properties of the PWT at rf power level from 4 to 8 MW. We present the measured beam parameters. We also discuss the future improvement of this structure.

II. MECHANICAL DESIGN OF THE PWT

The UCLA PWT linac prototype is shown schematically in Fig.1. It consists of eight cells with half-cell termination in both ends. It has a total length about forty two centimeters. The dimensions of the linac are listed in Table 1. The whole structure is removable for the convenience for study.

Geometry dimensions (mm)		Electrical parameters	
total length	420	frequency	2856 MHz
tank inside diameter	136	unloaded Q-value	14000
disk diameter	81	shunt impedance	53MΩ/m
drift tube length	178	transit factor	0.77
disk iris diameter	16	field ratio	2.5

Table 1. Geometry and Electrical Parameters of the PWT

The tank was manufactured from stainless steal with copper plating inside. The disks were made from OFHC copper. The disk-washers are soldered with four water tubes which provide cooling to the linac to stabilize the resonance frequency. The four water tubes pass through one end flange with the joints being vacuum sealed by viton gaskets. There are four small ports at each end of the tank, as shown in Figure 1. In an earlier design, the central array was supported by four connecting bars at both ends [4]. The

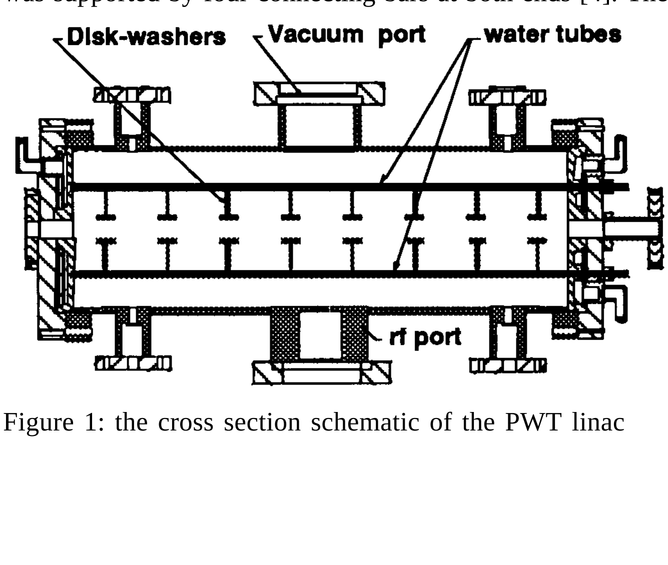

Figure 1: the cross section schematic of the PWT linac

four ports were used to house these connecting bars. Although the previous design simplified vacuum seal, the water cooling could not be provided to the disks, because of the existence of the joints between the central array and the connecting bars. Under the current design, all of these ports are idle, except one of them is used for housing an rf monitor. The cooling water temperature is controlled by a constant temperature bath. No water cooling is provided to the outside tank because its low rf power loss and its insensitive to affecting the resonance frequency.

To minimize the rf power loss and perturbation of the accelerating field, the water tubes, which also serve to connect the disks, are located at places where the field is at minimum. The tuning of the PWT was accomplished by slightly changing the dimensions of the end cells. The tuning from cell to cell is not necessary because of the strong coupling between cells. The fine tuning of the linac resonance frequency is achieved by adjusting the temperature of the cooling water.

III. ELECTRIC PROPERTIES

The linac shares a 25 MW XK-5 klystron with the rf gun. The rf power is distributed to the linac and the rf gun by using a direction coupler at a ratio of 2:1. The RF power was coupled into the linac by cutting an iris in the wall of a central accelerating cell. A high power phase-shifter is installed in the linac branch to adjust the injection phase of the electron beam into the linac. There is no rf isolator connected to the linac at current set-up.

The electrical parameters of the linac are listed in Table 1. Fig. 2 shows the high power rf signals: the forward pulse, the reverse pulse, and the pick-up signal from the rf monitor in the linac. The flat-top duration of the rf power pulse of the system is about 2 μs. The fill time of the linac is about 0.8 μs. Therefore, the pick-up signal does not have a flat top. The estimation of the Q-value from the monitor signal is consistent with the cold test.

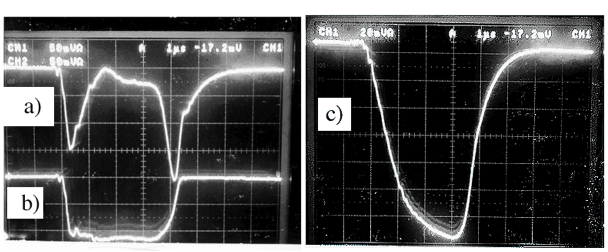

Figure 2: The rf waveforms from the PWT linac: a) reverse power; b) forward power; c) the PWT monitor signal (horizontal scale: 1 μs / div.).

The highest rf power fed into the linac we recorded is above 8 MW. However, the PWT linac did not sustain this power level for very long time. The possible causes are: a) excessive arcing occurred during conditioning, resulting in damage to the linac surface; b) vacuum problems due to faulty pumps. Besides, the PWT could not be baked to high temperature because viton gaskets are used at the water tube joints with one end-flange.

IV. MEASUREMENT RESULTS

The details of the UCLA rf linac beam line is described in [5]. Two doublets are placed at down stream of the linac, followed by a dipole magnet, which is used to measure the beam energy and the energy spread. Several phosphor screens are used to monitor beam profiles along the beam line. The emittance is measured by using both slits and quads-scanning. Beam charge is measured by an ICT and Faraday-cups.

Most of the measurements of beam parameters were carried out at low charge [5]. At a beam charge of less than 0.1 nC, we obtained a well focused beam by just using the solenoid at the gun exit alone. Fig. 3(a) shows a beam image at the screen after the dipole magnet. Fig. 3(b) and (c) show the beam profiles at horizontal and vertical planes separately. The rms spot size is about 0.5 mm for horizontal plane and 0.4 mm for vertical one (FWHM). The corresponding laser beam rms spot size for this electron beam is about 2 mm.

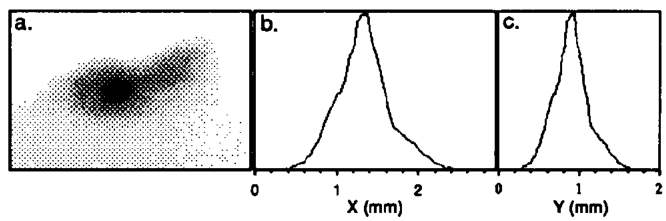

Figure 3: The beam image at the screen after the dipole: a. beam spot image on the screen; b. horizontal beam profile; c. vertical beam profile.

The beam energy is proportional to the square root of input power. Fig. 4 shows the measured electron beam energy variation with the input rf power to the linac. In comparison, the calculated results from measured PWT parameters of cold test are also shown in the figure. For the measurements, the beam energy exit from the rf gun is about 3.2 MeV. The measured energy agrees with the calculated results very well.

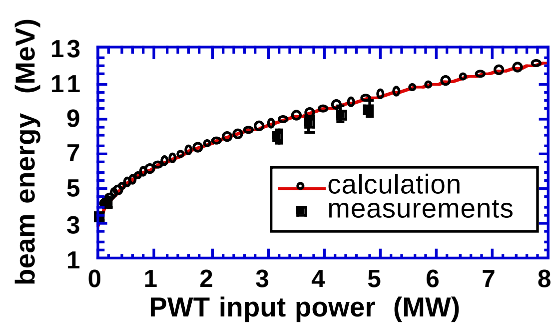

Figure 4: The beam energy variation with input power. At rf power 8 MW to the PWT, we measured a dark current energy of 12.2 MeV.

The beam energy spread is measured by measuring the bunch length after the beam passing a dipole magnet. The better than 0.1%. Since energy spread is very sensitive to the injection phase, phase-scan of energy spread variation is a good estimation of the beam bunch length. Although the adjustment of the phase shifter changes the rf power into the linac, the effect of the rf power on the beam energy spread is negligible. The measured results by scan of the phase are shown in Fig. 5. To estimate the bunch length, we used PARMELA [6] to simulate the beam dynamics. The solid line in Fig. 5 is the simulation results by assuming a beam bunch length of 2.5 ps (1 σ). This indicates that the beam bunch length is around 5 ps (FWHM), which agrees well with the measurement of the laser bunch length [5].

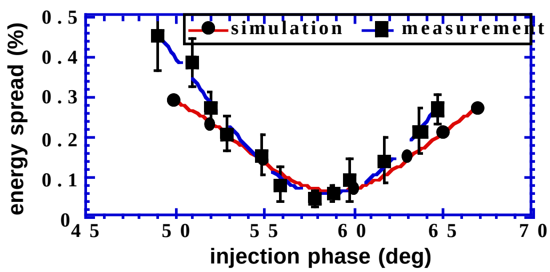

Figure 5: The energy spread variation with injection phase (beam energy around 9.5 MeV, beam charge less than 10 pC, PARMELA simulation assuming bunch length (1σ)=2.5 ps)

We measured the emittance by using the quads-scan tech-nique. One measurement of quads-scan is shown in Fig. 6. The beam energy from the gun is 3 MeV with a charge of less than 10 pC. The beam energy for this measurement is 9.6 MeV. By using thin-lens approximation of the quads, the normalized rms beam emittance is about 5 mm-mrad.

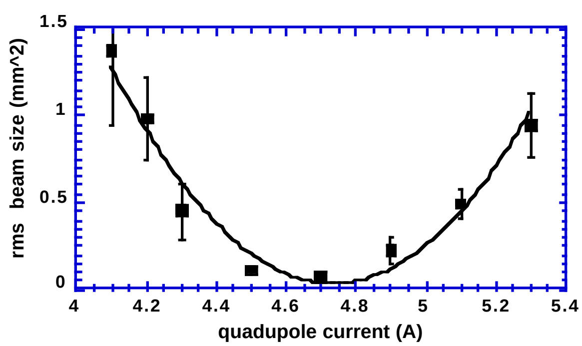

Figure 6: The quadrupole scan of rms horizontal beam size for emittance measurement (charge=5pC; energy =8 MeV).

V. FUTURE IMPROVEMENT

Although the high rf power operation demonstrates that the PWT can be used as an rf linac with many promising features, it is also evident that several improvements need to be done to make it a very robust structure. In order to achieve a high acceleration gradient, the ratio between the surface field to the on axis acceleration field has to be reduced. Otherwise, the acceleration gradient the rf linac may support will be limited by the high dark current, and even by possible break down. The ratio for the current prototype is over 2.5. Therefore, the surface peak field will, for an energy gain of 10 MeV, be higher than 130 MV/m, which is at the high end of an S-band structure. Another issue associated with high gradient operation is the vacuum pressure. To obtain a low vacuum pressure, the high temperature bake of the linac is essential. Therefore the viton gaskets at the water tube joints can not be used for vacuum seal.

To improve the performance of the PWT linac, a slightly modified structure, PWT3, has been studied and built. In the new design, flat disks are used to replace the loaded disks, reducing the ratio of maximum surface field to on-axis field from above 2.5 to about 1.2. Because the flat disks are much thicker than the loaded disks, water channels can be formed inside disks. Therefore, all the joints between different components can be brazed together. The shunt impedance of the modified structure is about the same as that of the loaded-disk one. The modified structure will be under high power test soon.

VI. CONCLUSIONS

Initial operation of the PWT at high rf power has demonstrated that this structure can be used in a compact, high brightness linac. Because of its advantages, like compactness, high efficiency, low cost, the PWT is also a good candidate for medical and industrial applications. The modified structure, PWT3, has been installed and will be tested in the near future.

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