The Plane Wave Transformer Linac Development at UCLA*

R. Zhang, S. Hartman and C. Pellegrini,
Dept. of Phys., UCLA, 405 Hilgard Ave., Los Angeles, CA 90024, USA

Abstract

A plane wave transformer linac (PWT), offering advantages of high efficiency, compactness, fabrication simplicity and cost, is being developed at UCLA. The PWT prototype at UCLA is an 8-cell, π-mode, S-band standing-wave linac. To fully understand its physical properties, numerical modeling of the PWT prototype has been carried out by using the 3-D code MAFIA. A microwave test-stand with a network analyzer has also been set up to test these properties. In this paper, we present the important physical features, such as mode structures, dispersion curves, wake field, from the computation and/or the experiment. The measurements show good agreement with the numerical computation.

I. Introduction

A compact RF linac with a laser-driven RF electron gun is being under development at UCLA. This linac system, as shown schematically in Fig.1, is dedicated to study of high brightness electron beam physics, high gain free electron laser (FEL) experiments, plasma focusing and plasma wake field acceleration[1]. For these experiments, especially the FELs, to be carried out successfully, a high quality beam will be very important.

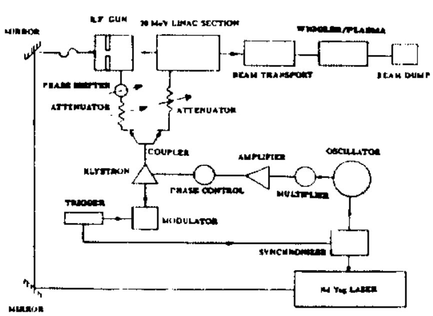

Fig.1 UCLA RF linac system schematic.

The rf electron gun consists of one and a half cells operating at π-mode at frequency 2856 MHz, with copper as a photocathode. The injector can generate electron charge up to 1 nC and a bunch length as short as 4 pico-seconds (FWHM). The exit energy of the electron beam can reach 4.5 Mev with a normalized emittance of about 10 π mm-mrad. The recent experimental results of the rf gun are reported in another paper[2].

The rf linac under development at UCLA is a prototype of the plane-wave transformer (PWT) structure[3]. Its cross section is schematically shown in Fig.2. The history of the PWT linac can be dated back to 1960s. This similar structure first was analyzed by V.G. Andreev[4]. The PWT is basically a disk-washer type linac. However, the disk-washer array in the PWT is separated from the cylindric tube. Therefore, the array acts as a center conductor to support a TEM-like plane wave traveling back and forth along the structure and transforms the transverse field of the plane wave into a longitudinal field for acceleration. It is the TEM mode which provides the coupling between the individual cells. In other words, this structure transform a plane wave (TEM mode) into a longitudinal electric field for acceleration of particles.

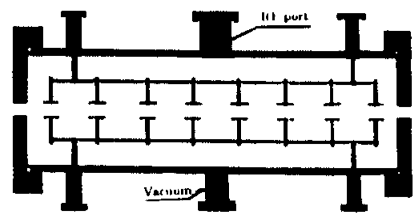

Fig.2 The cross section of the PWT prototype.

Different from the other known rf linac, the PWT operates on the high order TM_{02}-like mode instead of the fundamental TM_{01}-like mode. This feature concerns us about the frequency separation of the different modes, the mode structure and the wake field. To understand these properties are important to operate this linac. In this paper, these characteristics of the PWT structure are described. The rf modes found from the numerical simulation by the 3D code MAFIA[5] and from the microwave cold test are presented. Then the short range wake-field calculation is discussed. We conclude the paper by a summary and the discussion of further work.

II. Electrical Characteristics of the PWT

The PWT linac prototype consists of eight cells. It is a π-mode standing-wave rf linac. The field pattern of the operation mode, shown in Fig.3(a), is a TEM-like one excited between the outer tube wall and the inner disk-washer structure. The field distribution at certain cross section along the tube, shown in Fig.3(b), shows that the PWT is operated at TM_{02}-like mode instead of the conventional TM_{01n}-like mode. These electrical parameters are listed in Table I.

Table I. Electrical Parameters of the PWT

resonant frequency	2856.0 MHz
unloaded Q factor	35000
effective shunt impedance	78 MΩ/m
transit time factor	0.77
$E_{surface}/E_{axis}$	2.5

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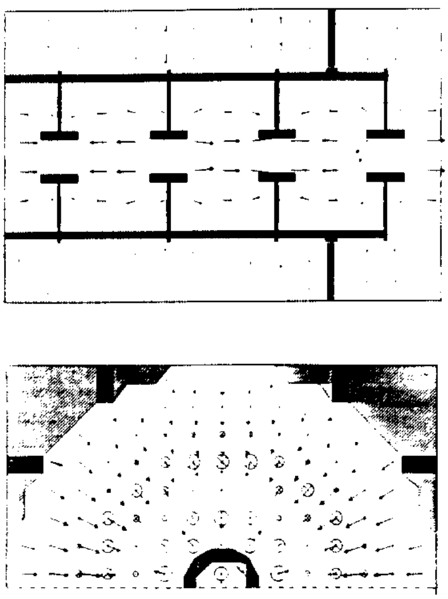
The high unloaded Q-value, thus a high impedance, is due to the fact that very little rf power is dissipated on the outer tube of the structure. The larger of the diameter of the outer tube is, the larger the unloaded value. Considering the finite rf pulse length in our system, a medium Q-value is better for our purpose. Besides, the mechanical tolerance of dimensions for the PWT structure is very high because of the large coupling between cells. The operation frequency has little dependence upon the diameter of the outer tube. We do the minor tuning by slightly changing the dimensions of the end cells. However, the misalignment of the central array with the tube and the unequal distance between cells may probably induce other modes around the operation mode.



a)

b)

Fig.3 The feild pattern of the operation mode: a)longitudinal field; b) transverse field.

III. Numerical simulation and Cold Test Results

In order to hold the disk-washer array in the PWT, some support rods are used. In practice, there are a lot of ways to place the rods. Besides the way shown in Fig.2, we can use straight rods connected to the end walls, which has the advantage for preserving the uniformity from cell to cell.

Because of these supporting rods, the cylindrical symmetry of the PWT is broken. Thus, the 3-D code MAFIA is used to numerically simulated this structure. From the field pattern we can identify different modes. Fig. 4 shows these mode frequencies as a function of phase advance. The dashed line is the dispersion curve of the π-mode without the support rods. Thus the introduction of the rods reduces the coupling between the cells. As long as the π mode dispersion curve is concerned, there is little difference for the ways to place the support rods.

There are two kinds of modes we are concerned. One is the modes whose resonance frequencies are very close to the operation frequency. As a result, it is possible

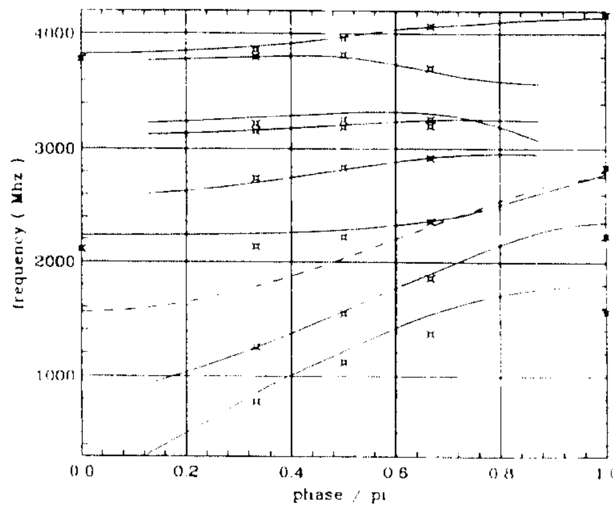


Fig.4 The mode frequencies vs. phase advance: solid lines — simulation for the prototype; dashed lines — simulation for the PWT without the support rods; marks — from measurements.

for those modes to be excited by the rf power supply due to the finite frequency band width of the klystron. The numerical simulation by MAFIA indicates the closest mode is separated about 10 MHz from the π-mode. In the measurement, we found the most close mode separation is about 16 MHz, which is beyond the bandwidth of the klystron. Besides, the alignment of the central array with the outer tube must be done carefully, otherwise, new undesired modes could be excited. Another kind of modes are those whose phase velocities are close to the velocity of electron beam, which could be excited by the electron beam. One of these modes is shown in Fig.5. The excitation of the undesired modes will increase the energy spread, cause the emittance growth and even induces the beam break up (BBU). In order to get a high quality beam, some measures have to be taken to damp these modes out.

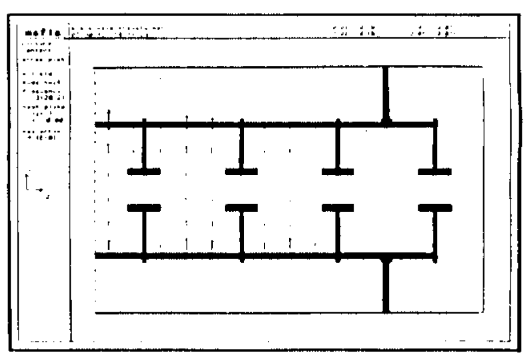


Fig.5 The field distribution of a high order mode.

To check the results obtained from the simulation by using MAFIA, we set-up a cold test stand with a network analyzer to measure the PWT. The measured unloaded Q-value is a little lower than the computation value due to the roughness of the disk surfaces. The electrical field distribution along the axis is, measured by perturbation method, shown in Fig. 6. The measured characteristic impedance (R/Q) agrees well with that found from numerical simulation. To measure the dispersion curves, one way is to measure the phase advance by pulling a metal bead along the axis. It is effective for modes with a high Q-value, but fails for low-Q and high order modes. To measure these high order modes, we measure a module with different cells. In this way, we can find most of the modes. These measurement results are shown in Fig. 4 by marks.

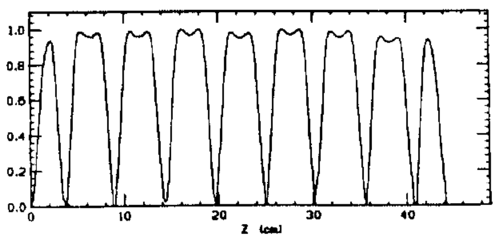


Fig. 6 The field distribution along the axis, from which we find the $R/Q = 3.3\ k\Omega/m$.

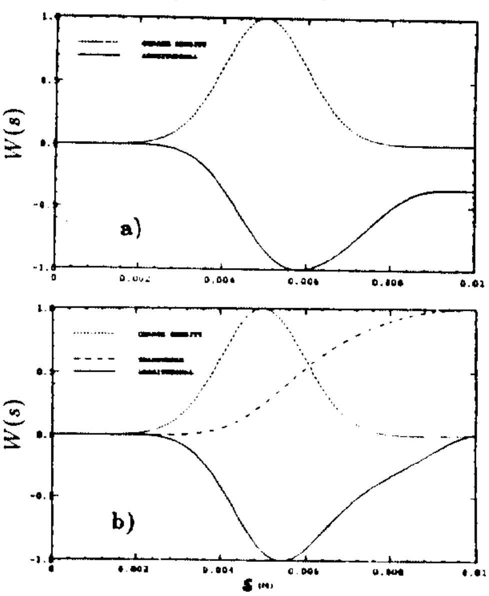


Fig.7 The wake field potential for an electron bunch of $\sigma = 1mm$. a) monopole wake; b) dipole wake.

IV. The Wake Field Calculation

When a bunched electron beam with high peak current traverses an accelerating structure, strong wakefield will be excited. The longitudinal wake will induce an energy spread of the electrons in the bunch; while the transverse wake leads to emittace growth. However, these effects may be compensated, at least partially, by the rf field when the appropriate injection phase is chosen. Therefore, it is helpful to calculate the wakefield in order to preserve a high brightness beam during the acceleration process.

As for the wakefield calculation, there are several codes available. ABCI[6] is used for 2-dimension geometry, while MAFIA is for 3-D structures. There are, however, some restrictions: the computing time and the memory size, in using MAFIA for short electron bunch wakefield calculation, which is as short as about 1 mm (1σ) for the beam at UCLA. On the other hand, there is no much error to be induced if we ignore these rods, even reduce the diameter of the outer tube, as far as the short range wake field is concerned[7] . Thus, we use the 2D code ABCI, to do the wakefield calculation. The results are shown in Fig.7. Fig. 7(a) shows the wake potential for monopoles, and Fig.7 (b) for dipoles. The maximum energy loss (longitudinal wake) is about 40 keV, which will induce an energy spread of about 0.3%. The maximum transverse kick is about 0.2 kV/cm, which is negligible comparing the transverse rf field. In the future, we will use an analytic formula to approximate the wake function and find out the optimal injection phase to preserve the beam quality.

V. Summary

The PWT linac has many advantages like compactness, high efficiency, low cost, etc. over other known structures. Because the separation of the cylindrical tube and the central disk-washer array, this structure is very easy to manufacture. These advantages make it attractive for this structure to be used in medical and industrial application. However, the operation of high order mode (TM_{02}-like) makes it difficult to build a long structure because of its small frequency separation from undesired modes. For the acceleration of multi-bunch electron beam, the high order mode damping becomes important to preserve a high quality beam and increase the BBU threshold. The approaches to this end are under study.

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