THE PLANE WAVE TRANSFORMER LINAC DEVELOPMENT AT NSRRC

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Abstract

A Plane Wave Transformer (PWT), standing wave linac operating at S-band frequency (2.9979 GHz) is being developed at NSRRC. This structure offers the advantages of high efficiency, compactness, fabrication simplicity and lower cost. The PWT prototype at NSRRC consists of three cells with two half-cells at the ends, separated by a set of four flat disks suspended and cooled by four water tubes inside a large cylindrical tank. To fully understand its physical properties, numerical modeling of the PWT prototype has been carried out by using the 2D code SUPERFISH and 3D code CST Microwave Studio. In this paper, we describe the principle properties of this structure, the electric parameters obtained from numerical simulations, and heat dissipation calculation. The mechanical design for prototype linac is also reported.

INTRODUCTION

The NSRRC high brightness photo-injector is designed to provide a beam with short length (~10 ps), low emittance (~1 mm-mrad), and high charge (~1 nC). To this end, a compact, high gradient and high brightness RF linac structure is needed to achieve our goals. Therefore, the PWT linac, which promises high impedance, high efficiency, and low cost, is designed to use in our system.

The NSRRC PWT prototype is a 2998 MHz standing wave linac, excited in π mode. It consists of a cylindrical cavity, loaded with four disks. The disks are separated from the cylindrical tank and supported by four steel rods parallel to the axis. These rods are also served as water pipes for cooling the disks. No cooling is required for the outer tank because it has low power density and also less effect on the resonance frequency. The RF is coupled via the large concentric cylindrical cavity instead of a single input cavity, as in conventional RF linacs. So the field is not formed cell by cell, but simultaneously in all of cavities.

Because of the higher amount of RF energy inside the structure and also strong coupling between individual cells, PWT linac has higher shunt impedance, quality factor and accelerating gradient than other conventional linacs. Manufacturing tolerances of accelerator components are also not so tight; therefore, the cost of machining and brazing is low, especially good for repetitive production of the sections.

Since the disks are separated from the cylindrical tank, they act as a center conductor to support a TEM-like plane wave in the coaxial manifold, and then this wave is transformed into a TM_{02}-like accelerating wave along the beam axis [1], and since PWT operates on a higher order TM_{02} mode, it raises concern on its mode structures and frequency separation of the operation mode from other modes that may be excited by the RF coupler or electron beam. Figure 1 shows the cross section of the NSRRC PWT prototype.

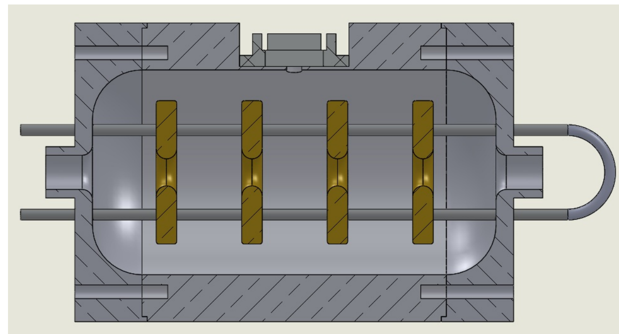

Figure 1: The cross section of the PWT prototype.

ELECTRICAL CHARACTERISTICS OF THE PWT

Since SUPERFISH is a two-dimensional code, It cannot be used, in principle, to study RF characteristics of a non-axisymmetric structure like PWT. But it is usually a good choice to begin with to set the basic dimensions of the structure. The advantage is that it gives the electric and magnetic fields distribution at all points inside the structure, and power distribution on all inner surfaces of the structure. These results are useful to choose where to place the supporting rods to cause minimum perturbation of the fields. Nevertheless, since the rods will considerably perturb the fields and the resonant frequency of the structure, a three-dimensional analysis is required for a complete study of the structure, for which we used the code CST Microwave Studio.

The E-field distribution inside the PWT structure is shown in Figure 2. To improve the effectiveness of acceleration, the design of the two end-cells were carefully investigated. Ideally, these cells would be tuned so that at the correct resonant frequency, the position of the electric field maximum would be in phase with the electron beam, making these cells actively accelerating. For a closed half-cell, the solid wall results in an E-field maximum, but when an aperture is opened in the center of the cell wall, the electric field is pulled into the aperture and the E-field maximum shifts away from the wall, primarily resulting in energy spread. The amount of the E-field maximum will also decrease from its original value. If the wall shape and position are properly chosen, the half-cell with aperture can give the proper phase and frequency to the E-field [2] as shown in the 2D SUPERFISH simulation results in Figure 3. It should be noted that the fields are normalized to E_0 = 1 MV/m. Other electrical parameters of the PWT structure,

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calculated by 2D SUPERFISH simulation, are listed in Table 1.

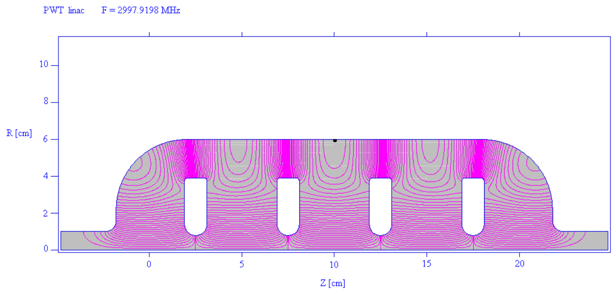


Figure 2: E-field distribution inside the PWT structure; calculated by SUPERFISH.

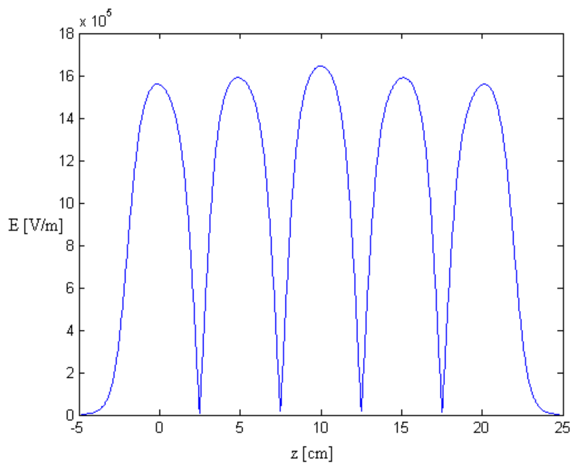


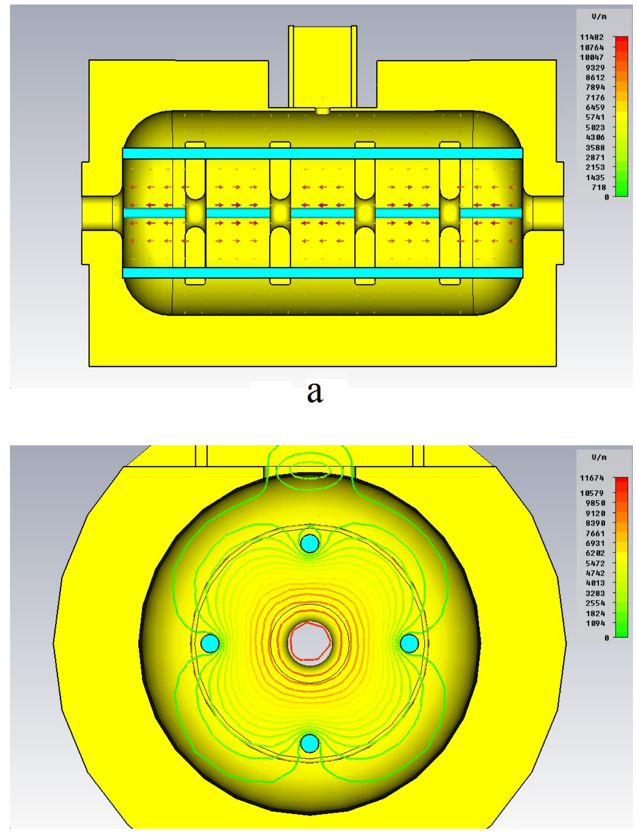
Figure 3:Accelerating field magnitude on the beam axis of the PWT structure; calculated by SUPERFISH.

Table 1: Electrical parameters of the PWT structure; 2D SUPERFISH simulation results.

Resonant frequency	2.9979 GHz
Unloaded Q factor	32750
Shunt impedance	95 MΩ/m
Transit time factor	0.74
$E_{surface}/E_{axis}$	1.09

In order to hold the disk array in the PWT, four support rods are used. These rods are also served as water pipes for cooling the disks. Because of these supporting rods, the cylindrical symmetry of the PWT is broken. Thus, the 3D code CST Microwave Studio is used to numerically simulate this structure. Simulation results shows that with the intention of minimizing the perturbation of the fields, supporting rods should be placed as far as possible from the beam axis. Figure 4 (a) shows the E-field arrays inside the PWT structure and Figure 4 (b) shows the E-field contours in transverse cross section view. The fields are normalized to 1 W of input RF power.

Because of the relatively high weight of the disks, supporting rods made of copper are not suitable for holding them. Steel rods are a good choice for mechanical consistency but the power loss of the structure will increase significantly due to the low electrical conductivity of steel. Table 2 shows the electrical parameters of the all copper PWT structure and Table 3 shows that of the structure with steel supporting rods. The lower Q value in CST Microwave Studio is because of the power loss on the surface of the supporting rods.



a

b

Figure 4: a) E-field arrays inside the PWT structure and b) E-field contours in transverse cross section view.

Table 2: Electrical parameters of the all copper PWT structure; 3D CST Microwave Studio simulation results.

Resonant frequency	2.9979 GHz
Unloaded Q factor	19000
Shunt impedance	75.4 MΩ/m
Transit time factor	0.75
$E_{surface}/E_{axis}$	1.1

Table 3: Electrical parameters of the PWT structure with steel supporting rods; 3D CST Microwave Studio simulation results.

Resonant frequency	2.9979 GHz
Unloaded Q factor	11400
Shunt impedance	45.2 MΩ/m
Transit time factor	0.75
$E_{surface}/E_{axis}$	1.1

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THERMAL ANALYSIS

The high frequency RF power used to accelerate the electron beam also produces heating on the surfaces of the metallic structure. At critical coupling of RF wave into the structure, when the fields are completely built up and volume of the structure is filled with energy, all of the RF energy will be dissipated on the inner surface of the PWT. To calculate the specifications of the cooling system, thermal analysis of the PWT structure was done using ANSYS.

The power of each RF pulse is about 10 MW and the pulse length is less than 2.5 µs. Transient thermal simulation results showed that even if the water flow rate is zero, there would be no significant changes in the dimensions of the structure and therefore, fast compensation of the heat dissipations inside the structure is not required. For a maximum repetition rate of 10 Hz, a water flow rate of 3.6 L/m is required. Figure 5 shows the steady state temperature distribution on the surface of disks for 22°C coolant water. In order to have a uniform temperature distribution, water circulation inside the disks is required.[3]

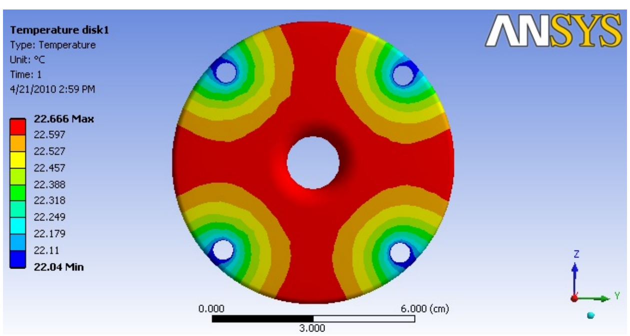

Figure 5: Steady state temperature distribution on the surface of disks for 22ºC coolant water.

7-CELL STRUCTURE

A 7-cell structure was also designed since our final goal is to develop a two 7-cell PWT's after we get good results from our primary prototype. These PWT structures will be used in the emittance control of the NSRRC split photo-injector. Figure 6 shows the E-field distribution inside the designed PWT tube calculated by 2D simulation with SUPERFISH and 3D simulation with CST Microwave Studio.

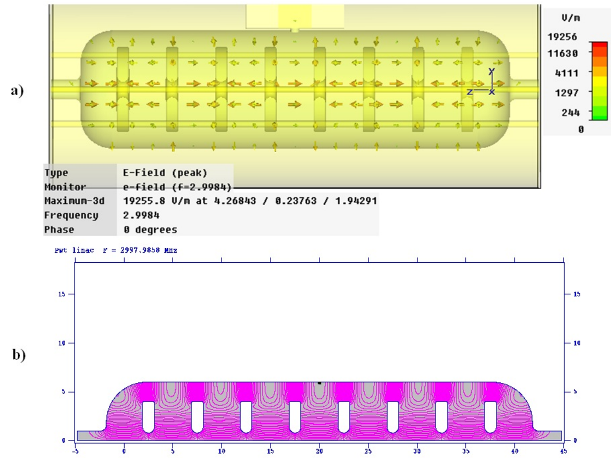

Figure 6: E-field distribution inside the PWT structure; calculated by a) CST Microwave Studio and b) SUPERFISH.

SUMMARY

Design of a PWT standing wave linac is reported. This structure has many advantages like compactness, high efficiency, low cost, ease of manufacture, etc. over other known structures. These advantages make it attractive for this structure to be used in medical and industrial application.

It has been shown by 2D and 3D simulations that the effects of the fields perturbation due to supporting rods is not considerable on the beam axis. However, since a high mechanical strength is required for the rods to hold the disks inside the structure, They need to be built from steel. This rises the concern of Q factor reduction due to the low conductivity of steel. This matter should be investigated more in the cold tests of the prototype. The designed PWT prototype is under development at NSRRC and will be tested in the near future.

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