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PBFA Z: A 20-MA Z-PINCH DRIVER FOR PLASMA RADIATION SOURCES*

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Sandia National Laboratories is completing a major modification to the PBFA-II facility. PBFA Z will be a z-pinch driver capable of delivering up to 20 MA to a z-pinch load. It optimizes the electrical coupling to the implosion energy of z pinches at implosion velocities of ~ 40 cm/μs. Design constraints resulted in an accelerator with a 0.12-Ω impedance, a 10.25-nH inductance, and a 120-ns pulse width. The design required new water transmission lines, insulator stack, and vacuum power feeds. Current is delivered to the z-pinch load through four, self-magnetically-insulated vacuum transmission lines and a double post-hole convolute. A variety of design codes are used to model the power flow. These predict a peak current of 20 MA to a z-pinch load having a 2-cm length, a 2-cm radius, and a 15-mg mass, coupling 1.5 MJ into kinetic energy. We present 2-D Rad-Hydro calculations showing MJ x-ray outputs from tungsten wire-array z pinches.

Introduction

The PBFA-II accelerator[1] at Sandia National Laboratories, used by the light-ion-beam ICF Program, has been modified to allow its use as a z-pinch driver. Renamed PBFA Z, its electrical design optimizes the coupling of the generator to magnetically-imploded loads, typically z pinches. This paper describes the performance goals, the electrical design constraints, the modeling, and the predicted z-pinch x-ray performance.

Performance Requirements and Basic Design Elements

We established the following performance goals: 20 MA delivered to a z-pinch load with a current rise time of ~ 100 ns, > 1 MJ of x-ray yield, and one shot a day capability. These goals drove the detailed design of PBFA Z. The 20-MA design goal was chosen as an intermediate pulsed power step to a desired 40-MA accelerator. The 100-ns driving pulse is a tradeoff between the desired, but expensive, short high-voltage pulses driving fast implosions and the Rayleigh-Taylor instabilities generated by cheaper, longer-pulse lower-voltage options. The requirement for shot rate is based on the perceived shots needed to get an acceptable learning rate in an R&D environment.

The basic mechanical and pulsed power design of PBFA Z, described in Ref. 2, was intended to minimize the cost of the modifications while meeting the performance goals. This resulted in modifying all of the components inside the coaxial pulse-forming lines (PFLs). (See Fig. 1.)

We used Screamer[3] and TLCODE[4] , transmission-line circuit codes, to model possible PBFA-Z designs over a wide range of electrical parameters such as driving impedance, load inductance, pulse width, and z-pinch mass. The optimum driving impedance to couple electrical energy to a z-pinch load is roughly set by the time constant of the system, Z ~ L/t. With a 100-ns driving pulse and a 10-nH inductance we found that the simple optimum of 0.1 Ω matched the more detailed Screamer prediction of 0.12 Ω quite well. Fig. 2 shows a series of Screamer calculations in which the driving impedance is varied while the input energy, inductance, and load mass are held fixed.

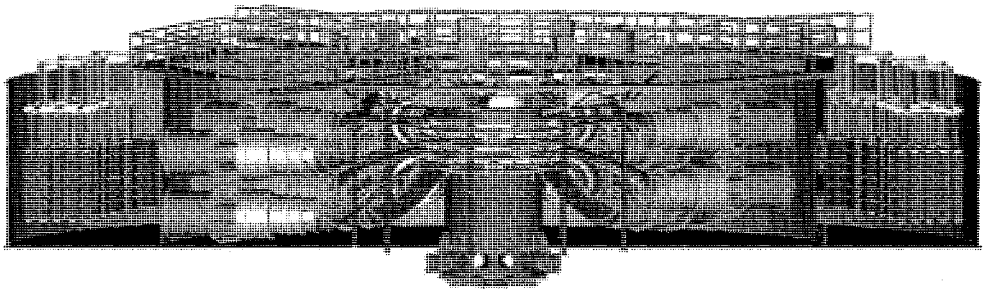

Fig. 1 A schematic of the proposed PBFA-Z accelerator showing the modifications planned inside the coaxial PFL section.

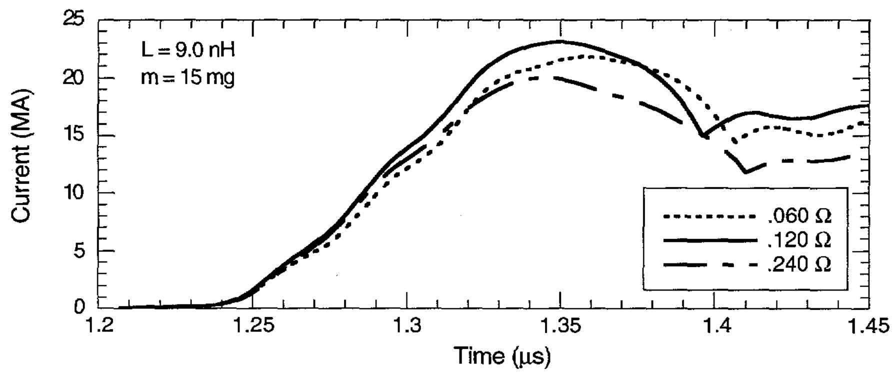

Fig. 2 A plot showing the effect of impedance on the current delivered to a z-pinch load with the input energy, total inductance, and pinch mass held constant.

The final PBFA-Z design uses a 0.12-Ω waterline, has a 120-ns pulse, and has a total inductance of ~ 10.25 nH. The baseline z-pinch load is 2-cm long, 2-cm radius, and 15-mg mass. The peak kinetic energy is 1.5 MJ assuming a 10:1 convergence ratio. Experience on Sandia's Saturn accelerator shows that we can extract the entire kinetic energy of the z pinch together with additional 50% from ohmic heating as x rays for high-Z loads, yielding an expected total x-ray output of > 2 MJ for PBFA Z.

Electrical Design

The PBFA-Z electrical design consists of constant impedance water transmission lines, a water-vacuum insulator stack, four levels of disk magnetically-insulated transmission lines (MITLs), a vacuum post-host convolute, an inner disk MITL, and the z-pinch load.

The PBFA-Z water lines consist of a transition from the existing co-axial section through bi-plate lines to the insulator stack. The key design issues are to operate in a regime where the lines do not electrically breakdown and to have a constant impedance line. We tested the existing PBFA-II water lines to determine the water break down characteristics. These tests used two PBFA-II modules delivering 2.5-MV voltage pulses with a 100-ns rise time to simulated PBFA-Z water transmission lines. In this case we used a 4.5-Ω water line with an 11.4-cm spacing. The water lines carried the voltage pulse without failure. We established a baseline water line electrical design of 36, 4.5-Ω water lines having a 14-cm line spacing.

We built a new insulator stack to minimize inductance in order to meet the 20-MA milestone as well as the desired z-pinch kinetic energy. We based our initial PBFA-Z design on the four-stack Saturn design.[5] This was the lowest inductance design for a MITL system based on a post hole convolute. The height of each insulator stack was based on its self-consistent voltage (generated from Screamer) and the insulator flashover criterion.[6] This resulted in the stack design shown in Fig. 3. We found that the optimal design had five insulators on A and B levels (the levels nearest the load) and six insulators on C and D levels. The insulator rings used were identical to PBFA II except that they are fabricated from cross-linked polystyrene.[7] The electric field grading across individual insulator stacks had a design criterion of ± 5% and was achieved by using flux excluders in the water just outside the insulators on C and D levels and by shaping the conductors near the insulators. The insulator stack will contain voltage and current monitors on each level.

The MITLs were designed using iterative applications of TLCODE,[4] SCREAMER,[3] TRIFL,[8] TWOQUICK,[9] and IVORY.[10] TRIFL is a new 1-D MITL simulation code. TWOQUICK and IVORY are 2-D E&M particle-in-cell codes. The design of the PBFA-Z vacuum MITLs is shown in Figure 3. The four axisymmetric MITLs shown are joined in parallel at a 7.6-cm radius by a double post-hole convolute.[11] Downstream of the convolute a single 5-cm-long MITL feeds power to the load. TWOQUICK simulations were used minimize the fraction of the total current carried by the electron-sheath. For the baseline load, the initial inductance inside the stack-vacuum interface is 10 nH. The double-post-hole convolute, an inherently three-dimensional configuration with magnetic nulls at current bifurcations, was modeled with QUICKSILVER,[12] a 3-D E&M particle-in-cell code. Current monitors will be located at three radial locations: in all four outer disk MITLs at an 80-cm radius, in all four outer disk MITLs just upstream of the convolute, and in the inner disk MITL.

Z-Pinch Performance

The predicted performance of tungsten z-pinch loads, generating mostly sub-keV radiation, on PBFA Z was obtained using a 2-D Eulerian Rad-Hydro code[13] benchmarked against Saturn tungsten z-pinch data. The code uses a simplified circuit model, based on Screamer calculations, to drive the tungsten z pinch. For these calculations we have fixed typical code variables such as resistivity, thermal conductivity, and artificial viscosity at their classical values. The only variable that was used to match to the Saturn data was a stochastic density perturbation, intended to mock up the effect of Rayleigh-Taylor instabilities and unavoidable, three dimensional, azimuthal perturbations in the actual wire array load. A calculation modeling a 120-wire, 17.5-mm diameter, 2-cm long tungsten array is compared with Saturn data where we applied a 5% density perturbation.[14] (See Fig. 4.) The code input is then changed to reflect the pulsed power and load details expected on PBFA Z. Fig. 5 shows the results for such a calculated implosion on PBFA Z. The code predicts a total x-ray yield of 2 MJ and a peak x-ray power of 180 TW. Based on the earlier agreement with Saturn data, we believe that these results are reasonable estimates for PBFA-Z x-ray performance. Future work will be performed to benchmark the calculations in detail against the Saturn data.

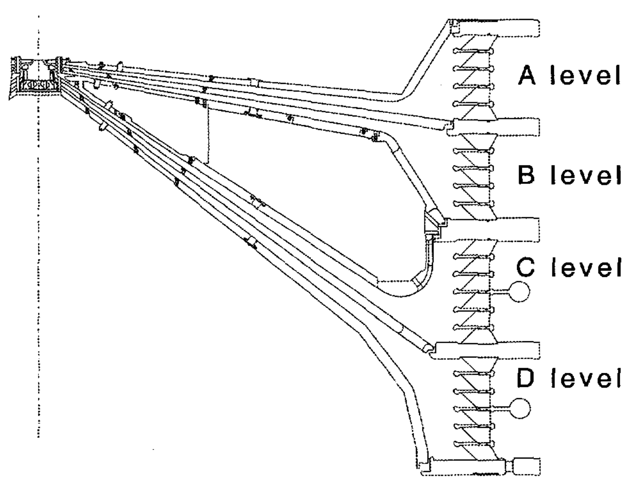

Fig. 3 A picture of the proposed MITLs for PBFA Z showing the transition from the insulator stack to the post-hole convolute.

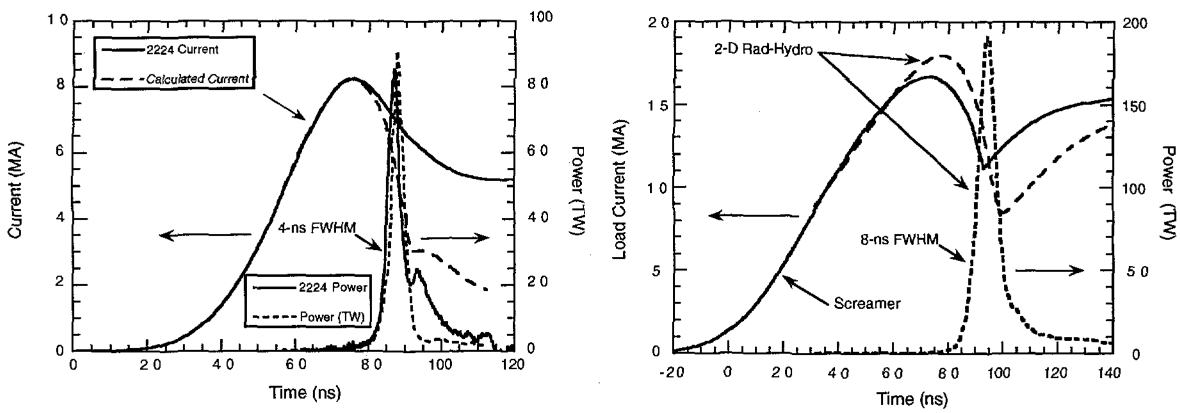

Fig. 4 The left plot shows a comparison of Saturn shot 2224 and Rad-Hydro calculations using a 5% perturbation. The right plot shows the same calculation done for PBFA-Z parameters.

Conclusion

PBFA Z is a modification of the PBFA II accelerator for z-pinch implosion experiments. PBFA Z is expected to deliver 20 MA to a z-pinch load. We expect that PBFA Z will deliver 2 MJ of x rays based on the results of detailed electromagnetic design code and Rad-Hydro calculations and comparisons with Saturn data. Experiments to confirm the pulsed power performance and to measure the x-ray outputs will be completed by the end of 1996.

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