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DESIGN VALIDATION OF THE PBFA-Z VACUUM INSULATOR STACK\*\*

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Abstract

Sandia has developed PBFA-Z, a 20-MA driver for z-pinch experiments by replacing the water lines, insulator stack, and MITLs on PBFA II with hardware of a new design. The PBFA-Z accelerator was designed to deliver 20 MA to a 15-mg z-pinch load in 100 ns. The accelerator was modeled using circuit codes to determine the time-dependent voltage and current waveforms at the input and output of the water lines, the insulator stack, and the MITLs. The design of the vacuum insulator stack was dictated by the drive voltage, the electric field stress and grading requirements, the water line and MITL interface requirements, and the machine operations and maintenance requirements. The insulator stack consists of four separate modules, each of a different design because of different voltage drive and hardware interface requirements. The shape of the components in each module, i.e., grading rings, insulator rings, flux excluders, anode and cathode conductors, and the design of the water line and MITL interfaces, were optimized by using the electrostatic analysis codes, ELECTRO and JASON. The time-dependent performance of the insulator stacks was evaluated using IVORY, a 2-D PIC code. This paper will describe the insulator stack design, present the results of the ELECTRO and IVORY analyses, and show the results of the stack measurements.

Introduction

Figure 1 is a drawing of the PBFA II<sup>1</sup> accelerator. The accelerator is contained in two concentric tanks. The outer tank is the oil tank which includes thirty-six Marx generators as the prime power source. The inner tank is filled with de-ionized water and contains the pulse compression and transmission network which provide the pulsed power to the vacuum insulator. The vacuum insulator on PBFA II contained the hardware needed to configure the machine for ion beam operation. In order to use the accelerator for magnetic implosions it was necessary to convert the electrical power flow to a low impedance, high current design. This was accomplished by replacing the water lines, the vacuum insulator stack, and the magnetically insulated transmission lines on PBFA II with hardware of a new design. The reconfigured accelerator is identified as

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PBFA-Z<sup>2</sup>. The modified accelerator was designed and built to deliver 20 MA of current to a 15-mg z-pinch load in 100 ns. Checkout tests of the modified accelerator began in October 1996.

#### Insulator Stack Design

The PBFA-Z insulator stack is 340 cm in diameter and 172 cm high. The stack consists of four separate modules, A through D. Each module contains a set of Rexolite insulator rings and a set of aluminum grading rings. The bottom two modules, C and D, are equipped with flux excluders to help grade the fields. A drawing of the PBFA-Z vacuum insulator stack, with the water line and MITL interface hardware, are shown in Figure 2.

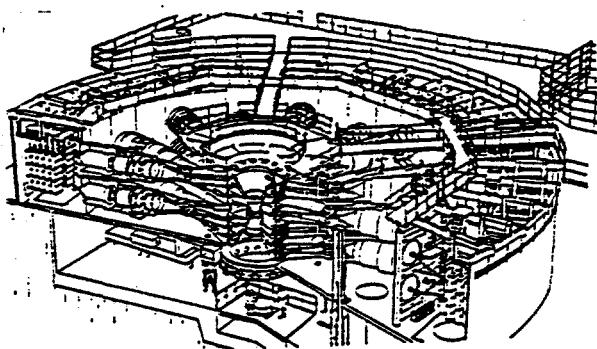


Fig. 1 PBFA II Accelerator

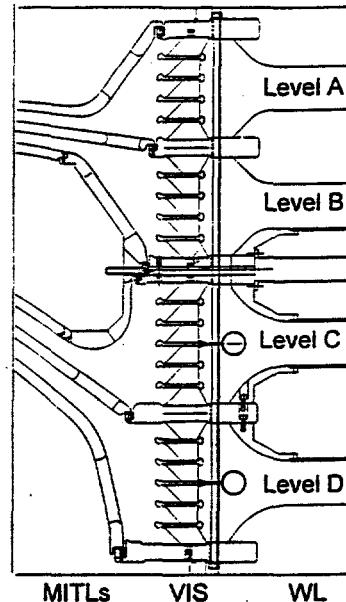


Fig. 2 PBFA-Z insulator stack

The stack grading rings were designed to keep the electric field stresses below 300 kV/cm on the vacuum side, below 250 kV/cm on the water side, and less than 30 kV/cm at the cathode triple points. The vacuum flares were designed to balance the peak fields on the grading rings. The number and shape of the grading rings, the radius of the water line-to-stack transition section, and the size and location of the flux excluders were selected to minimize field stresses and to keep the field grading below 10% in each module.

The PBFA-Z accelerator was modeled using circuit codes to determine the time-dependent voltage and current waveforms at the water lines, the insulator stack, and the MITLs. SCREAMER, a SNL-developed lumped element code was used to model the circuit from the Marx generators through the load and to optimize the Marx and water sections. TL code, a PSI transmission line code, was used to model the accelerator from the water transmission lines to the load, and to optimize the vacuum section design. The SCREAMER predictions of the stack voltages are presented in Figure 3.

#### Analysis Results

The electrostatic codes, ELECTRO<sup>3</sup> and JASON, were used to calculate the electric field stresses and the field grading during the various design iterations, using the peak voltages predicted by SCREAMER and the TL code. IVORY, a 2-D PIC code developed by MRC, was used to evaluate the time-dependent performance of the insulator stack.

Each level of the insulator stack was modeled separately. The geometry of the Level C model is shown in Figure 4. ELECTRO solves for the voltage and electric field distributions for specified geometries, media, media permittivities, boundary conditions, and boundary elements.

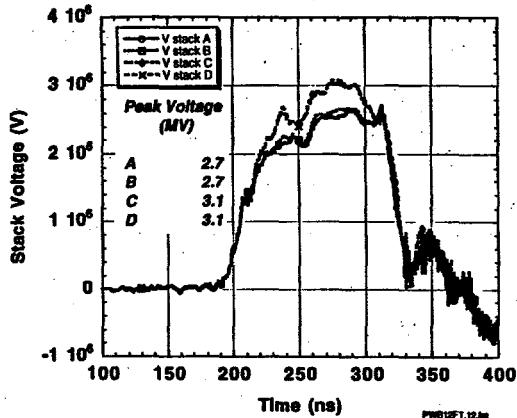


Fig. 3 Stack voltage predictions

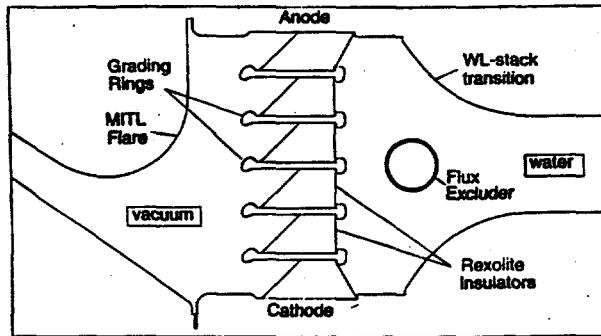


Fig. 4 Level C model

Figure 5 is a plot of the equipotential contours near the top grading ring on Level A. The shape of the grading edge was designed to follow the voltage contours, thereby minimizing the field stresses.

The constant voltage contours for Level C of the PBFA-Z stack are plotted in Figure 6. The plot shows the grading to be uniform. Each insulator contains the same number of contour lines and the insulator voltages vary from -2.3% to +3.6% from the average.

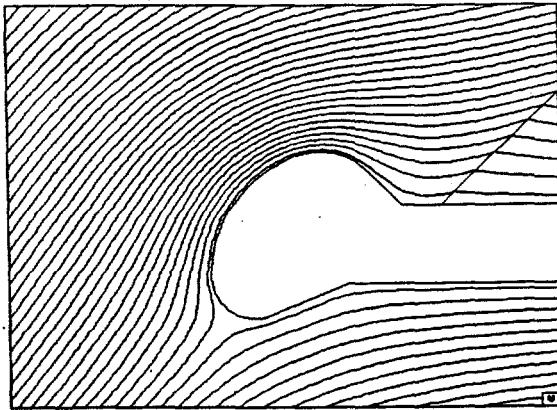


Fig. 5 Equipotential contour plot

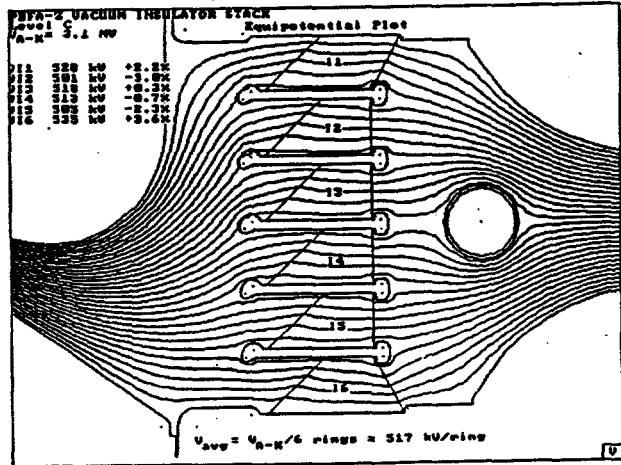


Fig. 6 Level C equipotential contours

The electric fields normal to the grading rings and the fields tangent to the insulator rings were plotted for each ring of the stack. Figure 7 presents the normal E-field plot for Grading Ring 3 on the vacuum side of Level C. Figure 8 presents the tangent E-field plot for Insulator Ring 1 on the vacuum side of Level C.

IVORY was used in a 2-D mode to simulate the PBFA-Z insulator stack and MITL flares. The vacuum and dielectric interfaces and grading rings were centered in the simulation region. Figure 9 shows the IVORY stack model with grading ring emission.

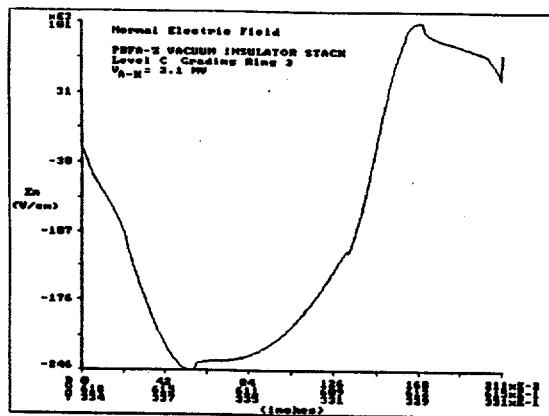


Fig. 7 Normal E-field plot

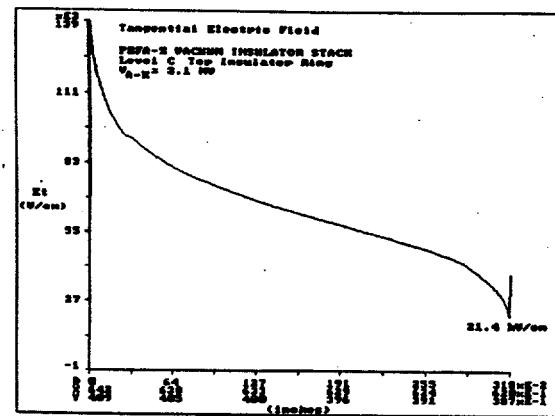


Fig. 8 Tangential E-field plot

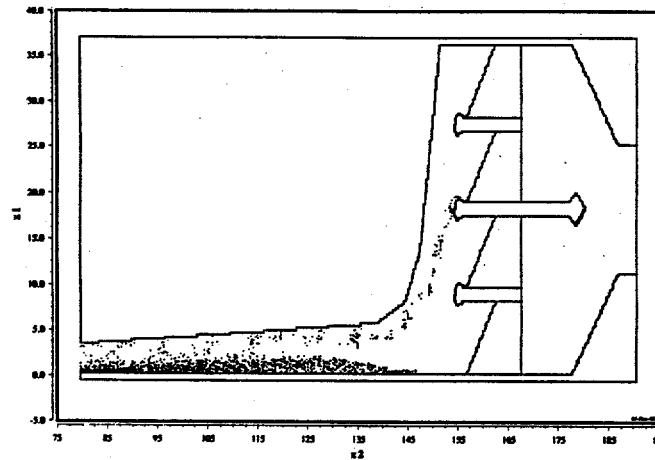


Fig. 9 IVORY insulator stack model

The grading calculations for the PBFA-Z stack are shown in Table I. The peak electric fields on Levels A and C are summarized in Table II. The peak fields on Levels B and D are comparable to those shown.

Insulator Ring	A - Level	B - Level	C - Level	D - Level
	$V_a-k=2.7 \text{ MV}$	$V_a-k=2.7 \text{ MV}$	$V_a-k=3.1 \text{ MV}$	$V_a-k=3.1 \text{ MV}$
	Variation %	Variation %	Variation %	Variation %
I1	+0.7	+3.2	+2.2	+2.9
I2	-5.6	-4.8	-3.0	-1.5
I3	+6.5	+6.3	+0.3	-1.0
I4	-4.6	-5.7	-0.7	0
I5	+3.0	+1.1	-2.3	-3.1
I6			+3.6	+2.3

Table I Grading summary

VIS Rings	A - Level			C - Level		
	Va-k=2.7 MV			Va-k=3.1 MV		
	E-Normal (Vac Side)		E-Tangent (kV/cm) (CTP)	E-Normal (Vac Side)		E-Tangent (kV/cm) (CTP)
	(kV/cm)	(Water Side)	(kV/cm)	(kV/cm)	(Water Side)	(kV/cm)
I1			22.6			21.4
GR1	236	153		209	152	
I2			21.5			20.9
GR2	239	195		234	185	
I3			23.8			21.7
GR3	258	193		246	169	
I4			20.4			20.9
GR4	211	158		215	185	
I5			17.6			19.1
GR5				177	155	
I6						21.7

Table II Peak field summary

#### Measurement Results

Performance of the PBFA-Z insulator stack was measured during the checkout tests which began in October 1996. Sandia V-dot and B-dot sensors were installed on each level of the stack to measure stack voltages and currents. The responses were integrated and corrected for instrumentation effects. The voltage and current results of Shot 40 are presented in Figures 10 and 11, respectively.

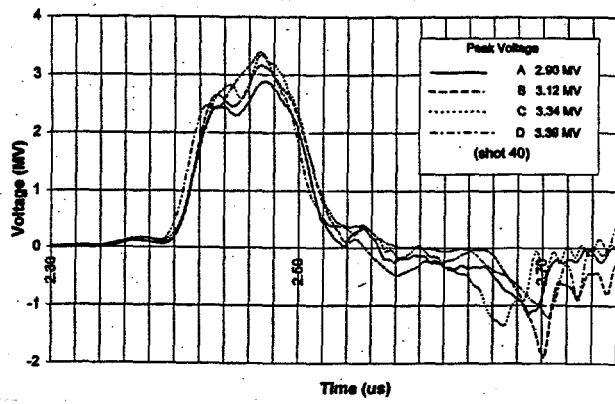


Fig. 10 Measured PBFA-Z stack voltages

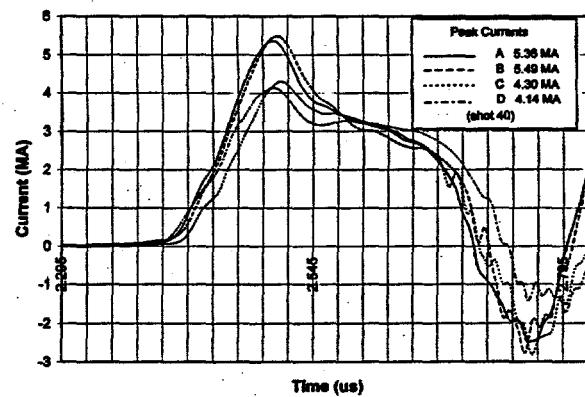


Fig. 11 Measured PBFA-Z stack currents

#### Conclusions

Based on the results of the ELECTRO analysis, the peak electric fields on the grading rings are less than 260 kV/cm on the vacuum side and less than 200 kV/cm on the water side. The cathode triple point fields are less than 30 kV/cm. The grading of the baseline design is less than 6.5% on modules A and B and less than 3.7%

on modules C and D. According to the results of the IVORY analysis, the voltage between rings on the baseline design can vary up to 10% without field emission and up to 19% with field emission. If the MITL gap is decreased by a factor of two, the voltage between rings could vary up to 50% from average and risk insulator breakdown.

The measured voltages exceeded the predictions by as much as 420 kV without stack breakdown. Figure 12 shows that Magnetic Flashover Inhibition<sup>4</sup> (MFI) is occurring as the voltage peaks on Level A. Similar results were obtained for MFI calculations for the other levels. The total current measured on the stack was 19.3 MA on Shot 40. The voltages and currents measured on Shot 40 were typical of the results obtained from other stack measurements.

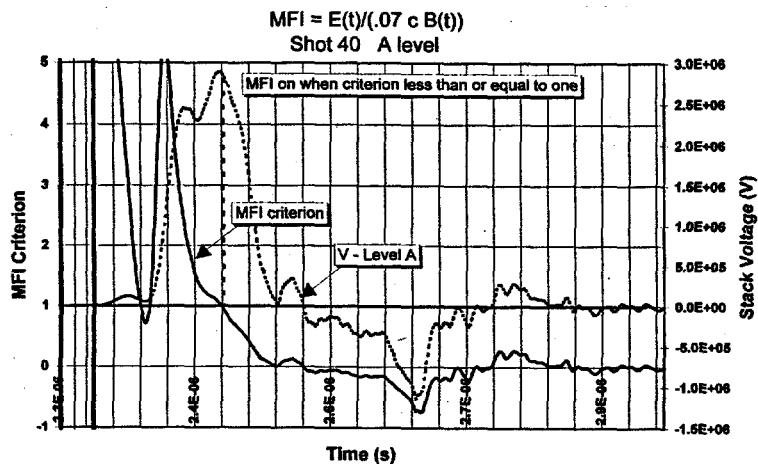


Fig. 12 Magnetic Flashover Inhibition on Level A of the PBFA-Z Stack

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#### References

- <sup>1</sup> B.N. Turman, et al., "PBFA II, A 100-TW Pulsed Power Driver for the Inertial Confinement Fusion Program," *Proc. 5th IEEE Pulsed Power Conference*, Arlington, VA, June 10-12, 1985, pp. 155-161, IEEE#85CH2121-2.
- <sup>2</sup> R.B. Spielman, et al., "PBFA II-Z: Conceptual Design Report," January 17, 1995, Sandia National Laboratories, Albuquerque, NM.
- <sup>3</sup> Integrated Engineering Software, Winnipeg, Manitoba, Canada R3H 0X4
- <sup>4</sup> J.P. VanDevender and D.H. McDaniel, 8th Int'l Symposium on Discharges and Electrical Insulation in Vacuum, Albuquerque, NM, Sept. 5-7, 1978.

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