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(A)

DESIGN AND EVALUATION OF THE XBT DIODE*

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Abstract

This paper describes the design and experimental results achieved with the 440 kV, microperveance 1.9, XBT (X-band Beam Tester) diode. The Pierce gun was developed for the 100 MW X-band klystron; the high power RF source to be used on the NLC (Next Linear Collider). The gun is electrostatically focused (no magnetic compression) to a beam diameter of 6.35 mm, with an area convergence of 110:1. Maximum cathode loading is approximately 25 A/cm^2, with a beam power density of 770 MW/cm^2. The measured beam current was within 2% of the value predicted by simulation with EGUN. Transmission through the highly instrumented beam tester was 99.98%. Some novel techniques were used to achieve near perfect beam transmission, which include the use of a reentrant-floating input pole piece.

A. Introduction

The X-Band Beam Tester (XBT) Beam Diode is a diagnostic tool used to evaluate the performance of a 440 kV, μP=1.90, electron gun. Design and performance parameters are given in table 1. This gun will be used on the SLAC 100 MW, NLC klystron. The purpose of this experiment was twofold. First, was to determine the beam transmission. This tester uses several isolated drift sections which are smaller than the intended klystron drift diameter. If good transmission can be achieved through these reduced diameter sections, we should be assured of good transmission in the klystron. Secondly, due to the high beam area compression (BAC), we require near perfect agreement between simulation and experiment. Previous experience with the SLAC 5045 klystron, which has a BAC of 36:1, suggested errors between simulation and experimental measurement of beam current to be approximately 10%.

table I

<u>Design Parameters of the XBT Beam Diode</u>

Klystron:	
Beam Voltage:	440 kV
Beam Current:	536 A
Pulse Length:	1.5 μs
Microperveance:	1.90
Beam Diameter:	6.4 mm
Tunnel Diameter:	9.6 mm
Peak Focus Electrode Gradient:	300 kV/cm
Peak Anode Gradient:	410 kV/cm
Beam Area Compression (BAC):	110:1
Cathode :	M-type
Cathode Loading (max edge):	25 A/cm2
Edge-Center Loading Variation:	2.78:1
B/Bbr:	2.8
Solenoid:	
Solenoid Current:	375 A
Bucking Current (nominal):	-18 A
Solenoid Power Consumption:	31.3 kW
Magnetic Field (Bo):	0.57 T

An outline of the XBT can be seen in figure 7. The body of the tube consists of four isolated sections; three with decreasing drift diameters, and an isolated tailpipe. The inside diameters of the three drift sections are 10.5

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mm, 9 mm, and 8mm, with the 8mm section closest to the collector. These sections are referred to as bottom, middle, and top; their relative positions with respect to the cathode. Ceramics were used to isolate all sections and the collector. Monitoring of the intercepted current on the four sections and collector was performed using calibrated 50 Ω resistor networks. The tailpipe monitoring circuit was modified to allow for DC biasing. This was done to repel any slow secondary electrons. At the conclusion of the experiment, the solenoid field was measured using the input pole-piece, output pole-piece, and solenoid current settings. The computer simulation of the magnet was then fine tuned to agree with the measurement to within 2%, and these data were used for the final calculations.

EGUN Simulation of Cathode and Isolated Drift Sections

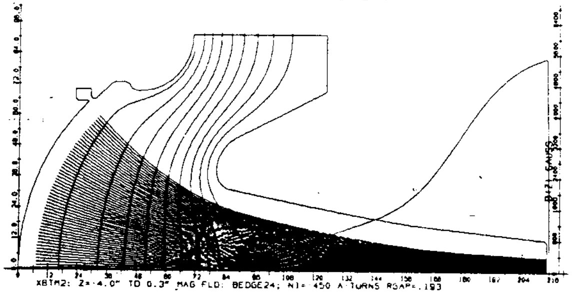

Figure 1

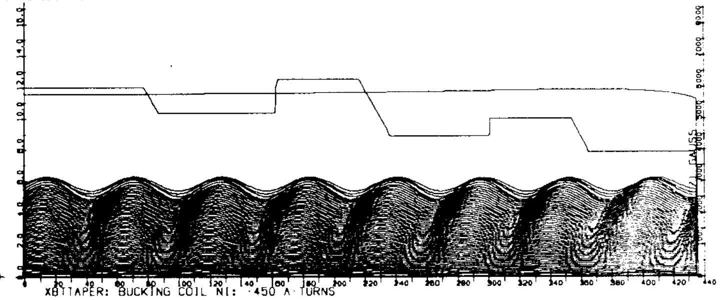

Figure 2

B. Beam Optics Design

Beam optics calculations were performed using EGUN [1], with the solenoidal field determined by POISSON [2]. Figures 1 and 2 show the beam in the cathode and isolated drift sections. This beam has scalloping of 8.9%[1], with an average diameter of approximately 6.4 mm. A bucking coil is used in the gun region to vary the beam diameter. Beam scalloping was minimized in this design by placing a magnetic lens near the beam waist. This lens is created by placing an annular gap in the input pole-piece (P/P), which leaves a ring shaped section floating (see figure 7). The floating P/P gives the gun designer an extra degree of freedom for matching the magnetic field to the beam. For most designs, there are four variables available to the gun designer; P/P aperture, reentrancy, bucking coils, and iron shields. The combination of P/P aperture and reentrancy control the field in roughly three areas: the region nearest the cathode, or the area below 0.35Bo; the slope of the field between the 0.35Bo and 0.75Bo, and the region above 0.75Bo. Iron shields and bucking coils are used to shape the flux near the cathode. Without the floating P/P, we could not simultaneously match the field to the beam in all three areas; this resulted in a highly scalloped beam.

The floating iron P/P permits the tailoring of the magnetic field below 0.35Bo and above 0.75Bo, while leaving the area between these regions essentially unchanged (figure 3). With this arrangement, we were able to reduce beam scalloping from greater than 25% to less than 10%. There was concern about the sensitivity of the gap symmetry to transverse fields. The transverse field was measured, and the data is shown in figure 4. This

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[1] Scalloping=Rmax-Rmin/(Rmax+Rmin)

data is normalized to the percentage of axial field. It can be seen that a slight asymmetry in the gap creates an appreciable transverse field, hence great care must be taken in construction to ensure that the gap is symmetric.

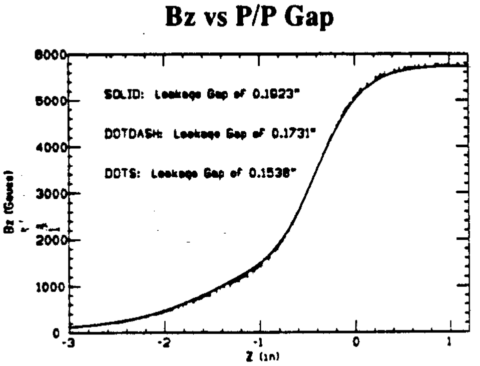


Figure 3

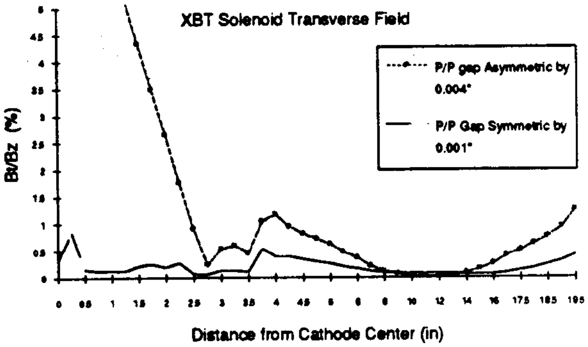


Figure 4

C. Electrode Thermal Compensation

An experiment was performed to determine the temperature of the cathode flashlight electrode at various locations (see figure 7). The cathode flashlight was sealed into a stainless steel vacuum chamber which had the same geometry as the anode. The chamber had an anode view port, so that the cathode temperature could be determined using an optical pyrometer. Twenty thermocouples were placed at various locations along the cathode flashlight assembly. With data obtained from this experiment, we found that the total height increase of the flashlight due to thermal expansion was 0.094" for a 1150 $^{O}C_b$ cathode temperature; approximately that required for fully space charge limited operation at 25 A/cm2. The cold cathode-to-anode spacing was increased by approximately 0.094" to compensate for this motion.

Compensation for thermal motion was also made in two other sensitive areas; for radial and longitudinal spacing increases of the cathode edge to focus electrode edge, and for growth of the entire focus electrode. During testing, we found the perveance of the gun to be higher than predicted by simulation. The computer initially predicted a microperveance of 1.836, while the actual tube microperveance was measured to be 1.902. Calculations were performed to take into account the radial growth of the focus electrode, not just the edge. This resulted in an increase in microperveance to 1.926, about 5%. Table 2 shows the sources and magnitudes of the relative errors between calculation and experiment, listed in descending order of importance, due to thermal growth of the XBT electrodes.

table II

Thermal Compensation*

1.) Flashlight Growth (>+10% error): Compensated in gun fabrication. Ca-A spacing increased accordingly.

2.) Radial and growth of the Focus Electrode (approximately +5% error): Compensation must be performed in the original calculations and fabrication (Compensation of the radial growth was not done originally, and was later found to be a source of error.)

3.) Changes in Radial and Longitudinal Cathode to Focus Electrode Edge Spacing (approximately +3% error): Compensated during gun fabrication.

*** please note that these errors differ from geometry to geometry.**

D. Testing and Experimental Results

The first step in the experiment was to determine the heater power to give space charge limited (SCL) operation at full beam voltage. This was performed by taking heater roll-off curves at 70 kV and 110 kV, which give beam currents of $I_0/16$ and $I_0/8$, respectively; Io is the beam current at full voltage. A Miram Curve [3] was generated from these data, and used to estimate the heater power requirements at full voltage. Using the curve, we determined that for SCL operation at 110 kV the cathode heater required 220 W of power, which corresponds to a temperature of 950°C. For typical M-type dispenser cathodes, doubling the cathode current requires a temperature increase of approximately 40°C to remain SCL. From this we deduced that the cathode should be operated approximately 150°C higher in temperature for SCL operation at full beam voltage (3*40°C+30°C safety margin=150°C). From this calculation, we can determine that for SCL operation at 440 kV, the cathode must be operated at approximately 1100°C, which corresponds to a heater power of 350 W.

The beam tester was processed up to 440 kV and data taken. Table 3 is a comparison of measurement and calculation. It can be seen that the agreement is good. The tube transmission was better than expected, especially since several sections have drift tube diameters smaller than the diameter to be used on the future klystron. A plot showing experimental data obtained at full voltage is shown in figure 5. Beam current was measured to be 555 A at 440 kV. The tailpipe shows interception of 2.89 A, while interception on the top isolated section was just 21 mA. Also note that the image charge can be seen to flow in the bottom, middle, and top isolated stages. This is consistent with what would be expected.

table III

Comparison of Calculation to Experimental Results.

Microperveance at 440 kV	
Initial Calculation:	µP=1.837
Measured:	µP=1.902
Error:	3.4%
Follow-up Calculation:	µP=1.926
Measured:	µP=1.902
Error:	-1.3%
Transmission at 440 kV, 555 A	
Top Isolated Section:	>99.98%
Tailpipe:	>98.00%

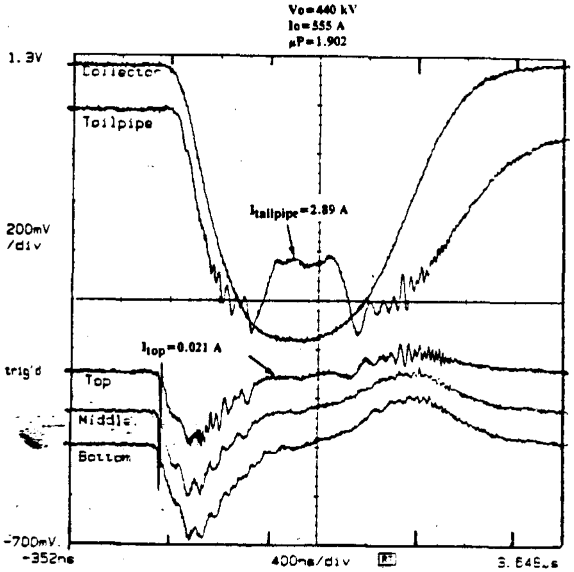


Figure 5

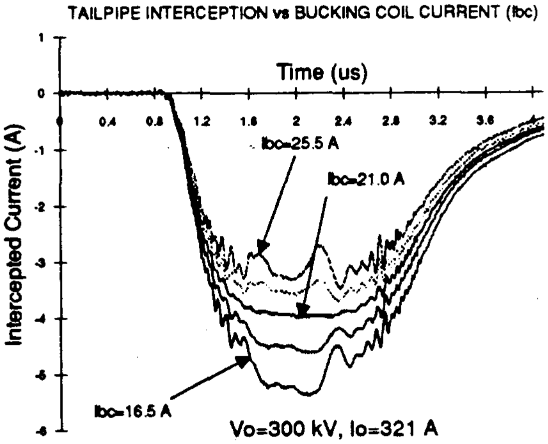


Figure 6

E. Tailpipe Isolated Section Interception

Figure 6 shows a plot of tailpipe interception versus Bucking Coil Current (I_{bc}). This interception is as much as 1.5% of I_0, therefore we would like to determine the cause of the interception. It has been suggested that the intercepted current is a superposition of primary, reflected primary, and secondary electrons. A negative 600 V_{DC} bias was applied to the tailpipe, which reduced the intercepted current by only 15%. We interpret this as due to secondaries having low enough energy to be repelled by this bias, whereas the primary and/or reflected primary electrons, which carry substantial energy, would not be effected.

Observe that tailpipe interception increases with decreasing I_{bc}, which would be expected if we were intercepting a small amount of primary electrons (the average beam diameter increases with decreasing bucking current). Also note that the ripple on the waveforms is minimum at I_{bc}=21.0 A, and increases on either side of this setting. A possible explanation for this phenomenon is that the ripple on the waveforms is due to a scalloping beam intercepting at one surface of the tailpipe. If this is true, then by observation of the data, we can conclude where the scalloping is minimum, namely when I_{bc}=21.0 A. A follow-up simulation was performed after measuring the solenoid used in the experiment, and we found a local minima in beam scalloping that agreed quite well with the observed waveform for these various settings.

F. Discussion and Conclusion

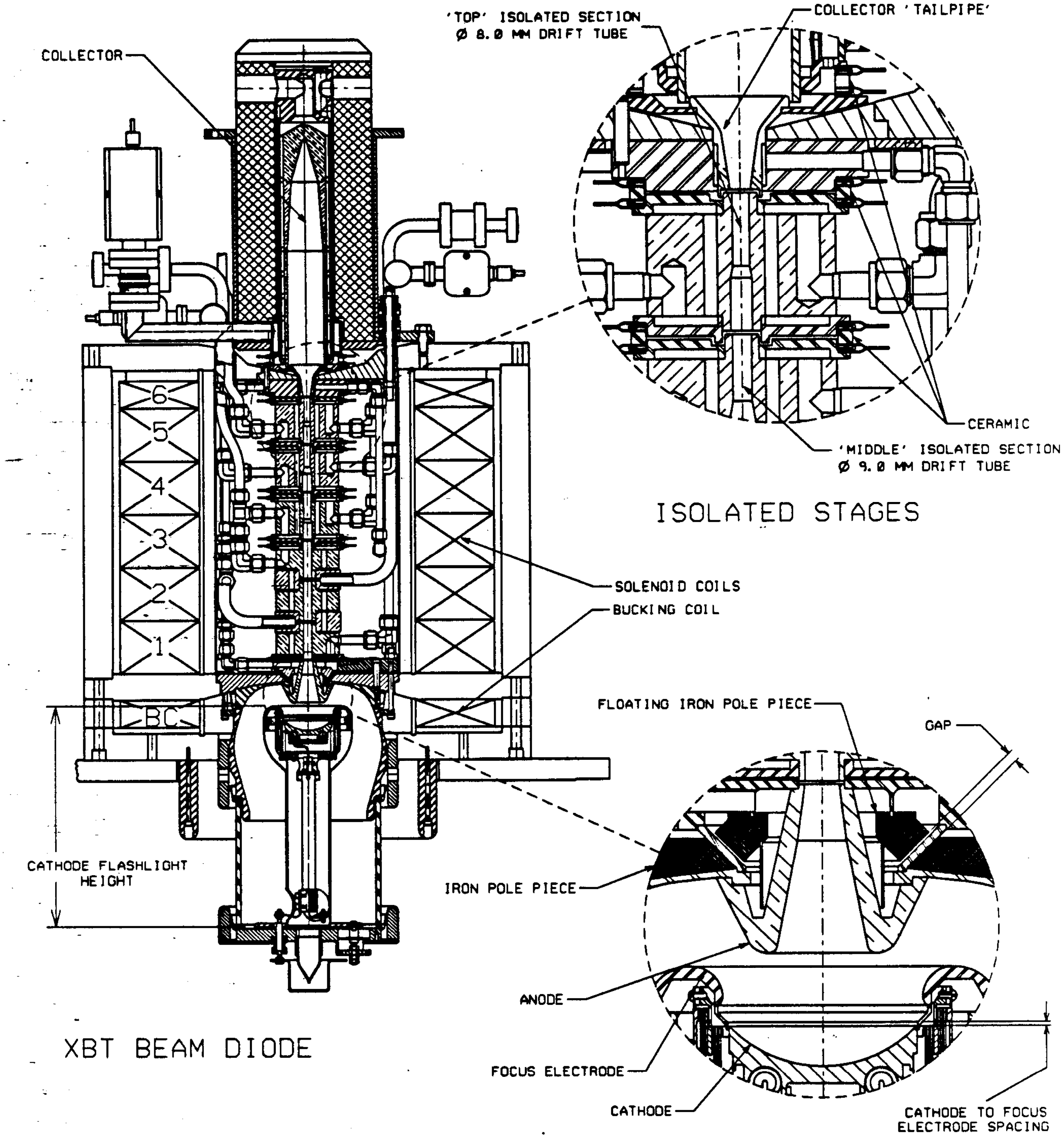
Future linear accelerators require RF power sources with long life, increased beam power, and higher frequencies. These factors typically require beam optics designs with greater BAC's. Beam optics designs with BAC's of 800:1 and greater are presently being designed for future linear beam tubes. It is therefore most important that the designer be able to rely more heavily on beam optics simulation, due to the difficulty of measuring the beam parameters at these high power levels. The XBT Beam Diode has proven that near perfect transmission was achieved. It has also shown that excellent agreement between computer simulation and measurement can be obtained, provided the cathode geometry is adjusted to compensate for thermal motion of electrodes. SLAC's next generation klystron for the NLC is being designed. It will operate at 550 kV, µP=1.2, and BAC of 120:1. Based on the data gathered from the XBT Beam Diode, we expect to be within 2% for this design also.

references

1) W. B. Herrmannsfeldt, "EGUN-an Electron Optics and Gun Design Program", SLAC-report-331, October 1988.

2) Los Alamos Accelerator Code Group, "Reference Manual for the Poisson/Superfish group of Codes", LA-UR-87-126, January 1987.

3) T. J. Grant,"A Powerful Quality Assurance Technique for Dispenser Cathodes and Electron Guns", IEDM, CH2099-0/84/0000-0334, 1984.



XBT BEAM DIODE

ISOLATED STAGES

CATHODE REGION

FIGURE 7