TEST AND DEVELOPMENT OF A 10 MW 1.3 GHZ SHEET BEAM KLYSTRON FOR THE ILC*

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Abstract

The SLAC National Accelerator Laboratory Klystron Department is developing a 10 MW, 5 Hz, 1.6 ms, 1.3 GHz plug-compatible Sheet-Beam Klystron as a less expensive and more compact alternative to the ILC baseline Multiple-Beam Klystron. Earlier this year a beam tester was constructed and began test. Device fabrication issues have complicated the analysis of the data collected from an intercepting cup for making beam quality measurements of the 130 A, 40-to-1 aspect ratio beam. Since the goal of the beam tester is to confirm 3d beam simulations it was necessary to rebuild the device in order to mitigate unwanted effects due to imperfect focusing construction. Measurements are underway to verify the results of this latest incarnation. Measurement will then be made of the beam after transporting through a drift tube and magnetic focusing system. In the klystron design, a TE oscillation was discovered during long simulation runs of the entire device which has since prompted two design changes to eliminate the beam disruption. The general theory of operation, the design choices made, and results of testing of these various devices will be discussed.

INTRODUCTION

Sheet-Beam Klystrons (SBK) have been studied during the last decade at frequencies ranging from GHz to THz, and from power levels from Watts to multi-megawatts. At the Klystron Department at SLAC, much attention has been given to the beam formation and transport as the rf design appears relatively straightforward. The SBK has possible advantages over single and multi-beam klystrons in certain parameter spaces due to: reduced energy and thermal densities; reduced current densities; reduced magnetic field, cathode loading and reduction of some instabilities resulting from the reduced current density; and, the potential for lower device cost. For a plug-compatible alternative for the ILC the reasoning has been mainly argued on the basis of cost of manufacture and possible cost advantages due to life-cycle issues.

KLYSTRON DESIGN

The ILC-SBK plug-compatible baseline design [1] has a single collector, an output structure, two windows, and a single cathode as seen in Fig. 1. In the view a quarter-section of the 256 cm long device has been cutaway. The Periodic Cusp Magnet (PCM) focusing scheme has pole pieces that fit between the cavities with a common flux return plate.

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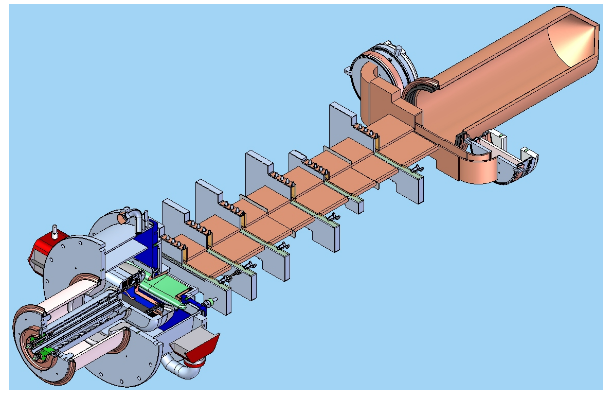

Figure 1: SBK Design.

The cathode uses ~2 A/cm^2 to maintain a long life, and the beam focusing results in a fairly laminar 40:1 aspect ratio elliptical cross-section beam with a slightly hollow (~10%) current density. The PCM stack design has headroom to allow for ramping of the field toward the output thus constraining the drift tube height and fill factor. Numerous 3D simulations using MICHELLE [2] were performed and a final gun design arrived at as shown in Fig. 2.

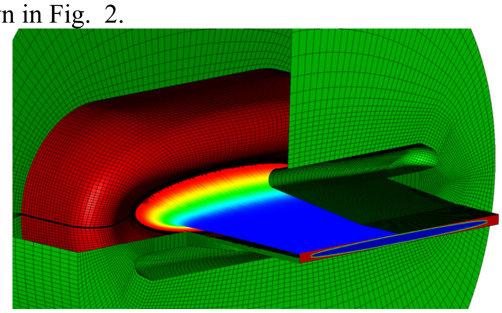

Figure 2: SBK Electron Gun.

The baseline PCM structure design uses radial permanent magnets mounted on a common flux return. The magnets consist of identical small blocks with ramping of the field profile accomplished by increasing the number of blocks and side focusing accomplished by shaping the pole piece tips. The DC beam profile in the constant PCM field is relatively unchanged from the beam minimum, a few inches past the anode, to the output cavity as shown in Fig. 3.

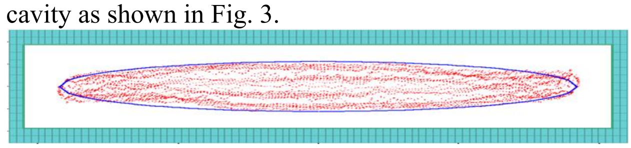

Figure 3: DC Beam cross-section after PCM transport using MAGIC [3] and MICHELLE.

Design and simulation of the rf interaction circuit was aided by the fact that 1D, 2D and 3D analysis all yield the same results due to: the low current density; the relatively low voltage; the high degree of cavity coupling; the flat field profile in the gaps; and, the high ratio of axial field to transverse field in the interaction region. MW output vs. Watts input, Fig. 4, indicate 10MW extraction is highly feasible.

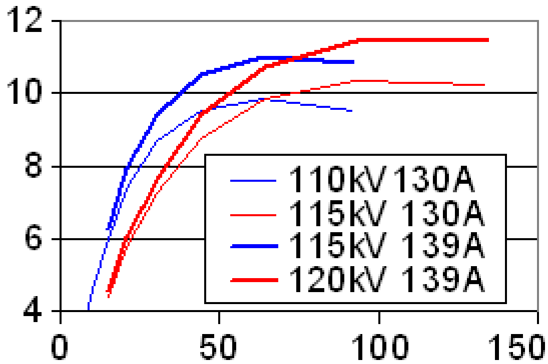

Figure 4: 3D interaction simulations for slightly different perveance beams (110-120kV, 130-139A).

During 3D MAGIC simulations an oscillation of TE modes trapped between adjacent cavities was discovered [4]. It was determined, for this particular design, that the only reasonable way to eliminate them was to increase the height of the drift tube and increase the magnetic field. Fortunately, the cavity coupling is excellent so by increasing the drift tube height and allowing the modes to flow past the cavity thereby reducing their respective Q values, the output power required may still be achieved. By simply doubling the drift tube height it is believed that all the modes are eliminated when using a solenoid field ~1 kG. Simulation of the klystron is shown in Fig. 5 where full power is reached using the newer drift tube size without detectible oscillations.

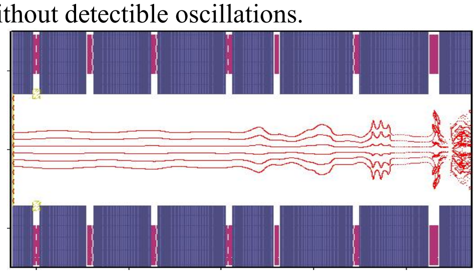

Figure 5: 10 MW 390 G-780 G solenoid design.

BEAM TESTER

Because of uncertainties in simulation of the complex 3D planar SBK gun, a scan of the physical electron beam was deemed necessary. The Beam Sampling Device (BSD) attaches to the anode plate of the SBK and is removable for insertion of a beam propagation structure, an rf structure, or other experiments. A quarter cut-out as shown in Fig. 6 reveals the copper and carbon analysis target (copper color with black tip) set on a 3-axis stage for positioning across the transverse dimensions of the beam with some axial movement. The target has a 0.008" diameter hole through which the beam current is sampled. Total current is measured by a loss ring across the isolation ceramics and the beam is collected at the collector plate at right.

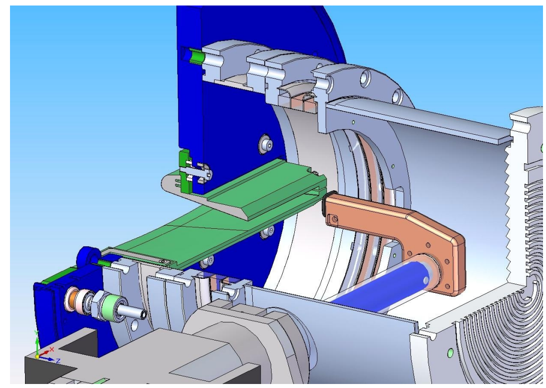

Figure 6: BSD Cutaway.

MODULATOR AND TESTING

Testing of the SBK includes the BSD test where the electron gun and BSD are processed at a 3-4 µs pulselength followed by scanning of the beam profile. After the BSD test, a short two-cavity section with focusing structure is inserted in the beam-line between the anode and BSD to test the beam transport and search for the edges of stability. Then the SBK is installed and any adjustments to the cavity loading, heater power, confinement field, output structure match and gun controls are done. Lastly, the whole SBK is installed on an ILC modulator and operated at the full ILC pulselength.

Testing of the BSD device was delayed due to damage in the FE bias supply system, a cathode heater short, a focus electrode to cathode (FE-K) short, and outgassing from internal carbon pieces used to reduce scattering of the electrons.

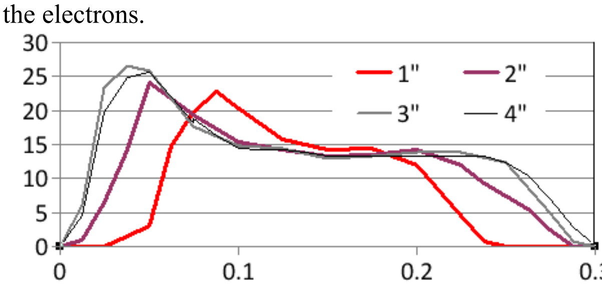

Figure 7: Diode beam current density vs. y-location at four different x-locations of the beam.

Initial scans, Fig. 7, of the beam using the BSD were performed by scanning from the lower edge of the beam to the top at several locations across the wide dimension. The center of the beam is at x=4" whereas x=1" is towards the edge of the beam. In general the behaviour is correct in that the shape is elliptical but in detail it is obvious that the lower edge of the beam is "hotter" in terms of current density.

Various theories were proposed to explain this behaviour: the cathode was operating partially temperature-limited; the FE bias is not functioning properly; the gun is drooping or some other surface is tilted or misaligned; the FE or anodes are distorted due to heat; or, the FE-K edge is incorrect.

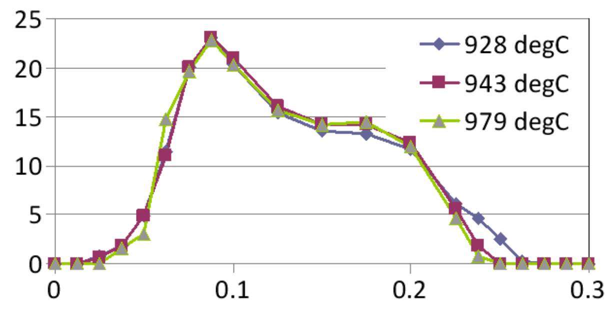

Figure 8: Diode beam current density vs. y-location at three different cathode temperatures.

The first of these theories is dispelled convincingly, Fig. 8, by dropping the cathode temperature by 50 degrees. The second theory may be dispelled by examining the isolated upper and lower anode currents when scanning the two bias controls, and by direct measurement of the bias voltages. This measurement also reinforced the BSD data in that the upper and lower anode currents indicate an asymmetry in the upper and lower beam current density.

The main theory at this point is that problems encountered with implementing the cathode heat shield package and the thermal conductivity of the FE mounting bracket have led to distortions of the FE and an alteration of the FE-K gap because of elevated temperatures. Due to questionable thermal conductivity across the mounting faces, the upper and lower FE may be at strikingly different temperature as seen in the ANSYS calculation in Fig. 9.

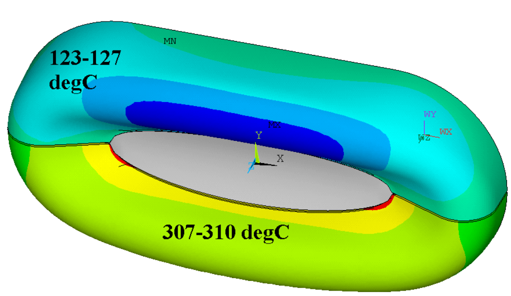

Figure 9: Upper FE design temperature and lower FE possible temperature.

Despite the issue with the beam edge, most of the testing has been encouraging. Some of the highlights are as follows:

1. The overall perveance is correct.
2. The gun is oscillation and breakdown free.
3. The bias system functions correctly.
4. The beam width and height are nominally correct.
5. Changing the FE-anode spacing doesn't alter the beam profile other than in an expected manner.
6. Data is very repeatable.
7. The beam is elliptical; emphasized in Fig. 10.

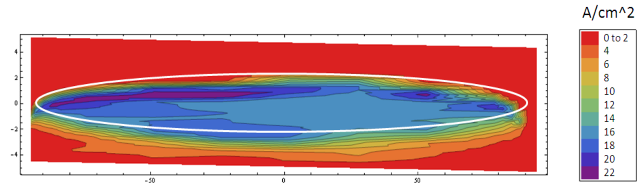

Figure 10: Measured beam current density profile (Upper/Lower FE bias: 900V/0V). The ideal elliptical beam profile is shown in white.

TWO-CAVITY STABILITY TEST

A two-cavity drift tube with PCM focusing structure is in the process of installation into the test stand. Originally this phase of testing was envisioned to test the beam transport and measure the beam current profile to see how it changes. However, this testing now will emphasize benchmarking of the TE mode stability issues. Since regimes of stability and oscillation should be detectable with changes in beam voltage and field strengths from ~250-600 G, the test will benchmark our 3D simulation codes.

SUMMARY

Testing of an SBK diode using the BSD has been completed and indicates an elliptical beam with a hot lower edge. The hot edge is thought to be caused by uneven FE temperatures leading to distortions in the FE surfaces. A two-cavity stability test should be completed during summer 2010 to benchmark 3D simulations. The SBK design now requires a solenoid field and larger drift tube to eliminate unstable behaviour.

REFERENCES

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