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A FIFTY MEGAWATT KLYSTRON FOR THE STANFORD LINEAR COLLIDER*

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Abstract

The proposed Stanford Linear Collider (SLC) has been designed to provide 50 on 50 GeV electron-positron collisions. The performance of the 240 klystrons driving the two-mile long linac must be upgraded to achieve at least 50 Megawatts of peak power output at a pulse width of 5 μsec and a pulse repetition frequency of 180 pulses per second. The operating frequency of the upgraded linac will continue to be 2856 MHz.

A klystron amplifier meeting these new requirements has been designed to operate at 315 kV, $\mu k = 2$, with a computed efficiency of slightly greater than 50%. Initial tests indicate the achievement of the basic power objectives; however, observed parasitic instabilities make beam focusing, RF drive frequency and drive level extremely critical. High electric fields in the electron gun, output gap and output window are all potential problems. Steps taken in the design to overcome these problems are discussed and test results are presented.

DESIGN CONSIDERATIONS

The theory and design of high power klystrons are fairly well established. The particular problems for the case at hand are brought about by the high peak power output and the increased pulse width requirements of the upgraded linac. Taking a practical upper limit of 2.0×10^{-6} A/V$^{3/2}$ for the perveance of a solid beam and an achievable efficiency of about 50%, the pulsed beam voltage is in the order of 315 kV. This rather high voltage causes high gradients in the electron gun and output gap, and special attention must be given to these areas. At the same time, the conversion efficiency should be made as high as possible in order to minimize primary power consumption for the 240 klystrons used in the linac. The considerations which go into the various critical components of the klystron are discussed below.

Electron Gun

In addition to providing the correct perveance, beam diameter, good laminarity and acceptable cathode loading, the electron gun must be able to withstand the operating voltage without breakdown. The design of the electron gun was carried out using the SLAC Electron Trajectory Program, with special emphasis on the shapes of the focus electrode and anode to minimize the voltage gradient between them. The resulting gun geometry and calculated trajectories with magnetic field are shown in Figs. 1 and 2. The maximum voltage gradient is 174 kV/cm at 315 kV anode voltage. The cathode loading averaged over the whole cathode area is [illegible].6 A/cm^2, while the ratio of maximum density at the cathode edge to the minimum density is 1.7:1.0.

Interaction Region

The RF interaction region was designed for high gain and efficiency. The cavity frequencies, drift lengths, and output gap impedance were optimized with the aid of a one-dimensional, time-stepping disk model computer program (1). Bandwidth was not a consideration since the intended application is at a single frequency of 2856 MHz. With a total of six cavities, suitably tuned and spaced, the calculated efficiency is 52%, with a saturation gain of 56.8 dB. The graphical outputs from the computer program are shown in Figs. 3 and 4 from which one can clearly see the process of bunching and energy exchange along the length of the tube.

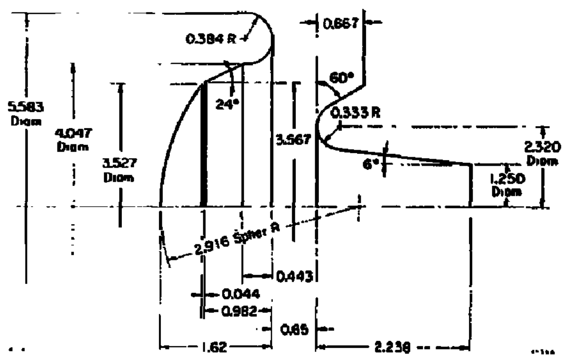

Fig. 1. Electron gun geometry.

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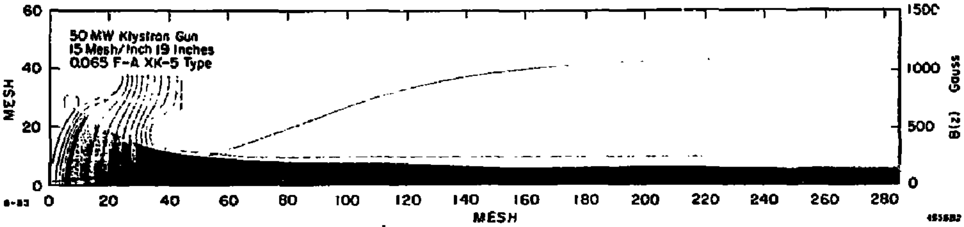

Fig. 2. Calculated electron traject ·ies with magnetic field.

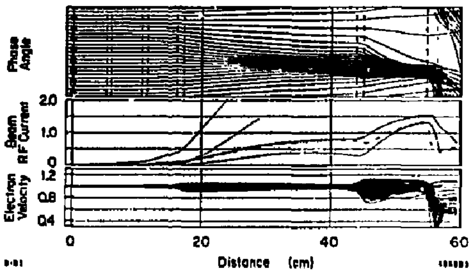

Fig. 3. Computer graphics output of beam-field interaction (50MW single-gap calculation). Input parameters and computed values: EB = 320.0kV; F = 2856.0MHz; A = 0.0159 m; B = 0.0110 m; IK = 362.0 A; ITER = 16; NSTEP = 30; NDISK = 24; PD = 125.0 W; β = 0.85; λ_g = 1.262 m; GAPZ = 0.0, 0.056, 0.111, 0.166, 0.444, 0.555; DF = 4.0, 9.0, 14.0, 24.0, 84.0, 0.0; QE = 200.0, 2000.0, 2000.0, 2000.0, 2000.0, 21.0; R/Q = 80.0, 75.0, 87.0, 96.0, 96.0, 85.0; GAPD = 0.0068, 0.0072, 0.0082, 0.0110, 0.0116, 0.0162; VGAP = 2.42, 7.76, 29.34, 95.62, 324.64, 418.35; MF-V = 0.000, 0.002, 0.010, 0.041, 0.353, 0.132.

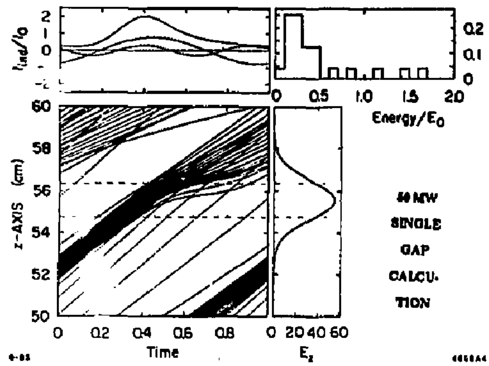

Fig. 4. Computer graphics output of beam-field interaction. Input Parameters and computed values: ITER = 16, NSTEP = 30, EB = 320.0 kV, IB = 362.0 A, F = 2856. MHz, PIN = 125.0 W, A = 0.0159 m, B = 00110 m, β = 0.85, GAPZ = 0.5554, GAPD = 0.01620, VGAP = 418.354, θ = 3.50, Impedance = 1468.8 ohms, Phase Angle = 0, Kinetic Efficiency = 0.529, Electromagnetic Efficiency = 0.514.

Output Gap

The output gap serves the important function of extracting the kinetic energy from the bunched beam. T. G. Mihran et al., (2) showed that the dc transit angle of the output gap should be as small as possible for best efficiency. In our case, because of the high RF voltages involved, we must compromise between maximum efficiency and freedom from RF breakdown across the gap. According to our computer program, the calculated output gap voltage at saturation is 418 kV, which is 1.32 times the dc beam voltage. With this given, the problem becomes one of designing an output cavity which will provide a reasonable degree of coupling to the electron beam and at the same time reduce the maximum gap field to a safe level. Making the radius of the drift tube nose larger and lengthening the gap spacing would reduce the field, but the beam coupling will suffer. The geometry we have chosen is shown in Fig. 5. The maximum electric field as calculated from the LALA program is 360 kV/cm for a gap voltage of 418 kV. The dc transit angle is 1.24 radians, the axial coupling coefficient is 0.94, and the radial coupling coefficient is 0.83. The optimum output gap impedance as found by the computer program is about 1450 ohms. With ordinary lower voltage klystrons where the output circuit is comparatively loosely coupled to the output cavity, one can determine the necessary Q_{ext} from a cold test measurement of R/Q. In our case, where the waveguide circuit is tightly coupled to the output cavity, conventional methods of measuring R/Q will yield too large an error because the resonance of the output system is no longer sharply defined. We, therefore, resort to a direct method of measuring the gap impedance as shown in a paper by Zhao (3).

Output Window

We have chosen a single output window of the pill-box type which has been used in our 40 MW, 2.5 μsec klystrons

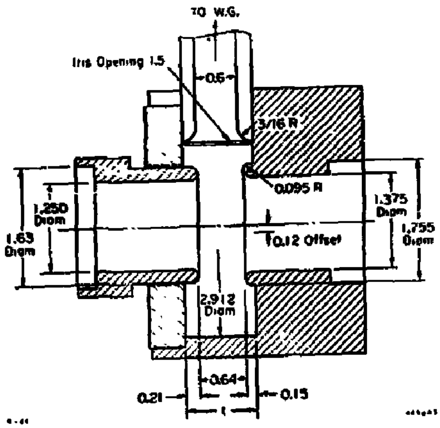

Fig. 5. Output cavity geometry.

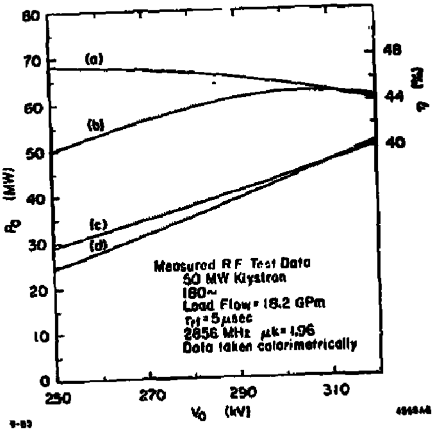

Fig. 6. Power output and efficiency versus beam voltage: (a) efficiency with optimum focusing at each voltage, (b) efficiency with fixed focusing, (c) power output with optimum focusing at each voltage, and (d) power output with fixed focusing.

for quite a number of years. With the higher peak power and wider pulse width requirements, there are potentially new problems. Before assembling to a klystron, each window is coated with titanium nitride and extensively tested in a resonant ring, first to a level of 200 MW at 2 μsec pulse width, then to 100 MW at 6 μsec pulse width. This serves the purpose of weeding out obviously inferior windows. However, conditions prevailing in an actual klystron may not be the same.

EXPERIMENTAL RESULTS

The measured performance of an experimental klystron designed on the above basis is shown in Figs. 6 and 7 and a photograph of the tube is shown in Fig. 8. As shown, the peak power output reached 50 MW at 5 μsec pulse width, 180 pulses per second, with an efficiency of about 45% and a saturation gain of about 60 dB. Compared to the theoretical predictions given by the computer program, the measured efficiency is low by seven percentage points and the measured gain is high by 3 dB.

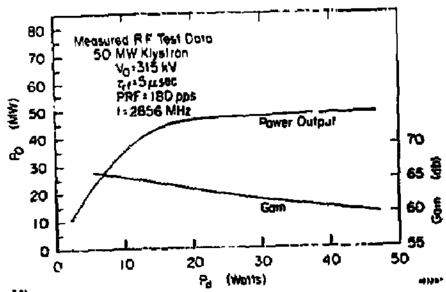

Fig. 7. Power output and Gain versus RF input power.

DISCLAIMER

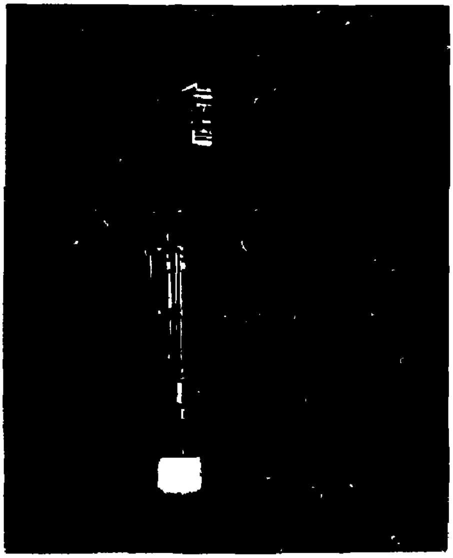

Fig. 8. Fifty MW klystron.

SUMMARY

In summary, it can be said that the power output objective of 50 MW at 5 μsec pulse width, 180 pps, has been achieved with reasonably high efficiency. However, there are problems that remain to be solved., e.g., window life, criticalness of adjustment, fault rate, et cetera. Development work is continuing.

References

(1) Due to Y. Okazaki.

(2) Mihran, Branch and Griffin, *"Design and Demonstration of a Klystron with 62% Efficiency,"* IEEE Trans. on Electron Devices, *Vol. ED-18, No. 2*, February 1971, p. 124.

(3) Y. X. Zhao, *"An Impedance Measurement Method for Double-Gap Klystron Cavity,"* IEEE Trans. on Electron Devices, *Vol. ED-29, No. 2*, February 1981, p. 316.