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DESIGN OF A 100 MW X-BAND KLYSTRON*

Kenneth Eppley
Stanford Linear Accelerator Center
PO Box 4349, Stanford, California, 94309

Abstract

Future linear colliders will require klystrons with higher peak power at higher frequency than are currently in use. SLAC is currently designing a 100 MW klystron at 11.4 GHz as a prototype for such a tube. The gun has been designed for 440 KV and 510 amps. Transporting this beam through a 5 mm radius X-band drift tube presents the major design problem. The area convergence ratio of 190 to one is over ten times higher than is found in conventional klystrons. Even with high magnetic fields of 6 to 7 kilogauss careful matching is required to prevent excessive scalloping. Extensive EGUN and CONDOR simulations have been made to optimize the transmission and rf efficiency. The EGUN simulations indicate that better matching is possible by using resonant magnetic focusing. CONDOR calculations indicate efficiencies of 45 percent are possible with a double output cavity. We will discuss the results of the simulations and the status of the experimental program.

Introduction

Future linear colliders will require rf sources with higher peak powers than are presently available from state-of-the-art microwave amplifiers. Designs for the Terrawatt Linear Collider which is under study at SLAC require sources of hundreds of megawatts of peak power at X-band [1]. The most likely frequency range is between 11 and 17 GHz. Some alternate designs have proposed the use of tubes in the 10 MW range, but to be economically feasible the cost per tube would have to be reduced manyfold below current levels.

One design would make use of an rf source of 500 to 1000 MW with a pulse length of 50 to 100 ns. This would directly drive the accelerating structure. Another option is to use a tube producing 50 to 100 MW with a pulse length of several hundred ns. This would be compressed using several stages of the binary pulse compression techniques described by Farkas [2] to form a shorter pulse of much higher peak power.

Design Parameters

To test the feasibility of pulse compression at realistic power levels, we are designing and building a 100 MW klystron at 11.424 GHz. The nominal design parameters of this tube are:

Frequency: 11.424 GHz

Peak power: 100 MW

Pulse width: 400 ns

Repetition rate: 120 pps

RF rise time: $\leq$ 10 ns

Gain: 55 db

Efficiency: 45%

Voltage: 440 kV

Current: 511 amp

Magnetic field: 6000 Gauss

Drift tube radius: 4.76 mm

Cathode radius: 4.46 cm

Beam radius: 3.5 mm

Modelling of the Gun

The design of the rf interaction region is conventional except for the use of a double output cavity to reduce the electric field gradient on the output gaps, and to increase the efficiency. The primary design problem is to transmit the high current beam through the small drift tube without large interception of the beam before the output cavities. Terry Lee made many trials using the EGUN code to obtain a gun design which would give a high compression ratio, avoiding excessive emission density and dangerously high field gradients. The design is a modification of the SLAC 5045 klystron cathode, which has been tested successfully at the desired voltage and current. The compression ratio was increased to produce a smaller beam.

After a number of trials with POISSON and EGUN simulations, Lee obtained a gun design for which the beam appeared to be fairly well matched to the magnetic field. CONDOR simulations predicted that, with 40 gauss at the cathode and 6000 gauss in the interaction region, the beam experienced only modest interception even after bunching. This corresponds to nearly immersed flow. If the field at the cathode were reduced, the EGUN simulations indicate that scalloping increases and interception is greater. In the CONDOR calculations, increasing the drift tube slightly, to 4.95 mm radius (where the second harmonic is just cut off) reduced interception and improved the efficiency.

Modelling the RF Interaction Region

A parameter study was made with the two dimensional code CONDOR, to find an rf cavity design for optimum efficiency. A final rf design has not yet been chosen. We give in Tables 1 and 2 the rf parameters of the cavities which gave optimal efficiency according to this parameter study. Since the first version of the tube will have a single output cavity for simpliicity, we examined both single and double output designs. The z values are the locations of the cavity centers, and the d values are the gap widths. R/Q values are defined on axis. The tube parameters are as in the nominal design, except that the drift tube radius was 4.95 mm.

Table 1. RF Cavity Parameters - Single Output Design

Cavity	1	2	3	4	5
z (mm)	0.	80	160	243	273
d (mm)	2.8	3.8	4.8	5.5	5.5
$\Delta\omega/\omega$	.0014	-.00105	.012	.058	-.0106
Q_{ext}	175	115	230	2000	15.3
R/Q	75.1	92.9	112	138	107

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Table 2. RF Cavity Parameters - Double Output Design

Cavity	4	5	6
z (mm)	243	260	276
d (mm)	5.5	5.5	5.5
$\Delta\omega/\omega$	.068		

The impedance matrix for the double output cavity [3] was given by $Z_{55} = Z_{56} = Z_{66} = 1057$, with phase angle 0. These values are defined on axis.

The calculated output power for a single output cavity was 88 MW, or 39% efficiency. The required input power at saturation was 130 watts, for a gain of 58 db. Using a double output cavity we obtained 100 MW, or 45% efficiency, 59 db gain. These values are somewhat lower than are calculated and observed for tubes such as the SLAC 5045 (which typically produced 43% for a single output cavity and 50% for a double output). The lower performance of the X-band tube may be due to to larger radius relative to the wavelength, which results in poorer coupling. Although the X-band tube had lower total perveance, its perveance density was higher, and this could also contribute to lower efficiency.

Application of Resonant Magnetic Focusing

Because of aberrations in the beam and less than perfect matching with the magnetic field, the beam scallops at the entrance to the klystron. Such scalloping is common in klystrons, and is not a serious problem in tubes with larger radii. For the design we described above, the simulations predicted only moderate interception. However, the calculations show that the scalloping is highly sensitive to small changes in the field profile. Small misalignments in the actual device could easily result in more severe scalloping and higher interception.

We used EGUN to study whether we could reduce the scalloping by altering the magnetic field profile, using "resonant field focusing." In this technique, a localized variation of the electric or magnetic field is imposed at the beam's minimum radius. With the proper perturbation of the field, it is possible in principle to freeze the beam at this radius and prevent subsequent scalloping. We performed this study on an earlier gun design than the one described above, but the results illustrate the utility of the technique. For this example, a pair of positive and negative perturbations in the magnetic field, located at 26.1 and 31.2 cm from the cathode surface, produced the optimum results. The variation was imposed using idealized coils of 3.63 cm radius. The radius had to be small so that the perturbation would be localized smaller than the betatron wavelength. The change in the fields was about 100 Gauss, which could be produced by a 1000 ampere turn coil at the given radius. Terry Lee is currently studying whether it is possible to wind such a coil directly around the drift tube. An alternative method might be to use iron pole pieces. The EGUN simulations are probably not precise enough to pinpoint exactly the optimum location of the coils in the real device, since small changes in the magnetic field profile could alter the location of the waist. An implementation of this method might involve a movable coil or one with several taps, which could be adjusted experimentally to optimize transmission.

Status of the Experiment

The first stage in construction of the tube is to test the gun and magnet design without rf cavities, to see if the beam can be successfully compressed to the required small radius. The diode is essentially complete. The magnet is still being assembled. Diode testing should begin by early April, 1989. If these tests are satisfactory, construction of the first complete tube is expected by about July, 1989.

References

1. R. Palmer, "Energy Scaling, Crab Crossing, and the Pair Problem," Proceedings of the DPF Summer Study Snowmass 1988 (SLAC PUB 4707, December, 1988).
2. Z. Farkas, "Binary Peak Power Multiplier and its Application to Linear Accelerator Design," IEEE Transactions on Microwave Theory and Techniques, Vol. MIT-34, No. 10, October 1986.
3. K. Eppley, "Optimization of a Lasertron Double Output Cavity," SLAC AP-48, February, 1986.

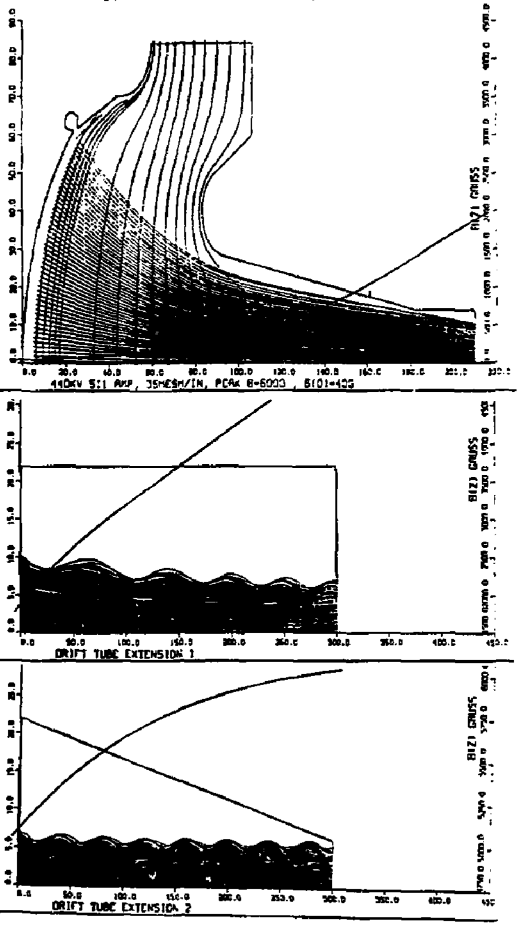

Figure 1. EGUN simulation of the gun: electron trajectories.

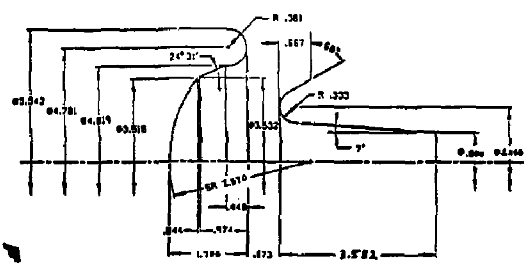

Figure 2. Geometry of the gun (dimensions in inches).

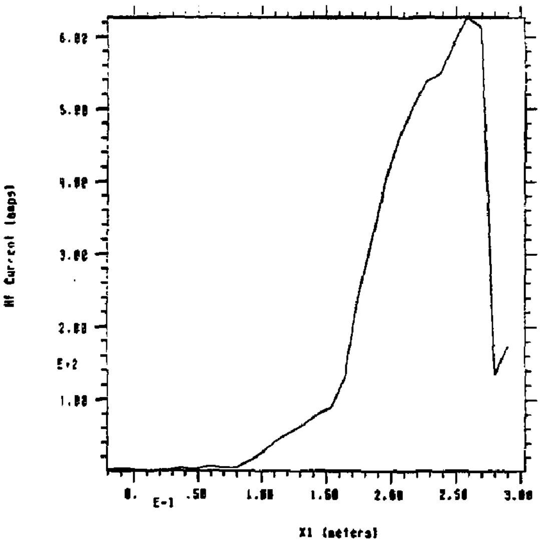

Figure 3. CONDOR simulation of the double output design: RF current (amps) vs. longitudinal position (meters).

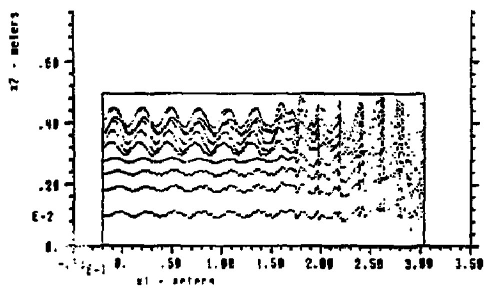

Figure 4. Electron position space distribution. X1 is Z; X2 is R; input cavity at X1=0, beam comes from left.

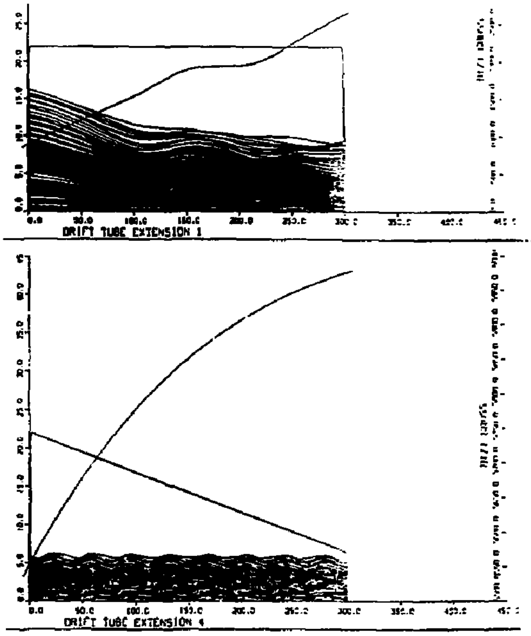

Figure 5. Example of "resonant magnetic focusing:" EGUN simulation including magnetic perturbation.

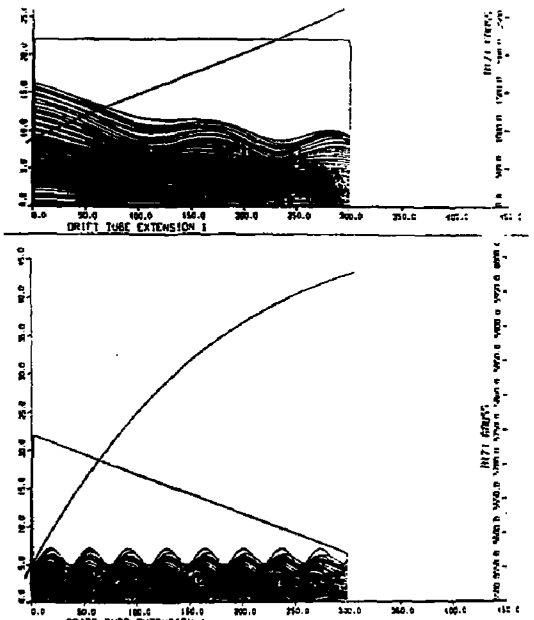

Figure 6. EGUN simulation of the same gun design without perturbation in field profile.

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