SLAC-PUB-5480
May 1991
(A/I)

100 MW KLYSTRON DEVELOPMENT AT SLAC*

A.E.Vlieks, R.S.Callin, G. Caryotakis, K.S. Fant,
W.R. Fowkes, T.G. Lee, E.L. Wright
Stanford Linear Accelerator Center, Stanford, CA 94309

Abstract

A klystron designed to operate at 11.4 GHz and 440 kV is presently SLAC's strongest RF power source candidate for the Next Linear Collider. It is expected to provide 100 MW of RF power with a pulse width of 1 microsecond. Many of the conventional tube technologies are being pushed to their limits. High electron beam power densities, RF electric gradients in cavity gaps and stresses on the ceramic RF output windows are among the most severe problems to be dealt with. This paper describes progress in the development of this device including results from single and double gap output cavities and various styles of RF output windows.

I. Introduction

RF power sources are under development at SLAC in order to satisfy the power requirements of a next generation linear collider. For peak accelerating fields of 50 MV/m a power requirement of 60 MW/m will be required in the current minimum design. To satisfy this requirement efforts are underway to develop a 100 MW klystron at 11.424 GHz. The design parameters for this klystron are shown in Table 1.

Table 1.
SLAC XC Klystron Design Parameters

Operating frequency	11.424 GHz
Peak Output Power	100 MW
RF Pulse Width	100–1000 ns
Pulse Repetition Rate	120 pps
RF pulse risetime	$\leq$ 10 ns
Beam Voltage	440 kV
Beam Current	511 A
Efficiency	45%
Saturation Gain	55 dB
Focussing Field	6 kG
Beam Areal Compression	190:1
Max. Surface Grad. in Gun (at F.E.)	308 kV/cm
Maximum Surface Grad. in Output Gap (for single-gap Cavity)	1.33 MV/cm
Maximum Surface Grad. in Output Gap (for 2-gap Cavity)	774 kV/cm
Average cathode current density	9 A/cm^2
Total length	≈ 1.5 m

We have currently designed and built three versions of a 100 MW klystron (called XC1, XC2 and XC3) to test various alternatives to RF windows, output cavities and beam optics. In addition, a series of diode tests were performed to test the breakdown limitations in cathode/anode designs[1] and beam transmission.

In addition to developing a klystron for a future collider, this program has a second purpose. This is to develop a power source to test accelerator structures and other devices. Thus far we have used these klystron prototypes to test a Binary Pulse Compressor[2] (BPC), to serve as a driver for a Crossed-field Amplifier(CFA) and (in the near future) to drive a high power Resonant Ring[3].

II. Initial Tests

The first test performed on this klystron design was a beam diode test. It consisted of an electron gun identical to the one designed for a 100 MW klystron, a drift section with the same length as the klystron, and the solenoid magnet designed for the klystron. The drift section was divided into several thermally isolated parts which were equipped with thermistors to measure beam interception. The purpose of the test was to verify the beam perveance, cathode/anode voltage standoff capability and beam quality which had been determined by the electron trajectory simulation code EGUN[4] and the magnet code POISSON[5]. Results verified that the perveance was at the design value of 1.75 μ perv. and that the beam interception was $\approx 2\%$. In addition, no difficulties with cathode/anode breakdown were found. A later experiment[1], with a specially coated focus electrode, indicated that a standoff capability of 360 kV/cm for 5 μs pulses and (in excess of) 400 kV/cm for 1 μs pulses could be expected.

III. Klystron: General Description

All three klystrons have been designed to operate at 440 kV with a perveance of 1.75 μ perv. The thermionic cathode has a diameter of 8.9 cm and a beam loading of ≈ 9 A./cm^2. The areal compression ratio of the beam is 190:1, which is a value somewhat larger than usual for a klystron. To accomplish this compression, the beam is first compressed electrostatically by a factor of ≈ 40 and then further compressed magnetically in a slow, adiabatic manner. This latter compression is performed in a long tapered drift tube section (30 cm) between the gun and input cavity. Magnetic focussing is accomplished with a 6 kG. solenoid magnet and a separate trim coil wound directly on the klystron body upstream of the input cavity. Results from EGUN[6] indicated that this trim coil might improve beam quality. The solenoid magnet field is controlled by six independent sets of coils (including bucking coil) to shape the field to the design value. In the third klystron (XC3) the field was modified by removing the trim coil and shaping the field with a smaller diameter steel gun pole piece.

* Work supported by Department of Energy contract DE-AC03-76SF00515.

Contributed to the IEEE Particle Accelerator Conference, San Francisco, CA, May 6–9, 1991

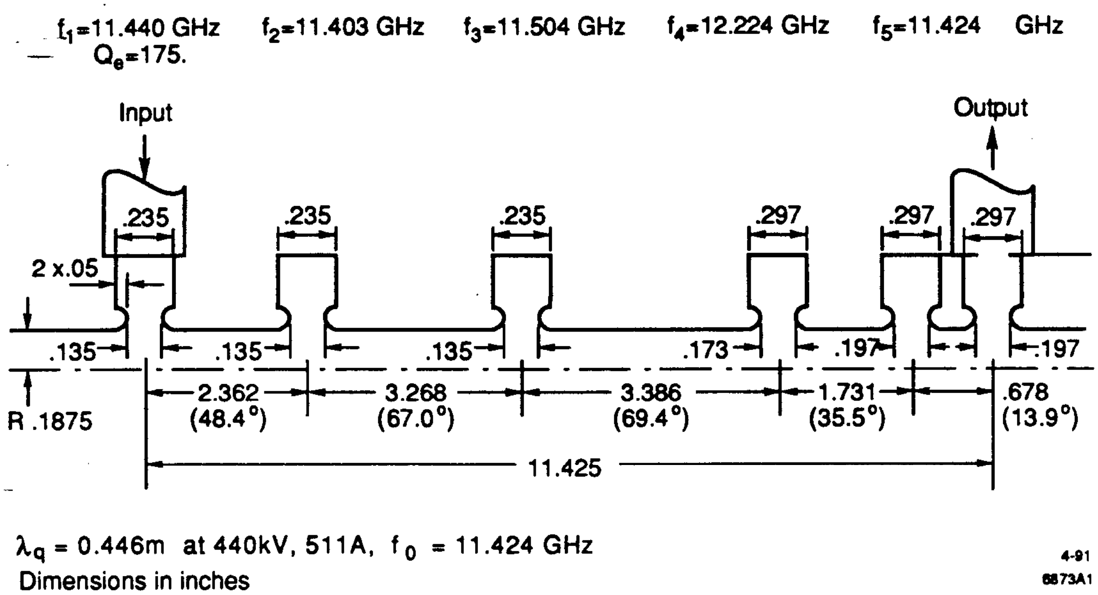

Figure 1. XC2 Klystron, Double-Gap Output Cavity Design Values.

The importance of the bucking coil is also diminished in this design.

The RF section consists of an input cavity, two gain cavities, a penultimate cavity and an output cavity. (See Fig. 1). Details of the different output cavities are described below.

The number of waveguides leaving the output cavity is different for the three klystrons but in all designs two output windows are used. For XC1, two waveguides leave the output cavity directly while XC2 and XC3 use a single waveguide. In this latter design, the power is then divided by a 3 dB splitter into two separate waveguides. Two different window designs have been used and are described below.

Pumping of the klystrons is accomplished by means of 2 l/s vac-ion pumps mounted on the input and output waveguides. Typical klystron pressures are 1-5$\times 10^{-9}$ Torr. as read by the pump currents.

IV. XC1

XC1 was the first X-band klystron tested in this program at SLAC. It was a five cavity klystron with a single gap output cavity. Thin (.79 mm) RF windows were used because of simplicity and the need for wide bandwidth. (The klystron was to be used in CFA experiments).

The peak power attained with XC1 was 65 MW. This was only attained at narrow pulse widths however (30–40 ns). At wider pulse widths RF breakdown limited the peak power attainable although RF conditioning did improve the RF breakdown threshold somewhat. Results of peak power generated at threshold both initially and after $\approx$ 250 hours of operation are shown in Fig. 2. As is seen in the figure, the peak fields in the output cavity for a 1 μs pulse were only 600 kV/cm which is much less than the 1330 kV/cm expected at 100 MW.

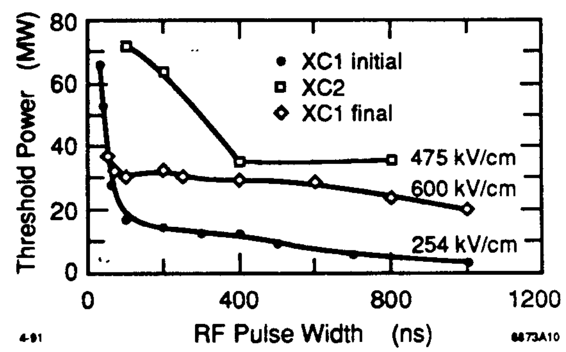

Figure 2. Measured Power Units as a function of pulse width for XC1 & XC2.

After studying the performance of the klystron, it was used as a driver for CFA experiments and BPC tests. Unfortunately during the latter tests, the windows were damaged which terminated further testing. Evaluation of the klystron indicated that significant beam erosion and RF breakdown had occurred in the output cavity. In addition, damage was observed at the other cavities and at the entrance to the drift tube.

V. XC2

Because of the problem of RF breakdown in XC1 it was decided to change the output cavity design to a dual-gap cavity. This would have the effect of reducing the peak cavity fields by $\approx$ 60%. In addition, some small changes were made to the RF circuit to improve its performance.

Other changes in this tube included the addition of beam diagnostics. The copper klystron body was thermally isolated into five sections by thin (.3 cm) stainless steel plates. Five thermistors were installed into the body within 2 mm of the drift tube radius at key locations. The most important of these were the two located at the rear end of the penultimate and output cavities. In addition, the collector was electrically isolated from the tube body to permit direct measurement of transmitted beam current.

Initial tests indicated improvements in peak power to 72 MW for pulse widths of 100 ns. Figure 3 shows the klystron performance as a function of beam voltage. The highest power levels were measured calorimetrically at pulse widths ranging from 100 to 200 ns at a pulse repetition rate of 180 pps. At the highest beam voltage, calorimetric power measurements were compared to RF measurements (crystal diode detector) under identical conditions and found to give equivalent results. As can be seen in Fig. 2, peak power levels of 35 MW were measured for pulse widths of up to 800 ns. These power limits were more the result of the experimental requirements at the time rather than a firm breakdown limitation. For the most part, this klystron was used to supply power to the BPC experiment which required $\approx 35\,\mathrm{MW}$ RF power at a pulse width of 800 ns. At the conclusion of BPC testing it was found that both RF windows were broken. This necesitated a pause in experimentation until these windows could be replaced. During repair, it was found that beam erosion due to interception had taken place in the output section of the klystron. It was unclear whether or not any RF breakdown had also taken place.

At the time of this writing, the windows of XC2 have been replaced with a more robust "thick" design and the tube is again operational. Improvements to beam optics is expected due to improved alignment procedures and tighter tolerances of the solenoid magnet to the klystron.

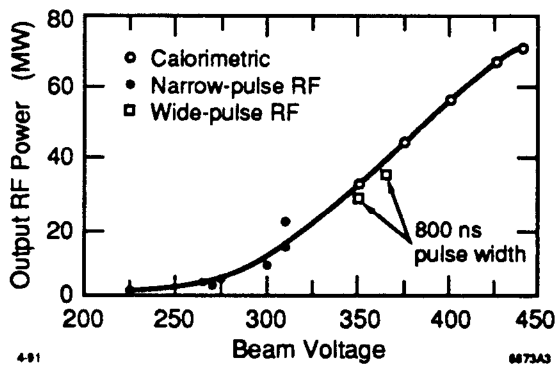

Figure 3. XC2 Output Power.

VI. XC3

This klystron was designed with the same modifications as the current XC2. The only difference was in the magnetic field profile near the cathode which was improved to reduce the beam fill factor and subsequent interception at the end of the magnetic compression stage.

During initial testing the beam intercepted the drift tube in the output cavity region causing melting. This resulted in the development of a 13.8 GHz. oscillation in the output cavity. This oscillation was present even in the absence of RF drive power. Its intensity was somewhat controllable by "squeezing" the beam with the solenoid magnet. The oscillation caused excessive heating in the output cavity, probably by disrupting the beam, and also outgassing in the windows. (The windows are opaque to this higher frequency mode). After disassembling the klystron, extensive damage was discovered in the septum and downstream gap of the output cavity. This cavity is currently being replaced and the tube will be in operation in the near future.

VII. Summary

Three X-band klystrons have been designed and tested as part of development of an RF source for a future Liner Collider. At this time 72 MW RF power has been generated with a pulse width of 100 ns and 35 MW has been generated at 800 ns.

In order to improve the current design significantly, the problems of beam interception and RF breakup must be overcome. Beam interception is a particularly difficult problem because the high current density of the beam can cause intrapulse melting for almost any level of body interception. To alleviate this problem, future klystron modifications will include improved beam optics, a larger output cavity radius, and beam collimators near the input and output cavity positions to limit the size of the beam and remove any beam halo. These modifications will also reduce the likelihood of RF breakdown if the latter was caused by gassiness caused by localized heating and melting. Modifications to the output cavity design are also underway in the form of lower field designs. These include a 3-gap output cavity and a multiple-gap traveling wave output cavity.

Further work in RF window design is also underway. In addition to the new "thick" ($.43\lambda'_g$), currently in test, a larger diameter (4.6 cm) design is being developed.

References

[1] "High Gradient Electron Guns." K.S. Fant et al., SLAC-PUB-5325 (August 1990).

[2] "High power Radio-Frequency Binary Pulse Compression Experiment at SLAC" T.L. Lavine et al. SLAC-PUB-5451 (May 1991).

[3] "RF Component Development for X-Band above 100 MW," W.R.Fowkes, R.S. Callin and M. Studzinski, SLAC-PUB-5545, (May 1991).

[4] "EGUN: An Electron Optics and Gun Design Program." W.B. Herrmannsfeldt, SLAC-PUB-0331 (October 1988).

[5] "Reference Manual for the POISSON/SUPERFISH Group of Codes." Los Alamos National Laboratory, LA-UR-87-126 (January, 1987).

[6] "Design of a 100MW X-Band Klystron," K. Eppley, SLAC-PUB-4900 (February 1989).