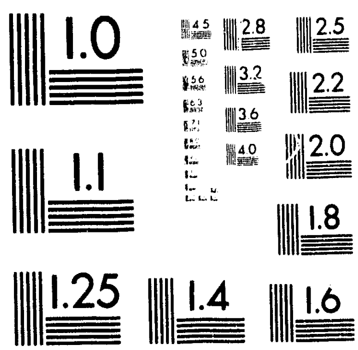
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PEP-II Prototype Klystron

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Abstract

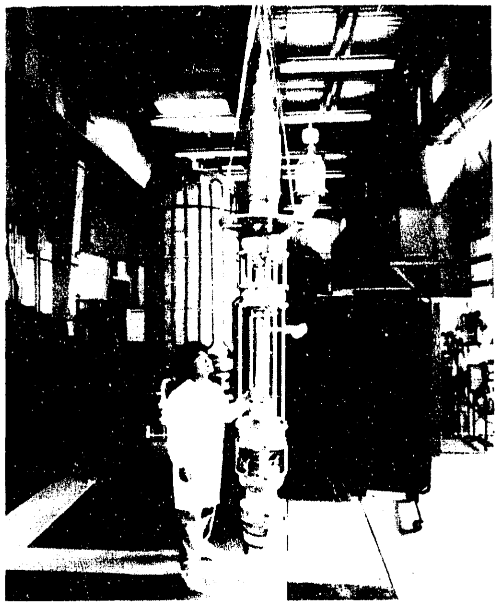
A 540-kW continuous-wave (cw) klystron operating at 476 MHz was developed for use as a power source for testing PEP-II rf accelerating cavities and rf windows. It also serves as a prototype for a 1.2 MW cw klystron presently being developed as a potential rf source for asymmetric colliding ring use. The design incorporates the concepts and many of the parts used in the original 353 MHz PEP klystron developed sixteen years ago. The superior computer simulation codes available today result in improved performance with the cavity frequencies, drift lengths, and output circuit optimized for the higher frequency. The design and operating results of this tube are described with particular emphasis on the factors which affect efficiency and stability.

I. INTRODUCTION

The initial goal was to develop a 500-kW cw klystron to operate at 476 MHz for use as a power source for testing rf cavities destined for the PEP-II Asymmetric Storage Ring. This tube is also considered as a prototype for a 1.2-MW klystron currently being developed as a potential rf source for PEP-II. It became apparent that the 500-kW cw PEP klystron operating at 353-MHz developed at SLAC sixteen years ago, might be used as a basis for scaling. Some quick calculations showed that the same gun, beam tunnel diameter, and collector could be used in a klystron operating at 476 MHz and at the same power level of 500 kW. The cavity designs, drift tube lengths, and output circuit would have to be changed to operate at the new frequency. Many of the design concepts and some of the existing parts from the original PEP klystron could also be used on the 476-MHz tube. It was determined that the development effort could be completed in approximately one year because of this similarity between the two klystrons. Approximately 175 new part and assembly drawings were required.

II. COMPUTER CODE PREDICTIONS

Both the one-dimensional JPNDISK and two-dimensional CONDOR were used to compare the original 353-MHz PEP design with its measured results. While the two codes gave different results and the absolute values in efficiency cannot be relied upon completely, the relative values are meaningful. Both codes predicted an optimized 476-MHz design efficiency about 8 percent higher than the 353-MHz tube. It was also apparent that the efficiency of the 353-MHz PEP tube could have been higher using the now improved simulation codes, but this would have been at the expense of additional tube length.



III. DESIGN

The design parameters for the klystron are given below.

DESIGN PARAMETERS

Operating Frequency (MHz)	476
Output Power (kW cw)	540
Beam Voltage (kV)	65
Beam Current (Amperes)	12.4
Beam µperveance (µamp/volt$^{3/2}$)	0.75
Efficiency	0.67
Saturation Gain (dB min.)	42
RF Drive Power (watts)	≤ 30
Number of Cavities (Incl. 2nd Harm.)	5
Normalized Drift Tube Radius, γa	0.67
Normalized Beam Radius, γb	0.43
Reduced Plasma Wavelength, λ_q (meters)	4.05
Output Waveguide	WR 2100
Focusing Magnetic Field (gauss)	190 (2.4 x B_{Br})
RF Interaction Length (meters)	1.67

The cathode is the dispenser type and the gun optics are identical to that of the PEP I klystron which had an oxide cathode operating at 353.2 MHz. The average loading is 98 mA/cm^2. The beam-tunnel diameter on both tubes is 7 cm. The cavity geometries were changed to accommodate the 35 percent higher operating frequency, but most could be

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machined from the same stainless steel spinnings used on PEP I. The cavity diameters were unchanged from PEP I; the resonant frequencies were determined by cavity length and gap spacing. Cavity three, operating at the second harmonic, was an exception and had to be completely redesigned. All five cavities are tunable, and cavities one through four have diagnostic loops. The drift tube lengths were all changed for optimum performance at 476 MHz as determined by computer codes.

INTERACTION SPACE PARAMETERS

Cavity No.	Frequency (MHz)	R/Q (ohms)	Q_{ext}	Transit Angle (radians)	Drift Lengths ($360°xL/\lambda_q$)
1	476.3	108	1000	0.95	
					35.4
2	477.5	103	∞	1.14	
					11.4
3	948.0	68	∞	0.80 (@2xf$_0$)	
					75.0
4	483.8	106	∞	1.00	
					33.6
5	476.4	102	70	1.00	

The output coupling loop design that was used on PEP I did not provide enough coupling for the design external Q of 70. The diameter of the output coax center conductor that forms the loop in the output cavity had to be tapered down from 3.34 cm to 1.91 cm in diameter. The coax-to-waveguide transition (56 Ω to reduced height WR 2100) that houses the cylindrical alumina ceramic window was not altered. The position of the abrupt step to full-height waveguide remained the same, but the inductive matching post was moved to provide a perfect match the waveguide to the 56-ohm, 8.5-cm diameter coax exiting the output cavity. The changes resulted in improved bandwith compared with the original PEP I output window assembly.

The final external Q achieved on the cold test model of the output cavity after five machining iterations was 70, the design value. The measured external Q, however, on the brazed version destined for the tube turned out to be 57. Unfortunately, no quick way of adjusting the coupling exists. It was decided to assemble the tube and optimize the external Q artificially in the waveguide output as described later.

IV. OPERATING RESULTS

The klystron began testing in spring 1992. The design power output of 500 kW was achieved at 66 kV instead of the design value of 65 kV. The efficiency was slightly lower than expected due in part to a lower than optimum external Q for the output cavity as described above. The initial measured efficiency was about 60 percent but was increased to 61.6 percent by artificially raising the external Q of the output cavity with an external matching element and some minor tuning of three of the cavities. No instabilities, such as multipactor, spurious frequencies, or sideband frequencies due to returning electrons were observed. The beam is well behaved, and the usual tradeoff between focusing for maximum power output and minimum body interception was not present. The first two cavities and the entire output circuit were coated with titanium nitride as a precaution against multipactor.

A saturation gain of 40 dB was achieved instead of the design value of 42 dB, and the optimum focus magnetic field was 234 Gauss instead of the design value of 190 Gauss. Plots of efficiency and gain are plotted as a function of rf drive in Figure 1.

V. CHANGING THE EXTERNAL Q OF THE OUTPUT CAVITY

The effective external Q was changed by placing a capacitive post in a section of waveguide with a longitudinal slot along its centerline on one broadwall so that the gap impedance could be changed by controlling the height and position of the post. The initial assumption was that the gap impedance should be increased by approximately the ratio

$$\sigma = \frac{Q_{ext-desired}}{Q_{ext-actual}} = \frac{70}{57} = 1.23\ ,$$

and the magnitude of the normalized capacitive susceptance to accomplish this is given by

$$\left|\frac{B}{Y_0}\right| = \frac{\sigma - 1}{\sqrt{\sigma}} = 0.206\ .$$

The location of the capacitive post with respect to the output-cavity detuned short is given by

$$\ell = \frac{\lambda_g}{4} + \frac{\lambda_g}{2\pi}\tan^{-1}\left[\frac{1}{2}\left[\sqrt{\left|\frac{B}{Y_0}\right|^2 + 4} - \left|\frac{B}{Y_0}\right|\right]\right]$$

towards the load. This produces a normalized admittance at the detuned short position of

$$\frac{Y}{Y_0} = 0.814 + j0.$$

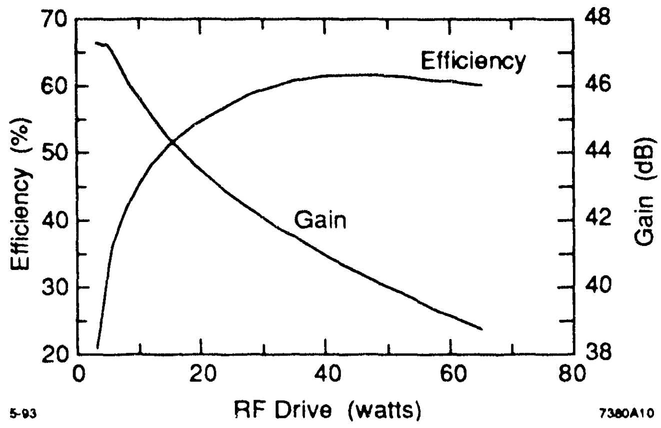
Capacitive post spacers were constructed to produce capacitive susceptances slightly larger and smaller than the calculated value, but the calculated value was found to be optimum for improving efficiency. The effect on efficiency of the z position in the slotted waveguide is shown in Figure 2.

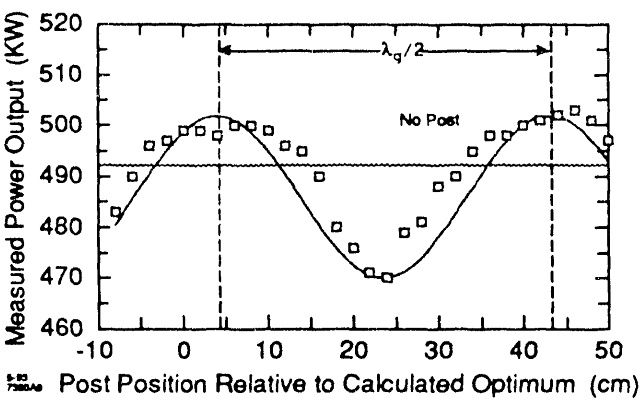
VI. FUTURE PLANS

A 1.2 MW klystron operating at the same frequency is jointly being developed by SLAC and Varian Associates. This new tube must have a combination of wide bandwidth and short group delay needed for powering high-current accelerator systems requiring fast rf feedback stabilization. The bandwidth and group delay of the 500 kW klystron described in this paper are not adequate. The first tube will be built and test^r^ at SLAC but the design will be a joint effort by both organizations. Testing of this tube is expected to start in the summer of 1994.

VII. ACKNOWLEDGMENT

The authors would like to acknowledge the members of the klystron manufacturing and testing groups who put their energy, dedication and skill together to bring this project together within a year of its inception. Particular thanks go to Harry Greenhill and Charley Griffin who made many valuable contributions to the tube design and testing facility.





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