Operating Results for the PEP II 1.2 MW Klystron

E. Jongewaard, G. Caryotakis, E. Doyle, R. Fowkes, C. Pearson, R. Phillips, E. Wright
Stanford Linear Accelerator Center, Stanford, CA 94309 USA
H. Bohlen, G. Huffman, S. Lenci, E. Lien, E. McCune, G. Miram, R. Vranas
Communications and Power Industries, Palo Alto, CA 94304 USA

Abstract

A CW Klystron operating at 476 MHz has been developed jointly by SLAC and Communications and Power Industries (formerly Varian Associates). The unique set of characteristics of this tube were strongly guided by requirements of the fast feedback necessary to prevent oscillations of the storage ring beams caused by the detuned accelerating cavity. The RF stabilization scheme requires the source to have a combination of bandwidth, short group delay, and an operating point that is 10% below saturation. Computer codes developed at CPI were used to design the beam optics and RF interaction region to meet these requirements. Operating results are presented and compared with computer predictions.

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1 INTRODUCTION

SLAC and CPI joined efforts under a Cooperative Research and Development Agreement (CRADA) to develop and test a prototype UHF super power klystron as a 476 MHz RF source for the PEP II Storage Ring currently under construction at SLAC. This klystron was originally designed to produce 1.6 MW CW saturated at 90 kV and 27 amperes. After the klystron development was well underway, the output power and headroom requirements were relaxed. As a result, the klystron will be operated conservatively at 83.5 kV to allow 1.2 MW saturated output. The klystron will be operated 10% below saturation and must be able to respond to fast feedback correction in both amplitude and phase in order to damp accelerating cavity oscillations induced by high current storage ring beams. This feedback scheme requires the klystron to have very short group delay ($d\phi/d\omega$) and wide bandwidth. When this development effort began neither of these features were available off the shelf in commercial tubes of similar power and frequency such as those used at LEP and TRISTAN storage rings.

The design parameters for this tube are listed in the table below.

DESIGN PARAMETERS

Operating Frequency (MHz)	476
Output Power at Saturation (kW)	1200
Operating Point Below Saturation (kW)	1100
Beam Voltage (kV)	83.5
Beam Current (A)	24.1
Efficiency (%)	>60
Saturated Gain (dB)	>43
1 dB Bandwidth (MHz)	±3.0
Group Delay at ±0.5 MHz (nanosec.)	100

2 ELECTRICAL DESIGN

The electron gun design has a peak cathode loading of 0.31 A/cm^2 and a maximum surface gradient of 50 kV/cm. Computer simulation predicts a beam diameter of 4.5 cm with a 5.8% scallop in a 7 cm tunnel diameter.

The seven cavity interaction region was optimized for the original operating voltage of 90 kV to provide the required combination of bandwidth and low group delay without compromising gain or efficiency. The staggered tuning arrangement of the first three cavities was expected to provide about 6 MHz of 1 dB bandwidth and about 150 nanoseconds of group delay across that bandwidth. A cavity tuned slightly below the second harmonic of the operating frequency is added to increase efficiency by reducing the electron density in the antibunch region as the beam passes through the output gap[1][2].

The output coupling loop is designed to give an external Q of 36 for the output cavity. This value is slightly below that which gives optimum efficiency but assures that the lowest velocity electrons will not be reflected and cause regeneration. The entire output coupling circuit was modeled using MAFIA. The measured results for both resonant frequency and external Q agreed with the simulation to better than 0.1%.

Both 1D and 2D klystron codes developed at CPI were used in the interaction design simulation. Results were verified at SLAC using the JPNDisk and CONDOR codes. Comparisons between the predicted results and actual performance will follow later in this paper.

3 MECHANICAL DESIGN

The klystron body consists of cylindrical copper plated stainless steel cavities joined by water cooled drift tubes and support frames. The output cavity, owing to its higher wall losses, has OFE copper walls with an outer stainless steel reinforcing structure. All cavities are water cooled for temperature stability. Each cavity except the output has a tuning mechanism that allows a frequency shift of ±1.8 MHz for the fundamental cavities and approximately twice that for the second harmonic cavity. A TiN multipactor suppression coating was applied to the cavity noses, the input drive loop, the output coupling loop and the vacuum side of the output window.

The limited bakeout station clearance required optimization of the collector design to minimize the tube length. The interior is contoured to have nearly constant flux for highest surface cooling efficiency. The large inside diameter of the collector necessitated a brazed on cooling jacket to avoid excessively high stresses in the collector wall due to the pressure of the coolant. This construction technique not only allows optimal design of the cooling channels, but also allows for the monitoring of beam deposition by measuring temperatures on the outer jacket.

The coaxial output window is face cooled by 50 scfm dry air ducted through a T-bar coupler into the inner conductor. The inner and outer conductors are water cooled on the vacuum side only. Compliant membranes are incorporated in the vacuum and air side center conductors to prevent excessive mechanical loading of the output window.

The magnet consists of twelve individual free-convection cooled coils with a 45% fill factor to allow access to the tuners. The magnet return path is formed by four symmetrically placed steel pipes that serve to support the coils as well as the supporting klystron in the horizontal position.

4 PERFORMANCE

The klystron went into test in mid-February 1995 and processed cleanly up to 60 kV. At this point the 2.6 MW dc power supply failed, and further testing of the klystron did not resume until mid-July 1995. Testing of the klystron continued and the full output power of 1.2 MW was achieved in less than four additional days of running. The klystron processed up to full power very easily with few gas bursts and no gun arcs. No instabilities such as multipactor, spurious oscillations, or sidebands were observed. Extensive calorimetric measurements of losses in the klystron indicated good agreement with predictions. Window losses and edge temperatures agreed very well with finite element computer models. Temperature profiles of the collector were made to determine electron beam distribution, again with very good agreement with predictions. The klystron operated at slightly higher efficiency (61%) than expected so that the nominal beam voltage for 1.2 MW saturated output power could be decreased to 82.2 kV from the anticipated 83.5 kV.

The measured saturated output power versus electron beam voltage is plotted along with the predicted results from the 1-D code JPNDisk in figure 1. Also shown is the very good agreement between the three methods used to measure the output power of the klystron, an RF power meter, calorimetric measurement of power dissipated into the RF load and a subtraction of all the measurable tube loss (primarily spent beam in the collector) from the input DC beam power.

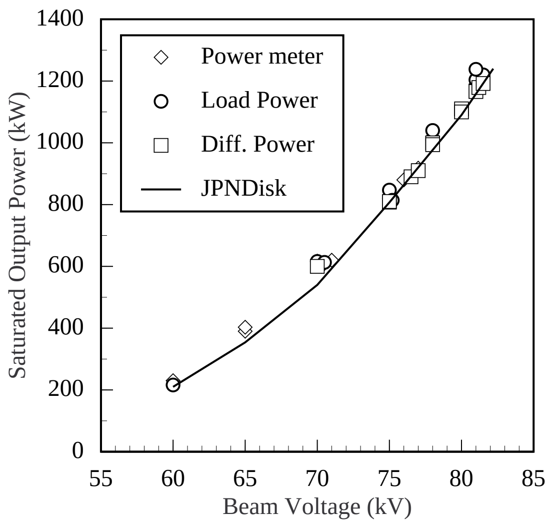

Figure 1. Measured and predicted saturated output power versus beam voltage

Figure 2 shows the predictions of the 1-D analysis codes used by CPI and SLAC. The CPI code over-predicts the saturated output and gain. CPI engineers routinely derate their 1-D code predictions by 10% which in this example would give very close agreement with the measured tube performance. The JPNDisk code is very good for the saturated output power but under-predicts the gain in the linear region somewhat. The predicted results from the 2-D code used by CPI and the code FCI are shown in figure 3. Both codes give a reasonable prediction for the saturated output power but both over predict the gain with the FCI code performing slightly better than the CPI 2-D code.

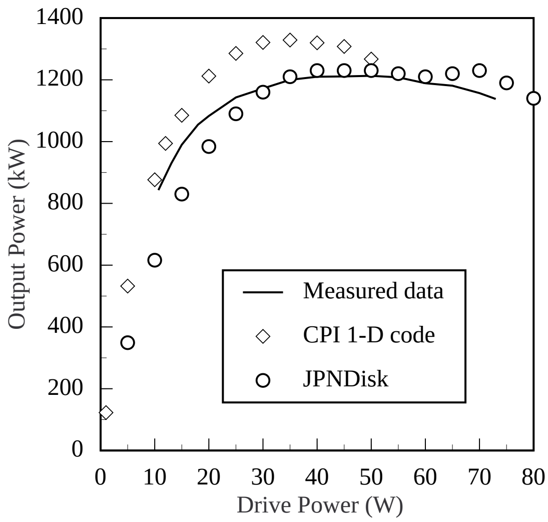

Figure 2. Measured and predicted output power versus drive power at 82.2 kV, 24.0 A

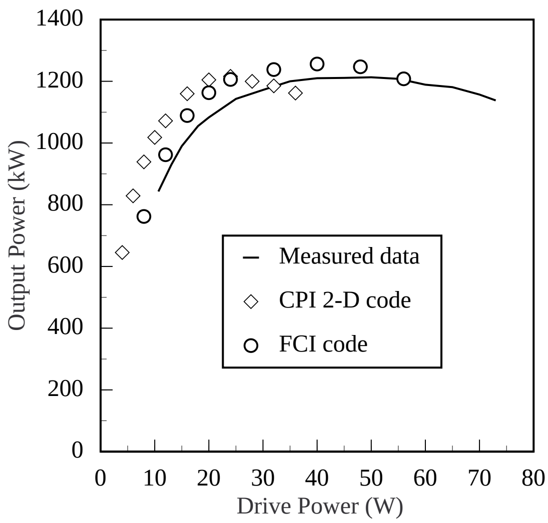

Figure 3. Measured and predicted output power versus drive power at 82.2 kV, 24.0 A

The measured group delay and amplitude response of the klystron over a 10 MHz band centered at 476 MHz is shown in figure 4. The RF drive was set to saturate the tube at 476 MHz and remained constant during these swept measurements. The group delay is seen to be very close to the desired 100 nsec at 476 MHz and is below approximately 120 nsec for the ±1 MHz around 476 MHz. The amplitude response is very nearly within 1 dB from -3 MHz to +5 MHz. Both of these results verify the suitability of this klystron for use in the fast feedback cavity drive system to be used in the SLAC PEP II storage ring.

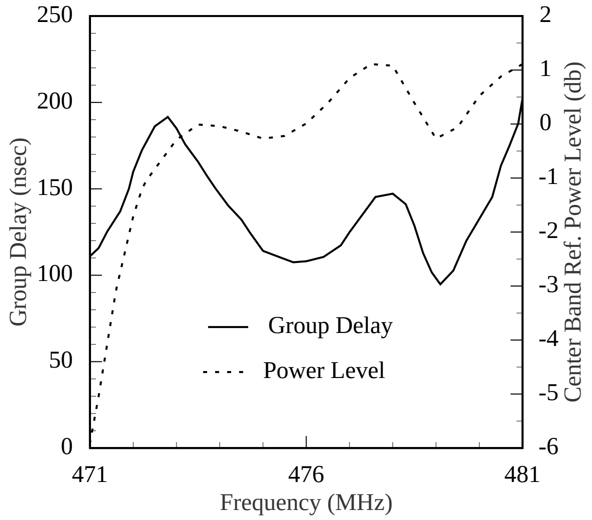

Figure 4. Measured group delay and output level versus frequency at 82.2 kV, 24.0 A

5 ACKNOWLEDGMENTS

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