DEVELOPMENT OF AN 805-MHZ, 550 KW PULSED KLYSTRON FOR THE SPALLATION NEUTRON SOURCE*

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Abstract

The Spallation Neutron Source (SNS) is an accelerator-based neutron source being built in Oak Ridge, Tennessee, by the U.S. Department of Energy. The SNS will provide the most intense pulsed neutron beams in the world for scientific research and industrial development. CPI is supporting the effort by providing 550 kW pulsed klystrons for the super-conducting portion of the accelerator. The primary output power requirements are 550 kW peak, 49.5 kW average at 805 MHz, with an electron beam-to-rf conversion efficiency of 65% and an rf gain of 50 dB. A total of 73 units are on order. Through April 2003, eighteen units have been factory-tested. Performance specifications, computer model predictions, and operating results will be presented.

INTRODUCTION

CPI, formerly the of the Electron Device Group of Varian Associates, has a long history of building high-power pulsed UHF klystrons for many applications. This 550 kW pulsed klystron will be used in the Superconducting linac of SNS. Up to 12 klystrons will be powered from a single power supply. Since the klystrons do not have a modulating anode, the cathode voltage will determine the beam current. The system must accommodate variation in klystron perveance as well as end of life operation. The result is the klystron with the highest cathode voltage requirement will determine the operating level of the entire group of klystrons.

Although the peak and average rf power requirements are fairly modest, the combination of high efficiency (65%) and high gain (50 dB) provided quite a challenge. The additional constraint on beam operation and microperveance limited design options.

A total of 73 of the 550-kW tube, VKP-8291A, have been ordered. The prototype unit had low efficiency, but all subsequent tubes have met all the specification requirements. Through April 2003, a total of eighteen units have been factory tested. The contractual delivery rate is 2 per month with the 73rd unit being delivered in December 2004.

DESIGN

Electrical Design

The electron gun design is primarily performed using XGUN, starting with the electrostatic beam optics. Once the performance is satisfactory, the design is refined with magnetic field is applied. Care is taken to evaluate and minimize the beam scallop down the drift tunnel. Analyses are performed at various operating conditions. The voltage gradients of the gun electrodes are analyzed with a goal of a maximum gradient of 60 kV/cm for this long pulse device. Great care is taken to ensure a well-behaved beam is obtained. The peak cathode loading is 0.6 Amps/cm2, which yields a predicted cathode life in excess of 100,000 hours.

Figure 1: VKP-8291A Klystron

The baseline for the electrical design was our 700 MHz, 1 MW CW klystron built for the APT project at LANL, which also had to meet a 65% efficiency requirement. The rf-circuit contains six cavities, including one tuned slightly below the second harmonic of the operating frequency. The design is optimized to provide the required efficiency and gain without compromising bandwidth. The first two cavities are staggered around the operating frequency to provide the bandwidth. Next is the second-harmonic cavity followed by two inductively tuned cavities to optimize the electron bunching. The output cavity then extracts energy from the beam.

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The rf-circuit is designed using 1-D and 2-D particle-in-cell codes developed at CPI. Many years of benchmarking the codes to measured results has lead to high confidence in the results. SUPERFISH is used for cavity design, while HFSS and MAFIA are used for the output cavity and output window design.

Mechanical Design

The klystron is required to operate vertically with the gun down and is shown Figure 2. The two buncher cavities and the two inductively tuned cavities have stainless steel walls with copper endwalls, with cavities 4 and 5 copper plated to reduce resistive loss. The second harmonic and output cavities have OFE copper walls. The 550-kW tube incorporates diaphragm tuners in the cavities for adjusting the frequency.

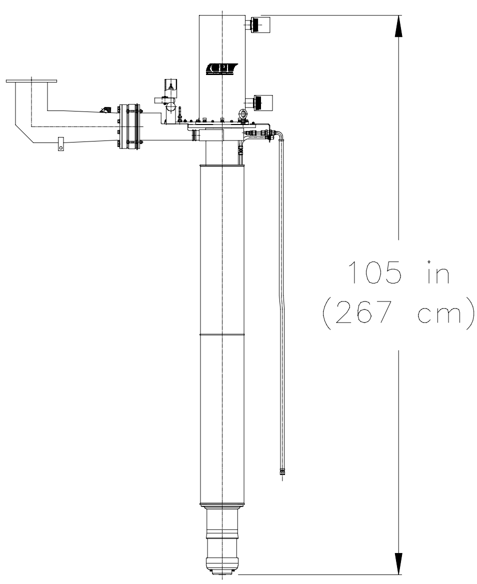

Figure 2: VKP-8291A Klystron Layout

The rf energy is extracted through a single window with an alumina ceramic. The pillbox window is designed around WR-975 wavguide.

The collector is designed to dissipate the entire beam energy. It is made from thick-walled copper with grooves milled into the outer wall for the coolant to pass. The water-jacket is part of the brazed collector assembly. The proof test pressure is 200 psi (13.6 bar).

TEST RESULTS

The prototype met all performance specifications except for the efficiency. Only 62.3% was achieved instead of 65%. The specification efficiency could be achieved when the magnet power was increased above the allowable limit. Modifications to the rf circuit were implemented to correct this deficiency. See Table 1 for the performance summary.

Table 1: VKP-8291A Performance Summary

	VKP-8291A Specification	VKP-8291A Typical
Frequency	805 MHz	805 MHz
Peak Cathode Voltage	75 ± 1.5 kV	75 kV
Peak Beam Current	11.5 Amps max	11.2 Amps
Perveance	.55 nom	.54
Peak Output Power	550 kW min	560 kW
-1 dB Bandwidth	± 1.3 MHz min	± 2 MHz
Efficiency	65 % min	67 %
RF Duty Cycle	9 %	9 %
RF Pulse Length	1.5 msec	1.5 msec
Peak RF Drive Power	5.5 Watts	4.3 Watts
Gain	50 dB min	51dB

The transfer and bandpass curves of all 18 units, along with the simulation predictions, have been plotted together for comparison as seen in Figures 3 and 4. The prototype klystron stands out as the only unit that did not meet the efficiency requirement. Otherwise the variation among the units is quite reasonable.

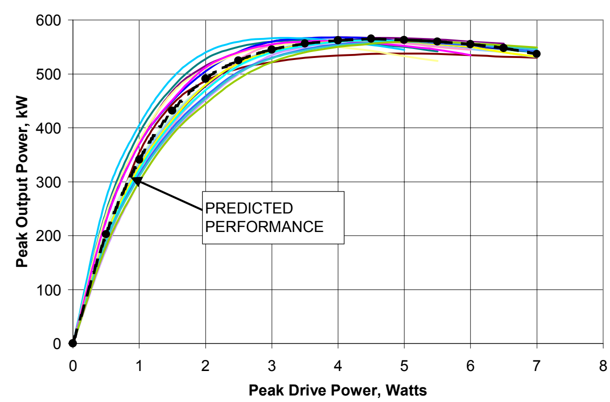

Figure 3: VKP-8291A Transfer Curves

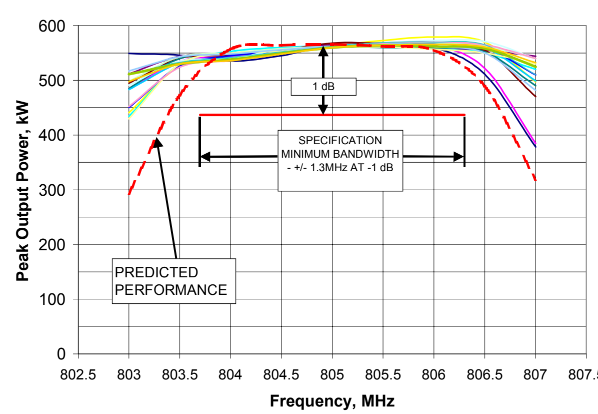

Figure 4: VKP-8291A Bandpass Curves

Each klystron has to demonstrate stable performance and achieve 80% of its rated power at six equally spaced positions of a 1.2:1 mismatch. Figure 5 plots a set of transfer curves at different mismatch positions and into a matched load for S/N 015.

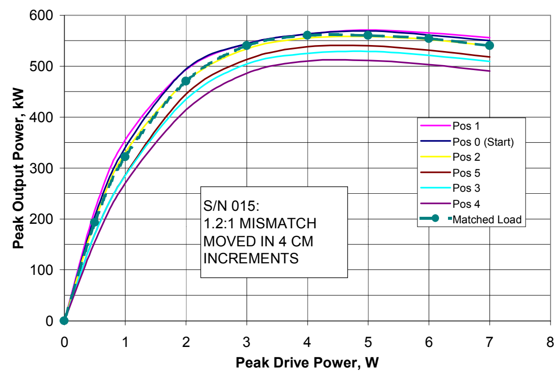

Figure 5: Performance into a 1.2:1 VSWR

The Phase Transfer Characteristic (the insertion phase of the klystron) is required to be a smoothly varying, monotonic function as the drive power is increased from 20% to 100% of the saturated drive, and is measured on each unit. Samples of the input and output power were processed through an Analog Devices AD8302 RF/IF Gain and Phase Detector. The phase detector output voltage was observed on a scope and averaged over many pulses. The phase shift was measured in 0.5 dB increments as the drive power was reduced from saturated output (0 dB) to –13.5 dB (4.5% of saturated drive).

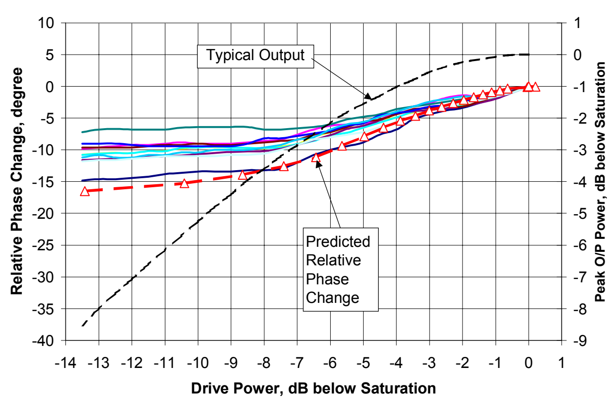

Figure 6: Relative Phase Change vs. Drive Power

The production rate to support this contract has provided an opportunity to evaluate operational and performance variation. Some of the variation is due to manufacturing tolerances, such as spacing in the gun that directly influence the microperveance, and some are due to optimizing performance at test. The gain and bandwidth are greatly influenced by the cavity tuning. We found if the gain is too high, the tube is much closer to instabilities should the magnet settings or beam voltage drift. Our goal is to set the gain just below 51 dB to provide margin.

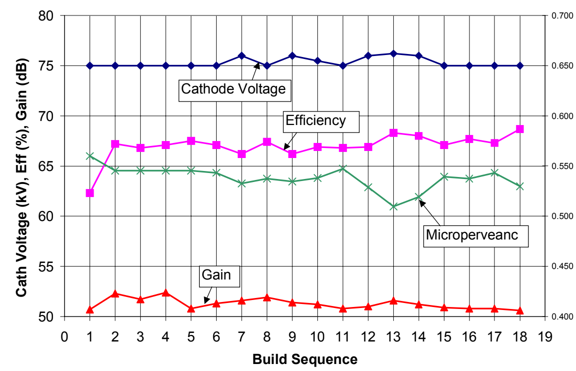

Figure 7: Summary of Performance in Build Sequence

CONCLUSIONS

The measured results instill high confidence in our simulation codes. The tube also demonstrates a high degree of stability under various operating conditions. Although the prototype 550-kW klystron did not meet the efficiency specification, all subsequent tubes have met all aspects of the specification.

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