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 has supported the effort by developing 2.5 MW and 550 kW pulsed klystrons. The 2.5 MW tube met all performance requirements, but a 5 MW version was chosen as the project evolved. Los Alamos National Laboratory (LANL) has placed an order with CPI for 65 of the 550 kW 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%. The prototype unit is schedule to be in test in July. Performance specifications, computer model predictions, and prototype operating results are presented.

1 INTRODUCTION

CPI, formerly the Electron Device Group of Varian Associates, has a long history of building high-power pulsed UHF klystrons for many applications. In the early 1970's, approximately 70 VA-862A klystrons were built for the Los Alamos Meson Physics Facility (LAMPF, now known as the Clinton P. Anderson Meson Physics Facility). These tubes were rated for 1.25 MW peak, 150 kW average at 805 MHz.

CPI was awarded the contract by LANL to build one 2.5 MW klystron, VKP-8290A, in May 1998, with the unit delivered in September 1999.

An order for 65 of the 550-kW tube, VKP-8291A, was place in February 2001. The prototype unit had a performance issue and the second unit is being assembled with modifications. The contractual delivery rate is 2 per month

2 DESIGN

2.1 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 rf-circuits contain six cavities, including one tuned slightly below the second harmonic of the operating frequency. The designs are 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.

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, coupling loop, and output window design.

2.2 Mechanical Design

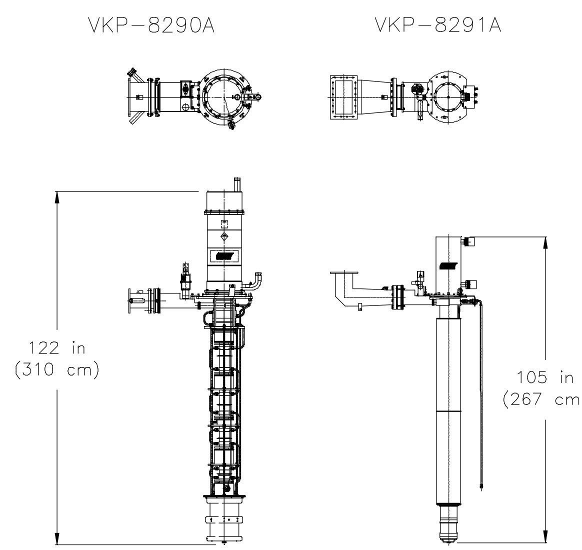

Figure 1: Comparison of SNS Klystrons

Both klystrons were required to operate in a vertically with the gun down. Figure 1 shows the tubes on the same scale. 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. All cavities on the 2.5 MW klystron, except the output, have one adjustable drift-tube tip and an adjacent flexible cavity endwall to allow for

*Work supported by US Department of Energy adjusting the tuning. The 550-kW tube incorporates diaphragm tuners in the cavities.

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

The collector for both tubes is designed to dissipate the entire beam energy. On the VKP-8290A, it is isolated from the body to allow the monitoring of body current. It is made with thick-walled OFE copper with drilled-holes for the coolant to pass. The end-cap bolts on with an o-ring seal. On the VKP-8291A, the collector 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. Both collectors were proof tested at 200 psi (13.6 bar).

Figure 2: VKP-8290A Klystron

3 TEST RESULTS

3.1 805-MHz, 2.5-MW Peak Klystron

The peak power (2.5 MW), efficiency (55%), gain (45 dB), and bandwidth (± .7 MHz) specification were all achieved. The bandpass and transfer curves can be seen in figures 3 and 4. The comparison to the predicted performance is quite close. This data was taken at a beam voltage of 113 kV and a beam current of 41.5 amperes.

Additionally the klystron had to demonstrate stable performance and achieve 85% of its rated power at six equally spaced positions of a 1.5:1 mismatch. Figure 5 plots a transfer curve at different mismatch positions.

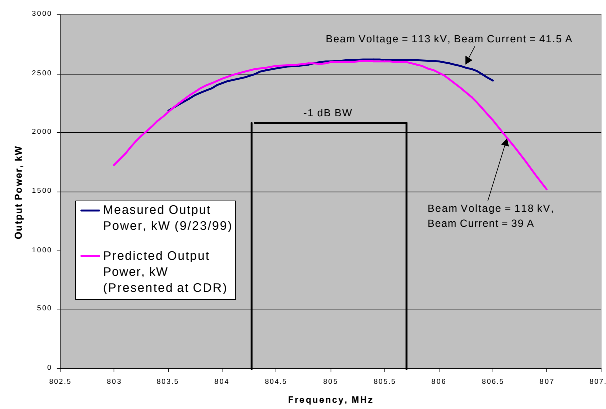

Figure 3: VKP-8290A Bandpass Curve

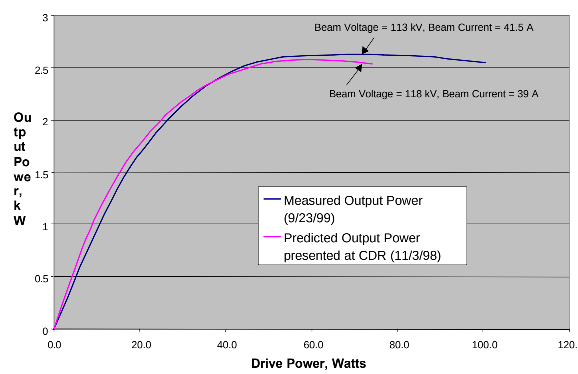

Figure 4: VKP-8290A Transfer Curve

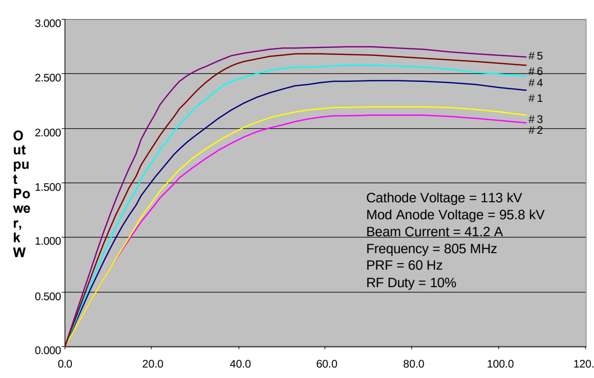

Figure 5: VKP-8290A Transfer Curves at Equally Spaced Mismatch Positions

3.2 805-MHz, 550-kW Peak Klystron

The prototype unit had a performance issue and the second unit is being assembled with modifications. The following picture shows the klystron. Figures 7 and 8 present the predicted performance of the VKP-8291A. Actual test data is expected in July.

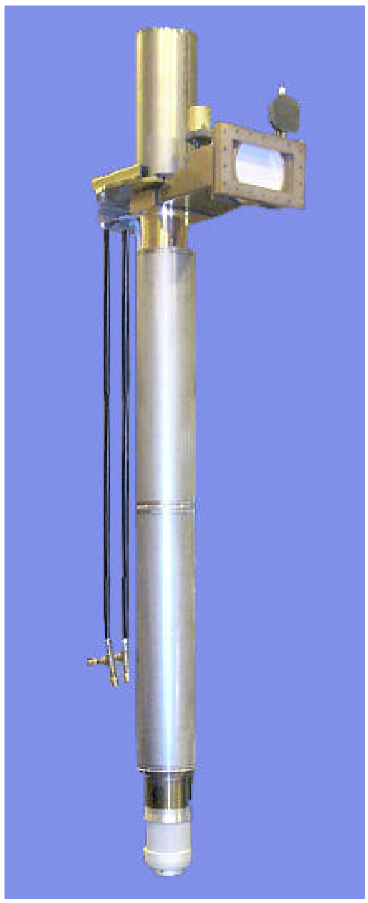

Figure 6: Prototype VKP-8291A

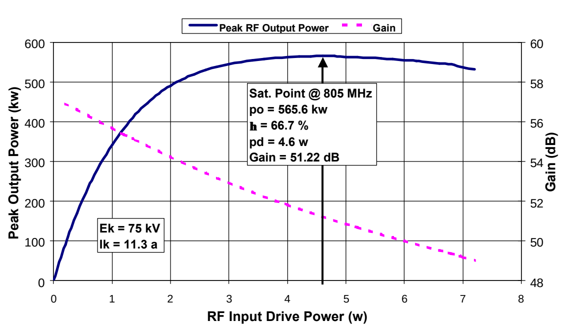

Figure 7: VKP-8291A Predicted Transfer Curve

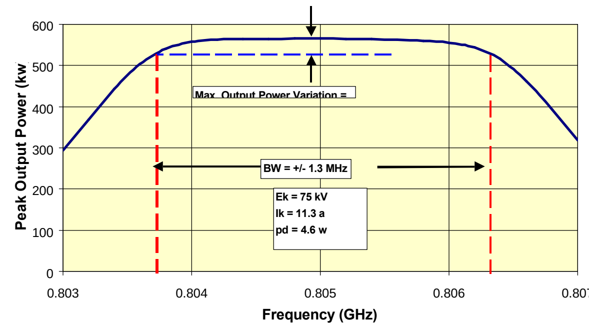

Figure 8: VKP-8291A Predicted Bandpass Curve

4 CONCLUSIONS

The measured results of the 2.5 MW klystron instill high confidence in our simulation codes. It also demonstrated a high degree of stability under various operating conditions. Although a minor set-back was experienced on the prototype 550-kW klystron, all aspects of the specification are expected to be met.

	VKP-8290A Measured	VKP-8291A Specification
Frequency	805 MHz	805 MHz
Peak Cathode Voltage	113 kV	75 kV
Peak Mod Anode Voltage	95.8 kV	N/A
Peak Beam Current	41.5 Amps	11.3 Amps
Perveance	1.1	.55
Peak Output Power	2,605 kW	550 kW
Efficiency	55.5 %	> 65 %
RF Duty Cycle	10 %	9 %
RF Pulse Length	1.67 msec	1.5 msec
Peak Drive Power	67 Watts	5.5 Watts
Gain	45.9 dB	> 50 dB

Table 1: Performance Comparison

5 ACKNOWLEDGEMENT

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