STATUS OF THE 805-MHZ PULSED KLYSTRONS FOR THE SPALLATION NEUTRON SOURCE

S. Lenci, E. Eisen, CPI, Palo Alto, CA, 94303, USA
M. McCarthy, ORNL, Oak Ridge, TN, 37831, U.S.A.

Abstract

Communications and Power Industries, Inc (CPI) produced 81 klystrons for the Spallation Neutron Source at Oak Ridge National Laboratory [1]. The klystrons are rated for 550 kW peak, 50 kW average at 805 MHz. Seventy units have accumulated 1.3M hours of filament operation and 1.0M hours of high voltage operation through February 2008. A higher power 700 kW version has been developed and is now in production with 20 of the 38 unit procurement delivered through May 2008. Performance specifications, test results, production statistics, and operational status will be presented.

INTRODUCTION

CPI, formerly of the Electron Device Group of Varian Associates, has a long history of building high-power pulsed UHF klystrons for many applications. CPI first supported SNS by providing 81 pulsed klystrons, model VKP-8291A, for the super-conducting portion of the accelerator. All of the klystrons have been delivered with 70 installed. Through February 2008, the 70 klystrons have accumulated 1,306,377 filament hours 1,014,299 high voltage hours.

A higher power 700 kW version has been developed with comparable factory test results. 20 of the 38 unit order have been delivered through May 2008.

DESIGN AND TEST RESULTS

The design overview and test results of the 550 kW klystron have been previously reported [2].

The klystron performance through the production run has been very consistent. Table 1 compares the typical performance to the specification.

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

Figure 1: VKS-8291 klystron.

VKP-8291A PRODUCTION RESULTS

The production rate of 4 units per month 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 optimization 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 was to set the gain just below 51 dB to provide margin. Figure 2 displays the key performance data of the 81 units.

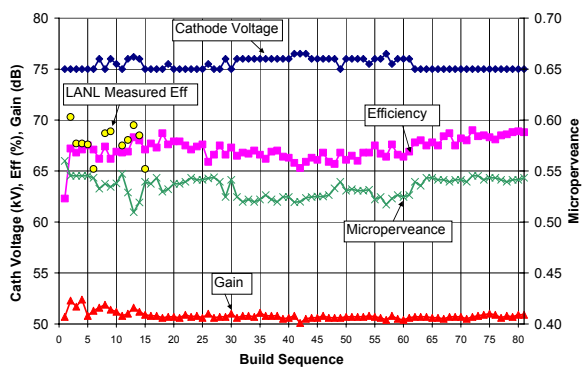

Figure 2: VKP-8291A Summary of performance in build sequence

VKP-8291A OPERATIONAL STATISITICS

VKP-8291A klystrons fill 70 sockets at SNS. Through February 2008, they have accumulated 1,306,377 filament hours and 1,014,299 high voltage hours. The average for each unit is 18,663 filament hours and 14,490 HV hours. Only one of the original 70 klystrons has been removed due to erratic ion pump readings. The hours per klystron are graphically represented in Figure 3.

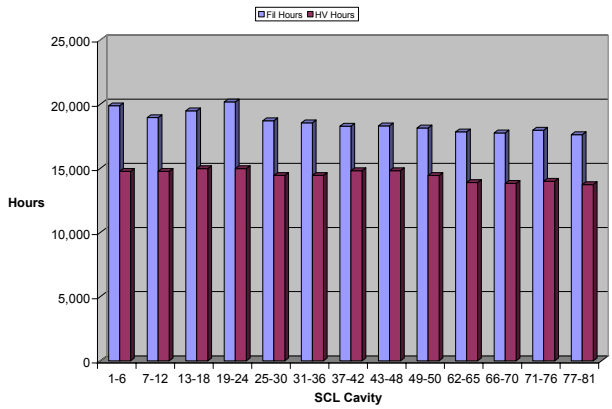

Figure 3: VKP-8291A Operating hours vs. SCL cavity number thru February 2008.

Up to 12 of these klystrons are powered from a single power supply (modulator). The klystrons do not have a modulating anode, so 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. Either 5 or 6 klystrons are operated on a single transmitter with two transmitters per modulator; these units will have the same accumulated operating hours.

Operation began in October 2006 at a pulse repetition rate (PRR) of 5 Hz. The PRR was increased to 15 Hz (December 2006), then 30 Hz (May 2007) and to the operational PRR of 60 Hz in November 2007.

HIGHER POWER CAPABILITY

The primary output power requirements for the VKP-8291A are 550 kW peak, 49.5 kW average at 805 MHz, with an electron beam-to-rf conversion efficiency of 65%. SNS wanted higher peak power klystrons for greater control margin of cryocavities that are outperforming their original design specification. It was determined that a peak power of 700 kW was needed. Analysis of the 550 kW klystron confirmed that with minimal changes, the klystron was capable of the higher power.

Testing at higher peak power levels demonstrated the VKP-8291A rf circuit is capable of 1 MW peak power operation [2]. To achieve this at the nominal 9% duty required increased cooling of the rf circuit and collector. Additional action items included optimizing the output cavity coupling and cavity tuning. The gun gradients were reviewed to ensure reliable operation at the higher beam voltage. The 700 kW version has the same mechanical interface as the 550 kW tube and fits into the same electromagnet. This commonality allows the klystron to be easily assimilated into the SNS gallery.

Table 2: Key Klystron Specification Differences

	VKP-8291A Specification	VKP-8291B Specification
Frequency	805 MHz	805 MHz
Pk Cathode Voltage	75 ± 1.5 kV	83 ± 2 kV
Peak Beam Current	11.5 Amps max	13.7 Amps max
Peak Output Power	550 kW min	700 kW
Efficiency	65 % min	65 % min
RF Duty Cycle	9 %	9 %
RF Pulse Length	1.5 msec	1.5 msec
Peak RF Drive Power	5.5 Watts max	7 Watts max

The electron gun is a diode-type gun for cathode-pulsed operation and has a dispenser-type cathode with an osmium-ruthenium coating (M-type). Its estimated operating temperature is 940°C. A predicted life expectancy has been developed for the emission using cathode life models that have been verified by accelerated life test data. The peak current loading for the VKP-8291A is 0.6 Amps/cm^2, which results in a predicted cathode life excess of 100,000 hours. The cathode loading for the VKP-8291B is .7 Amps/cm^2 resulting in essentially the same predicted life.

The VKP-8291B performance has met or exceeded all expectations. The tubes have been very well behaved and their performance has been very consistent. Figure 4 displays a typical family of transfer curves taken at a range of cathode voltages.

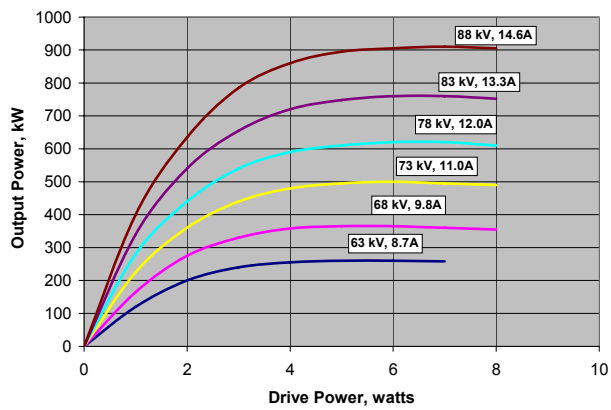

Figure 4: Typical VKP-8291B operation at various beam voltages (S/N 082)

Typical output power management of klystrons in accelerator operation is to vary the output power by adjusting the drive power, resulting in constant beam power consumption regardless of the output power. Furthermore the maximum operating level is roughly 10%

below saturation to allow for operation in the linear region of the klystron for feedback control. This results in the actual operating efficiency reduction of 10% from the maximum available. Figure 5 displays the data from the family of curves in Figure 4 as efficiency versus output power at a constant drive power of 5 watts and at a constant beam voltage of 83 kV. The increase in efficiency at lower output power levels is fairly dramatic. If operation in this manner were practical and fast enough, energy savings could be significant especially when operating a large number of devices.

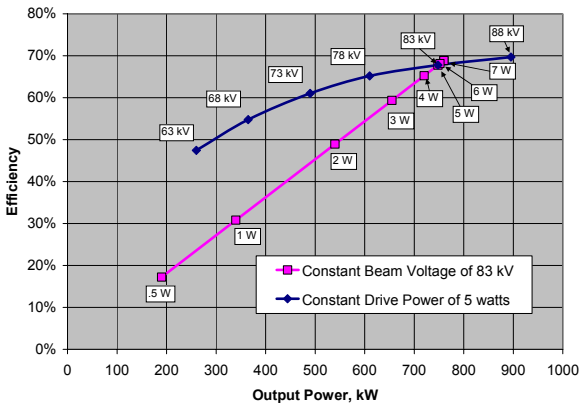

Figure 5: VKP-8291B output power vs. efficiency (S/N 082)

VKP-8291B PRODUCTION SUMMARY

Through May 2008, 20 klystrons have been tested and each met all performance specifications. Amazingly the efficiency in the factory has hovered near 70% over the first 20 units. Testing of the following 8 units will be moved to a different test position to accommodate production needs. This will provide an opportunity for internal cross-calibration. We also look forward to test results from ORNL.

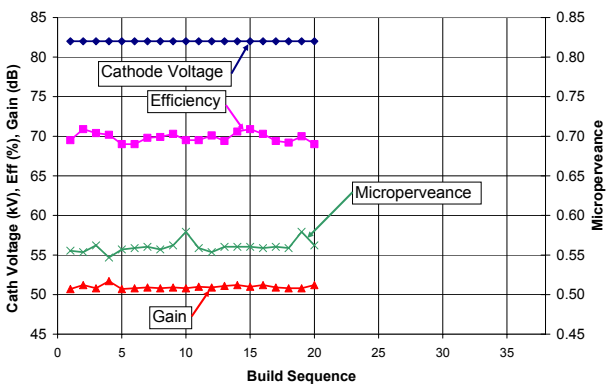

Figure 6: VKP-8291B summary of performance in build sequence.

BEAMSTICKS

In addition to the klystrons, CPI has developed a test set load, or beamstick, for SNS that allows them to test and verify changes to their klystron modulators. The beamstick consists of the VKP-8291A/B klystron gun and collector with a short drift section. No magnetic field is required. They are designed to operate at 83 kV with a beam current of ~25.5 Amps, for a perveance of 1.1 $A/V^{3/2}$. The test set load will consist of 6 beamsticks operated in parallel. When combined, the beamsticks will provide a peak current load of ~150 amps at 83 kV, which is the equivalent of 11 VKP-8291B klystrons.

Figure 7: VKW-8491A beamstick.

CONCLUSION

With the klystrons for SNS, CPI has demonstrated that our design capability and manufacturing techniques can be applied to producing large, high power klystrons at a high rate of delivery with consistent results. The 700 kW version is in production and meeting all factory test requirements. The low cathode loading of these klystrons will provide long life. The klystron reliability in the machine to date is very encouraging. Also the utilization of the klystron gun and collector into a beamstick provides a valuable test set load for the customer.

ACKNOWLEDGEMENT

The authors would like to thank their co-workers and management team at CPI for their contributions and support throughout the development and production of these products. Finally many thanks go to the technical contacts at the supporting labs, in particular Dan Rees at Los Alamos National Lab, Mike McCarthy (klystrons) and Ken Rust (beamsticks) at Oak Ridge National Lab.

REFERENCES

[1] http://neutrons.ornl.gov/

[2] S. Lenci, E. Eisen, "Large Scale Production of An 805-MHz, 550 kW Pulsed Klystron For The Spallation Neutron Source," PAC'05, Paper WPAT032, p. 2230.