RECENT PROGRESS IN CW KLYSTRONS AT CPI

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Abstract

The need for super-power klystrons for particle accelerators has been growing in recent years. The key requirements for these devices are high efficiency and reliability. CPI has delivered to three different applications around the world: 700-MHz, 1-MW-CW klystron for the Accelerator Production of Tritium (APT) project at Los Alamos National Laboratory (LANL), 499.76 MHz, 800-kW-CW for the Cornell Electron Storage Ring (horizontal orientation), and 499.67 MHz, 800-kW-CW klystron for HERA at Deutsches Elektronen-Synchrotron (DESY) (vertical orientation). Among the many-shared features on the super-power tubes are a six-cavity rf circuit (with one cavity tuned slightly below the second harmonic of the operating frequency), a single output window, and a modulating anode in the electron gun. The second-harmonic cavity is used to enhance efficiency. Computer predictions, performance specifications and operating results will be presented.

1 INTRODUCTION

CPI, formerly the Electron Device Group of Varian Associates, has a long history of building high-power UHF klystrons for many applications. In the early 1990's CPI worked with Stanford Linear Accelerator Center (SLAC) under a Cooperative Research and Development Agreement (CRADA) to develop a 476-MHz, 1.2 MW CW source for the B-Factory [1]. CPI provided the electrical designs of the electron gun and rf circuit while SLAC led the effort on the mechanical design.

CPI was awarded its first contract to build a super-power klystron in late 1995 by LANL for the 700-MHz, 1-MW-CW klystron for the APT Project. Shortly after that orders were placed by both Cornell University and DESY for 500-MHz, 800-kW CW klystrons.

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 beam optics are refined with magnetic field applied. Care is taken to evaluate and minimize the beam scallop down the drift tunnel. Analyses are performed at various operating conditions. Figure 1 provides an example of the beam optics analysis of the VKP-7952A klystron at various mod anode voltages. The voltage gradients of the gun electrodes are analyzed with a goal of a maximum gradient of 60 kV/cm. Great care is taken to ensure a well-behaved beam is obtained.

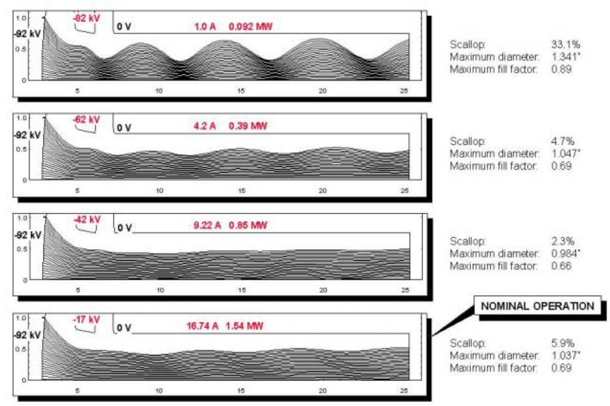

Figure 1: Example of Beam Optics Analysis

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

The 700-MHz klystron was required to operate in a horizontal orientation. The approach was to design the klystron with sufficient mechanical integrity so that it could be loaded into the magnet horizontally. The rf-cavities are supported by six support rods that run from the base of the input cavity to the base of the collector. Each cavity has a support plate that was captured by the rods. A pivoting mechanism is placed at the collector base plate, which was very near the tube center of gravity, so the tube could be rotated from vertical to horizontal.

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, except the output, have one adjustable drift-tube tip and an adjacent flexible cavity endwall to allow for adjusting the tuning. The rf energy is extracted through a single coaxial window. The transition to waveguide is made through a T-Bar transition.

The collector is designed to dissipate the entire dc beam energy. It is made from thick-walled copper with grooves milled into the outer wall for the coolant to pass. The water-jacket bolts on with an o-ring seal and was proof tested at 200 psi (13.6 bar).

After bake-out, the gun high voltage insulators are high-potted. Once some preliminary hardware is assembled, the tube is loaded into the electromagnet. It is then processed and tested. Once completed, the tube is shipped in the electromagnet to the customer. Minimal effort is required at the site for installation. The tube/electromagnet assembly is put in place and the appropriate electrical, cooling and mechanical connections are made.

Figure 2: VKP-7952A Klystron for APT

The 700-MHz APT klystron and the 500-MHz Cornell tube were both designed for horizontal operation and had the described mechanical design. The tube for DESY operates vertically with the gun up and did not need a full power collector. The electron gun was to operate in air. The tube was shipped in the magnet horizontally and was then tipped to a vertical position at the customer site during installation.

3 TEST RESULTS

3.1 700-MHz, 1-MW CW Klystron

The basic power, efficiency, gain, and bandwidth all met the specification. The bandpass and transfer curves can be seen in figures 3 and 4 This data was taken at a beam voltage of 92 kV and a beam current of 16.7 amperes.

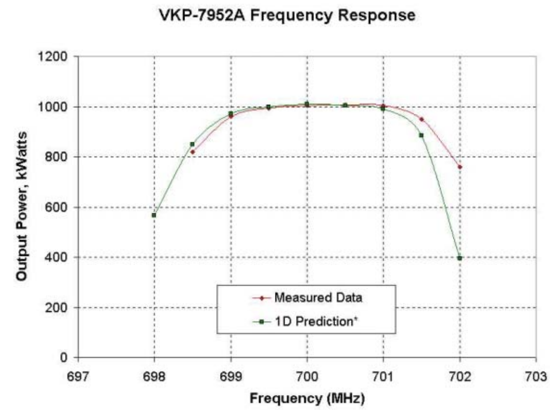

Figure 3: VKP-7952A Bandpass Curve

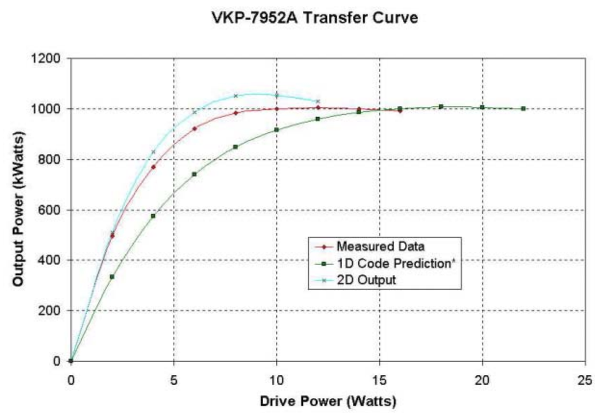

Figure 4: VKP-7952A Transfer Curve

Additionally the klystron had to demonstrate stable performance and achieve 85% of its rated power at six equally spaced positions of a 1.2:1 mismatch. Figure 5 plots the output power, body power, and mod anode current as a function of mismatch position.

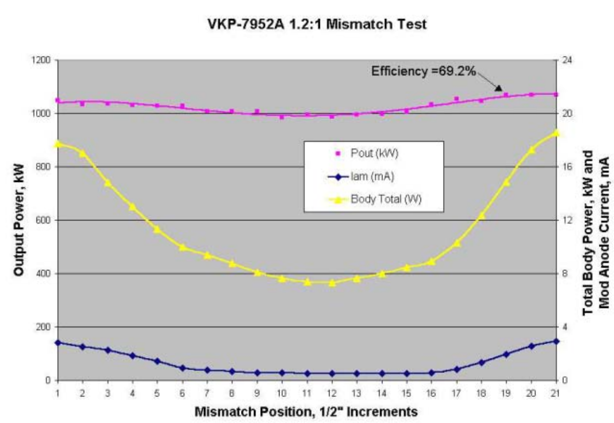

Figure 5: VKP-7952A Performance into 1.2:1 VSWR

3.2 500-MHz, 800 kW CW Klystrons

On the 500-MHz klystron for Cornell University (VKP-7957A), two family of transfer curves were taken. The goal was to characterize the gain at various beam operation. The first plots output power versus drive power at a constant beam voltage of 76 kV. The beam current is adjusted by varying the mod anode voltage. The gain clearly decreases at the lower beam powers as seen in Figure 6. However if the beam impedance is kept constant, the gain at saturation is fairly constant at lower beam powers. Figure 7 shows the various transfer curves at constant beam impedance.

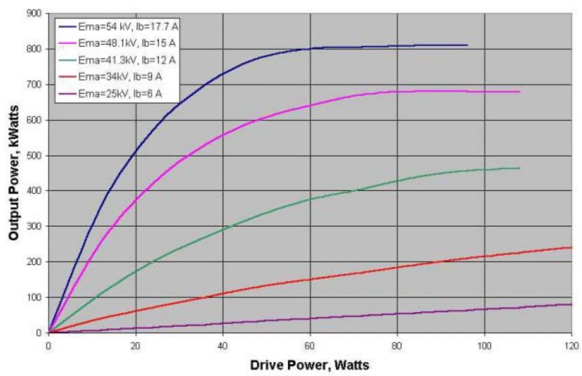

Figure 6: VKP-7957A Transfer Curves at Constant Beam Voltage

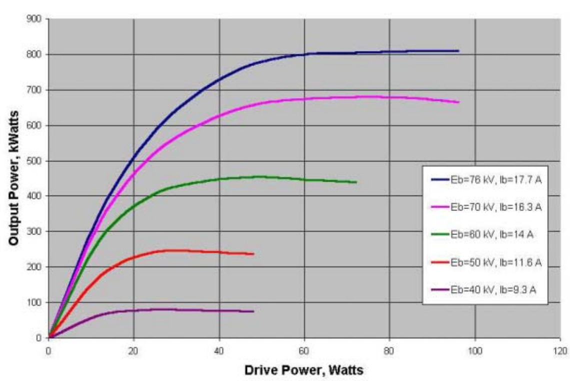

Figure 7: VKP-7957A Transfer Curves at Constant Beam Impedance

Table 1 summarizes the key measured data on the 3 different super-power klystrons developed by CPI. The specification requirements were met in all three cases. Even at high efficiency, each tube performed without a hint of instability under various operating conditions.

	VKP-7952A	VKP-7957A		VKP-7958A	
Frequency, MHz	700	499.76		499.67	
Cathode Voltage, kV	92	76	63	74	62
Mod Anode Voltage, kV	75.5	54	52.7	56.5	56.3
Beam Current, Amps	16.8	17.7	17	18	17
Output Power, kW	1,020	822	608	826	611
Efficiency	66%	61%	57%	62%	58%
Drive Power, watts	51	70	36	18	8.2
Gain, dB	43	40.7	42.3	46.6	48.7

Table 1: Measured Data of Super Power Klystrons

4 CONCLUSION

CPI has reinvented its methodology for the electrical and mechanical design of high-power and super-power klystrons for scientific applications. The measured results, especially the high degree of stability under various operating and mismatch conditions, instill high confidence in our computer simulations. A mode of producing the large klystrons is in place.

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- Michael Ebert – DESY
- Roger Kaplan – Cornell University

6 REFERENCES

[1] W. R. Fowlkes et al., “1.2 MW Klystron for the Asymmetric Storage Ring B Factory”, SLAC-PUB-6778