Development and Production of a 201 MHz, 5.0 MW Peak Power Klystron

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Abstract: *Communications & Power Industries LLC has designed and manufactured the VKP-8201A, a high peak power, high gain, VHF band klystron. The klystron operates at 201.25 MHz, with 5.0 MW peak output power, 34 kW average output power, and a gain of 36 dB. The klystron is designed to operate between 1.0 MW and 4.5 MW in the linear range of the transfer curve. The klystron utilizes a unique magnetic field which enables the use of a proven electron gun design with a larger electron beam requirement. Experimental and predicted performance data are compared.*

Keywords: klystron; UHF; VHF

Figure 1. VKP-8201A Klystron, 210" x 80" x 50"

Introduction

In an effort to meet the targets for proton beam delivery to current and near term Fermilab programs, the Fermilab Proton Improvement Plan (PIP) was developed to address the necessary hardware modifications to the proton source machines (Injector, Linac, and Booster) while maintaining acceptable activation levels and ensuring viable operations of its machines. Among many tasks in this program is the High Level RF task which was formed to address a long term viability of the high power RF drive system of the DTL Linac. To support this, CPI has developed a 201.25 MHz klystron capable of producing peak saturated output power of 5.0 MW and average power of 34.0 kW. This klystron posed a unique challenge due the extremely low frequency which required a size well beyond typical manufacturing sizes. An emphasis was placed on the linearity of the transfer curve for smooth operation in a closed feedback system loop.

Design

The klystron design balanced specification requirements with the available manufacturing facilities, particularly those production tools with size constraints. The completed klystron is shown in Figure 1.

RF Circuit: The klystron utilizes a 5-cavity design with a second harmonic cavity for increased efficiency. While a 6-cavity design would have been preferable, the length of the klystron was limited by both the maximum exhaust furnace size and limited floor space in the final application's site. The 1st and 2nd cavities are tuned to achieve a bandwidth of 2 MHz at -3dB power output. The efficiency goal was 49% and predicted gain was 38 dB.

The RF circuit design was completed using CPI's internal 1-D simulation code, LSCEX. After detailing the design with LSCEX, the stability of the klystron was verified by using TESLA to predict the beam interception and probability of reflected electrons [1].

Output Cavity and Coaxial Window: The design of the output cavity and window was performed in HFSS. In order to achieve the desired Q_e, a loop which spanned nearly the entire cavity was designed. Due to the large size of the loop and the relatively low average power requirements, no active cooling was included in the output loop, instead relying on conduction cooling through the cavity. The coaxial output window was oriented at 45 degrees from the beam axis and exited the cavity end wall. This oriented the output loop for the maximum area of enclosed flux while also keeping the window within the size limits of the exhaust furnace.

Electron Gun: The electron gun was designed using CPI's internal 1-D XGUN code. The decision was made to minimize the complexity and size of the electron gun as a means of reducing risk. The current density of the cathode when using a pre-existing and relatively small diameter gun was well below 1 A/cm^2 so the benefits of moving to a larger diameter gun were minimal. Additionally, the mechanical support structure and HV hold off ability had been proven on previous projects. An M-type dispenser cathode was chosen.

Magnetic Field: A unique magnetic field design was required in order to enable the use of a small cathode. The magnetic field is produced by an air-cooled solenoid. The field in the gun and entrance regions of the klystron is

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configured to create the necessary profile for proper convergence, but then to still allow the beam to expand to a larger size before passing the input cavity gap. MagNet was used for all magnetic field analysis.

Collector: The collector was designed for long life and to minimize returned electrons in the beam tunnel. The thermal fatigue stresses in the surface of the copper were checked using ANSYS Mechanical and the electron beam trajectories and secondaries were analyzed using Analyst and MICHELLE.

Mechanical Structure: Due to a limit placed on the overall weight of the klystron and the extremely large size, special attention was placed on the mechanical design. The cavities used a partially domed end wall geometry that increases strength while still allowing for gap tuning by movement of the drift tubes. The cavities are load bearing and were simulated in ANSYS to check for resistance to buckling. The overall size of the final klystron with x-ray shielding is 210”x80”x50” with a weight of approximately 10,000 pounds.

Testing Results

The klystron achieved the predicted peak and average power levels with very little processing time. The efficiency was significantly lower than predicted and thus the klystron required a higher beam voltage of 130 kV in contrast to the predicted voltage of 122 kV. Additionally the actual gain was relatively low at 36.6 dB as opposed to a predicted value of 37.8 dB. The associated drive powers were 1,200 W and 800 W, respectively. A summary of all predicted and measured parameters are shown in Table 1.

Table 1. VKP-8201A Specification performance and measured performance.

Parameter	Units	Specification	Measured
Frequency	MHz	201.25	201.25
Bandwidth (-3 dB)	MHz	2.0	2.9
Peak Power	MW	5.0	5.0
Average Power	kW	34	34
Pulse Width (RF)	μsec	450	450
PRF	Hz	15	15
Gain	dB	37.8	36.6
Efficiency	%	49	43.1
Beam Voltage	kV	121	130
Beam Current	A	84	90.0

The klystron’s transfer curve met Fermilab’s linearity requirements with a monotonically increasing slope that had no discontinuities. CPI is continuing to investigate the RF circuit design in order to determine the cause of the gain jump at about 500 watts, as seen in Figure 2, as well as to improve the gain and efficiency.

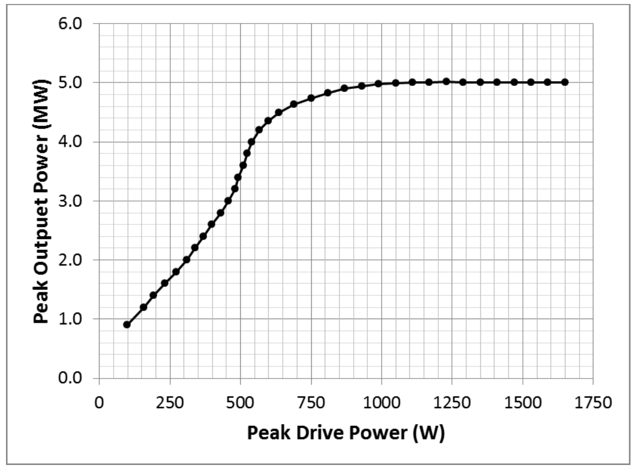

Figure 2. VKP-8201A transfer curve

The bandpass characteristics are shown in Figure 3. The klystron meets the requirement of a 2 MHz bandwidth measured at -3 dB of the saturated output power.

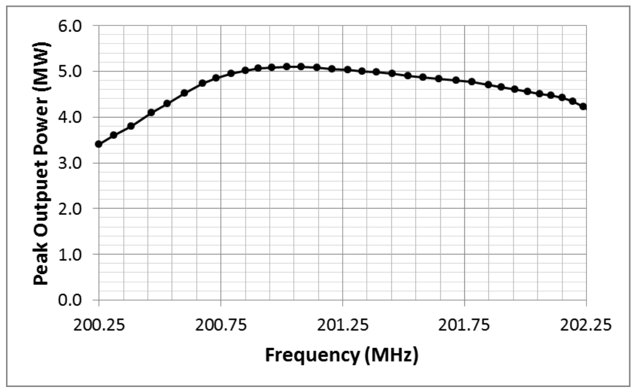

Figure 3. VKP-8201A bandpass curve

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References

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