A Pulsed Depressed Collector for a 5 MW S-Band Klystron

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***Abstract*—Design of a beam energy recovery system for application to the CPI VKS-8262S S-band klystron is presented. The multi stage pulsed depressed collector optics, mechanical and thermal design, energy recovery modulator, and experimental program will be highlighted.**

Keywords— Electon tubes, high-voltage techniques, klystrons, pulsed power systems

I. Introduction

For many RF accelerator facilities, there is substantial investment in existing high power RF power source infrastructure. However, there are programmatic as well as economic motivations for upgrading the power sources both in peak power as well as increased efficiency. The Generator for Recovering Energy from RF (GREEN-RF) program initiated in early 2015 to address the question, "How can we increase the energy efficiency of existing US Department of Energy (DOE) facilities while substantially reusing existing hardware?" There is motivation to apply the developments to both accelerator as well as broader commercial uses. Funded by the DOE Accelerator Stewardship Program, a partnership between SLAC National Accelerator Laboratory and Communications and Power Industries, LLC (CPI) is addressing these challenges.

TABLE I. Parameters for Klystrons Studied in the GREEN-RF Program.

	CPI VKS-8262S	*SLAC 5045*
RF Efficiency	45%	45%
Beam Voltage	120 kV	350 kV
Perveance	2 $\mu A/V^{3/2}$	2 $\mu A/V^{3/2}$
Average RF Power	5.7 kW	41 kW
Peak RF Power	5.5 MW	65 MW
RF pulse Width	5.8 µs	3.5 µs
Target Collector Efficiency	57%	45%

Depressed collectors are commonly used to increase the overall efficiency of RF devices [1]. Because of complications encountered at very high peak powers and the requirement that existing modulators shall be reused, we are pursuing a new approach to incorporate this technology: a feed-forward energy recovery modulator. This technique has been demonstrated on a low power tube. Efforts are currently underway to apply this technology to the 5.5 MW CPI VKS-8262S and the 65 MW SLAC 5045 (see Table I) [2, 3].

II. Energy Recovery Modulator

The GREEN-RF approach to recovering energy from a depressed collector is to add a second, small energy recovery modulator to self-bias the collector stages. This modulator recovers energy during one pulse, and resonates the energy back to the main driving modulator during the inter pulse period. In this way, the driving and recovery modulators are decoupled during the pulse [2].

Fig. 1. Photograph of an inverse Marx topology energy recovery modulator for the CPI VKS-8262S. The Marx has 5 stages and will be connected to a 4-stage depressed collector.

Collector stages must be biased at potentials approaching the beam voltage (100's kV), while typical modulators store energy between 1 and 25kV. Therefore, the "inverse Marx" was invented to convert the potentials for this application [4]. This topology is effectively a pulsed step-down converter: energy is recovered at high voltage, and resonates back to the modulator at low voltage.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics, under Contract DE-AC02-76SF00515.

An inverse Marx was designed and built for the 8262 tube, shown in Fig. 1. As discussed in the next section, a 4 stage depressed collector was designed. One feature of an n-stage inverse Marx topology is that it may bias 1 to n number of collector stages. Adding more "taps" for more collector stages is straightforward. The bias potential varies over the length of the pulse as the inverse Marx capacitors charge up. This topology is detailed further elsewhere [4].

III. Radiation and Oil Cooled Designs

High peak power, high voltage pulsed depressed collectors produce challenges not encountered in more ubiquitous applications of depressed collectors such as in TWTs and lower-voltage klystrons. During the design of the collector optics for this device, it was found that the traditional conical stage shapes did not produce substantial efficiency gains (<5%) over cylindrical-shaped stages. In the interest of a more cost-effective prototype, this cylindrical arrangement was chosen, see Fig. 2.

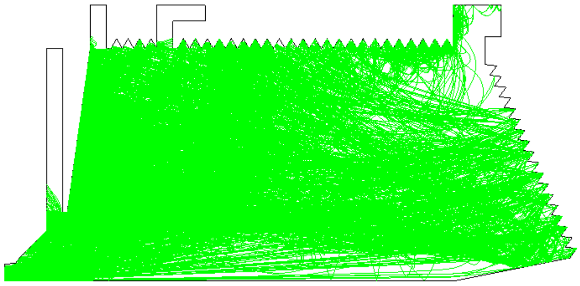

Fig. 2. Michelle simulation of spent beam and the 4 stage depressed collector.

For removing heat from the collector, two schemes are pursued. First is a "traditional" oil-cooled design. For this approach, oil flows over the outer surface of copper collectors stages. Ceramic cylinders isolate and support the stages. A grounded outer can contains the oil. The oil serves the dual purpose of cooling the stages as well as providing high voltage insulation. An advantage of this approach is that it has been successfully implemented in many prior applications. However, the large ceramic vacuum seals may present issues for some applications.

The second cooling approach that is being built is a radiation-cooled design, shown in Fig. 3. Here, ceramic rods support the stages, but the vacuum envelope is now the outer grounded metal can. The graphite collector stages radiate heat to the metal, water-cooled can. The advantage of this approach is that the vacuum seal is much simpler, a more compact design is achievable, and an oil cooling circuit is not needed. Challenges for this approach include proper handling of the large absolute temperatures and temperature gradients encountered with the collector stages.

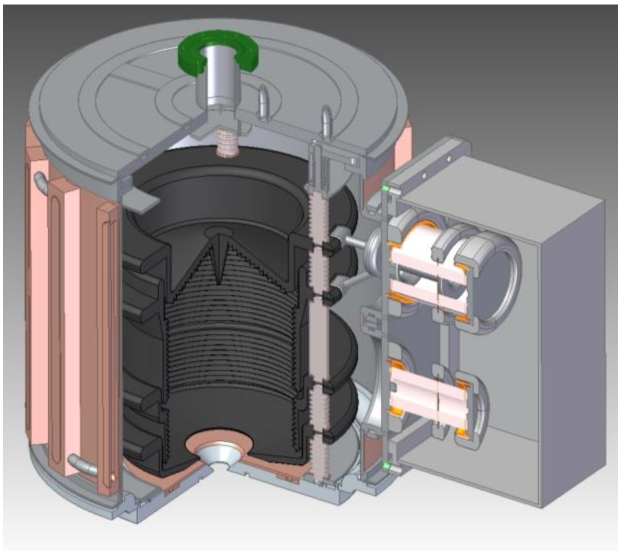

Fig. 3. Solid model of the radiation cooled collector.

IV. Experimental Demonstration and Project Status

Both versions of the depressed collectors have been finalized and are being fabricated at CPI. Delivery of the oil-cooled version to SLAC is anticipated in late Spring of 2017. At SLAC, the tubes will be tested with the SLAC-fabricated energy recovery modulator.

A follow-on study is underway to demonstrate the technology on the 65 MW SLAC 5045. Results from this design are presented elsewhere [5].

Acknowledgment

This work was supported by the Department of Energy under Contract DE-AC02-76F00515.

References

[1] Kosmahl, Henry G. "Modern multistage depressed collectors—A review." Proceedings of the IEEE 70, no. 11 (1982): 1325-1334.

[2] Kemp, Mark A., Aaron Jensen, and Jeff Neilson. "A self-biasing pulsed depressed collector." *IEEE Transactions on Electron Devices* 61, no. 6 (2014): 1824-1829.

[3] Kemp, Mark A., Aaron Jensen, and Jeff Neilson. "Experimental demonstration of a pulsed, self-biasing depressed collector." In Vacuum Electronics Conference, IEEE International, pp. 207-208. IEEE, 2014.

[4] M.A. Kemp, "Inverse Marx modulators for self-biasing klystron depressed collectors," *IEEE Electronics Letters*, vol. 50, no. 18, pp. 1294-1296, Aug. 2014.

[5] Kowalczyk R., et al. "A Depressed Collector for the 65 MW 5045 Klystron." In Vacuum Electronics Conference, IEEE International, pp. IEEE, 2017 (to be published)