ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-WEPLM53

50 kW CW MULTI-BEAM KLYSTRON*

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Abstract

This klystron has been designed to deliver 50 kW CW at 952.6 MHz and to serve as a microwave power source for ion acceleration in the Electron Ion Collider (EIC) being developed at Thomas Jefferson National Accelerator Facility. The main components of a novel klystron, which are the electron gun, cavity-chain, magnetic system, and partially-grounded depressed four-stage collector, were conceptually designed. The efficiency is 80%, a number in which the power consumption by the solenoid and filament is already factored. The tube is a combination of proven technologies: it uses multiple beams to have its perveance low to boost beam-power to RF-power efficiency. It uses a partially-grounded depressed collector to recover energy, thereby increasing the overall efficiency. A low operating voltage of 14kV makes the tube more user-friendly, avoiding need for costly modulators and oil insulation. A sectioned solenoid is used to insure superb beam-matching to all components downstream from the electron gun, increasing the tube performances.

INTRODUCTION

The tube, described above, is to serve as an efficient microwave source [1] for the Electron-Ion Collider (EIC) as developed at Thomas Jefferson National Accelerator Facility (TJNAF). The tube [2] is to operate at 952.6 MHz, producing 50kW continuously with an efficiency of 80%. We must point out that VKL7811, the present microwave source (klystron) at TJNAF, at this time can deliver only 10kW, with a low efficiency of 32% only.

The parameters of our tube are given in Table 1, and its general layout is shown in Fig. 1. As of this writing, the tube is fully developed; that is to say, all of its main components—the magnet, the gun, cavity structure, and the partially-grounded depressed four-stage collector—are designed. The simulated performances of the tube are illustrated in Fig. 2 and Fig. 3.

COMPONENT DESIGN AND PERFORMANCES

Figure 4 shows a few details of the gun and cathode geometries. The gun's total perveance is 3.26 $\mu AV^{(-3/2)}$. The cavity chain geometry is illustrated in Fig. 1. The distance between the anode and the middle plane of the gap of the first cavity is 40±2mm. The distances between the cavity gaps (the middle planes) are 88, 94, 120, 172, and 56 mm, respectively. The gap sizes are 12, 12, 10, 12, 12, and 10 mm, respectively. Figure 6 shows a geometry of the second harmonic cavity. Our Final Technical Report to the U.S. Department of Energy (DoE) describes all details and dimensions of the cavity chain (herein, we do not reveal them for the sake of certain proprietary information). The beam dynamics in the cavity chain has already been presented elsewhere [2].

Table 1: Klystron Parameters

Parameter Name	Value
Operating Frequency	952.6 MHz
Bandwidth at 3dB	4.5 MHz
Output power	54-55kW
Output style	one WR975
Input power	45W
Saturated gain	31 dB
Beam voltage	14 kV
Total beam current	5.4 A
Total beam power	75.6 kW
Number of beams	6
Overall efficiency	80%
Filament power	0.135 kW
Power for magnets	0.5 kW
Total length	1630 mm
Depressed voltage for stage 1	1.1 kV
... for stage 2	2.25 kV
... for stage 3	3.4 kV
... for stage 4	4.55 kV
Water flow for collector	60 l/min
Max. average collector power	75 kW
Peak loading of collector	125 W/cm^2
Average collector loading	<50 W/cm^2
Cathode loading	0.8 A/cm^2
Diameter of a cathode	12 mm
Beam common circle	52 mm
Diameter of drift tubes	20 mm
Peak of electric field in gun	16 kV/cm
Peak of electric field in output cavity	22 kV/cm
Max. magnetic field	400 Gs
Power recovered by collector	8.1 kW
Necessary efficiency of the HV-circuit for power recovery	93 %

* Work supported by the U.S. Department of Energy, grant #DE-SC0018471
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Figure 7 gives a sample of beam dynamics simulations; it displays the energy change when the bunched beam progresses from the last bunching cavity (penultimate) to the output cavity and further. Observe that the bunched beam loses energy efficiently—the cavity chain alone is responsible for about 70–72 % in the tube efficiency. Still, to reach 80%, additional means are required. This is accomplished by employing four-stage depressed collectors, configured as a partially-grounded collector [3] to capture the reflected and secondary electrons. Figure 8 illustrates the electron distribution before the beam enters the collector, which presents a certain challenge for an efficient depressed-driven energy recovery. However, it is still possible to recover more than 8kW while voiding any back streaming from the collector to the cavity chain. Figures 9 and 10 show the beam dynamics in the collector for some scenarios. Altogether different cases were analyzed, including cases of both the modulated and unmodulated beam, and either biased or non-biased collector stages.

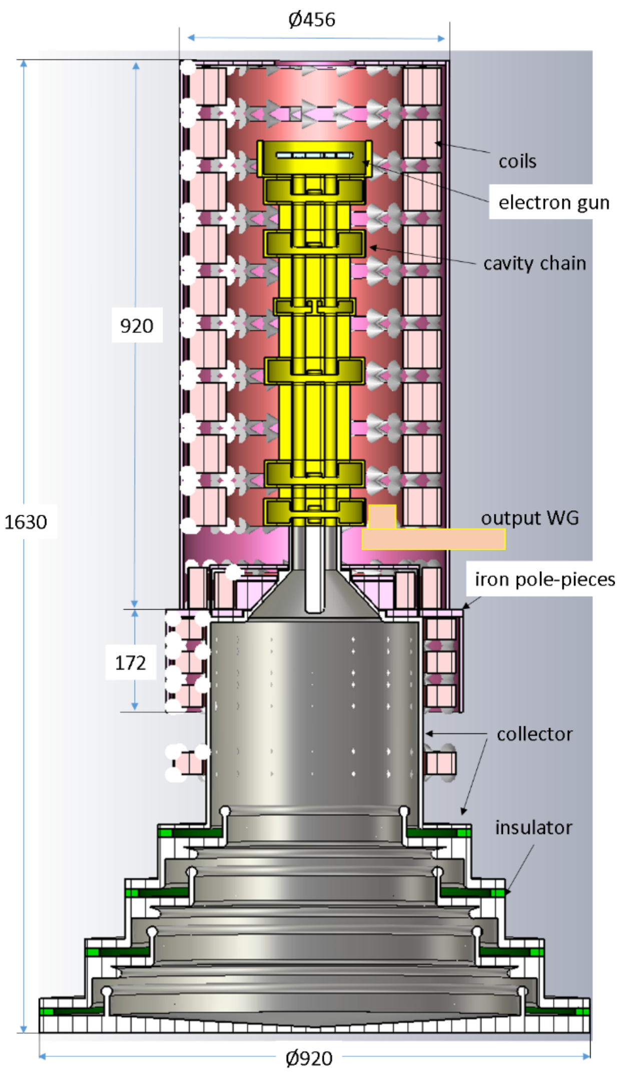

Figure 1: General layout of the developed tube. Our technical report to DoE has all dimensions, and operation parameters (e.g., current for the coils).

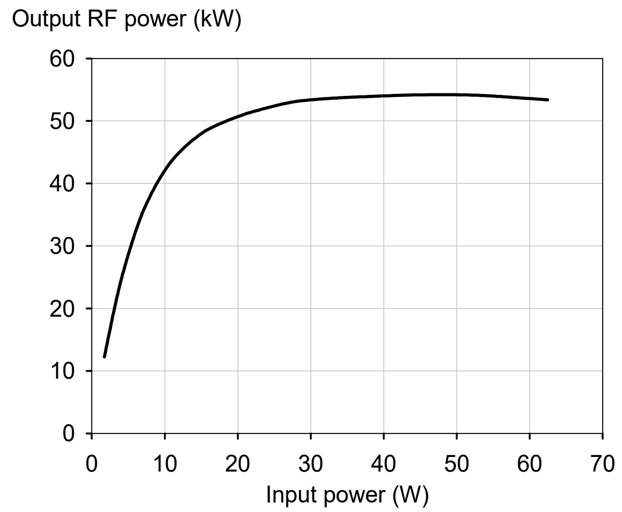

Figure 2: Transfer curve at 14 kV, when the tube is 80% efficient.

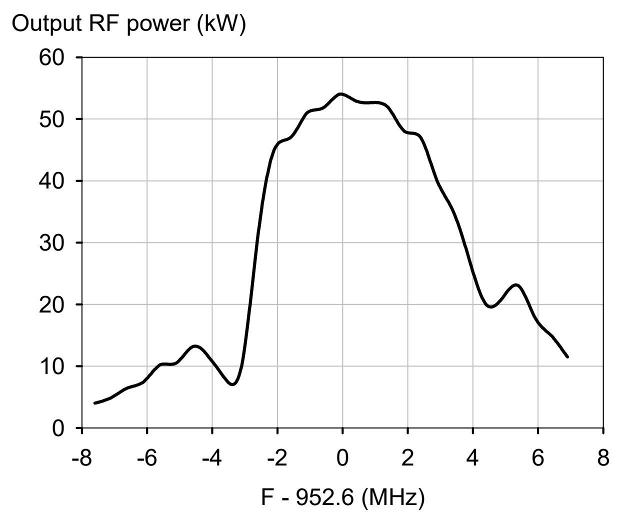

Figure 3: Tube bandwidth at 14 kV, when the tube is 80% efficient.

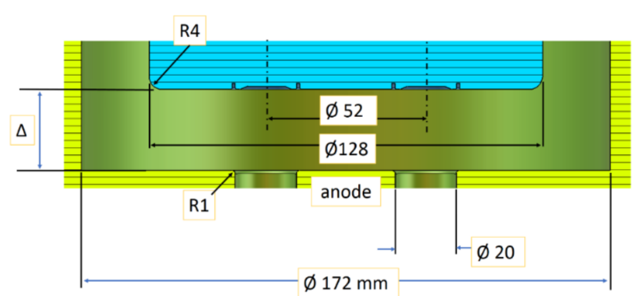

Figure 4: Cathode-anode configuration (see more details in Fig. 5). Δ = 27mm.

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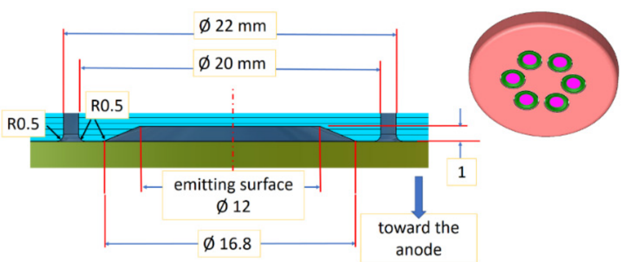

Figure 5: Emitter configuration.

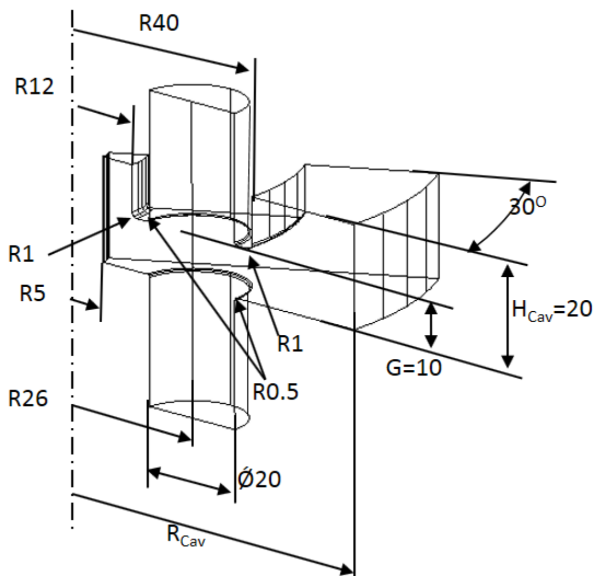

Figure 6: Geometry of the second harmonic cavity (the third cavity in the chain, counting from the gun).

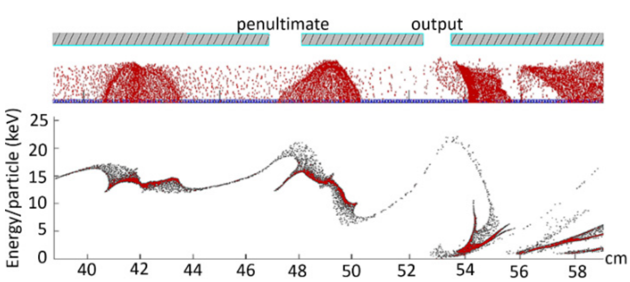

Figure 7: Bunched beam dynamics in the vicinity of the last bunching cavity (penultimate), and the output cavity.

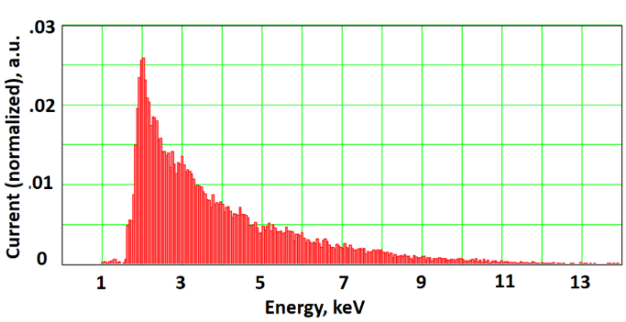

Figure 8: Beam energy-current distribution in the spent beam before the collector (normalized to 1), when the gain is at saturation.

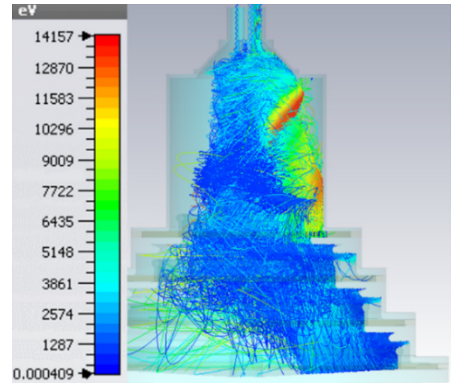

Figure 9: Beam dynamics in the collector (one beam out of six is shown for the sake of presentation clarity), when the stages are biased, and the beam is modulated. The maximum heat-flow is 55 W/cm^2.

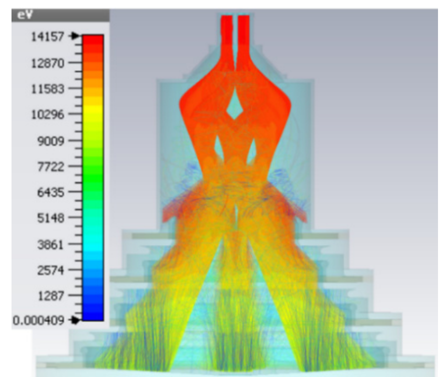

Figure 10: Beam dynamics in the collector (all beams), when the stages are biased but the beam is not modulated. The maximum heat-flow is 117 W/cm^2.

CONCLUSION

A new compact klystron was developed to work at 952.6 MHz delivering 50kW continuously with the efficiency of 80% as may be needed for future accelerator applications, (e.g., at TJNAF). The design was fully developed and reported to DoE in the framework of the SBIR/STTR program.

ACKNOWLEDGMENT

The authors are grateful to Mr. Glenn W. Stefanovics (Branford, CT) for proofreading and correcting the paper.

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[1] `https://science.energy.gov/~/media/sbir/pdf/TechnicalTopics/FY2018_Phase_1_Release_1_Topics.pdf`, and references therein.

[2] V.E. Teryaev *et al.*, "50kW CW Highly-Efficient Multi-Beam Klystron at 952 MHz for a Future Linear Collider", in *Proc. 18th Advanced Accelerator Concepts Workshop. (AAC2018)*, Breckenridge, CO, Aug. 2018, pp. 137-141. ISBN: 978-1-5386-7721-6.

[3] Y. Jiang, V.E. Teryaev, J.L. Hirshfield, "Partially Grounded Depressed Beam Collector," *IEEE Trans. Electron Devices*, vol. 62, no. 12, pp. 4265-4270, 2015. `http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7308018`