Design and Testing of a 900 kW, 140 GHz Gyrotron

Stephen Cauffman, Monica Blank, Philipp Borchard, and Kevin Felch
Communications & Power Industries, Palo Alto, CA, 94304 USA

***Abstract*—A 140 GHz gyrotron capable of producing output powers up to 900 kW for 1000-second pulses has been developed at CPI. Factory testing demonstrated 1000-second operation at the 25 A CW current limit of the test facility, at which the output power was about 500 kW, and demonstrated 900 kW operation for short pulses. The gyrotron was then shipped to Hefei, China, and installed as part of the electron cyclotron heating and current drive system for the EAST tokamak. Commissioning of the gyrotron at the EAST site is currently in progress, with the goal of demonstrating operation at full parameters (900 kW for 1000-second pulses).**

I. Introduction

THE Experimental Advanced Superconducting Tokamak (EAST) will employ an electron cyclotron resonance heating (ECRH) system which produces up to 4 MW of power, for pulse lengths up to 1000 seconds, at a frequency of 140 GHz [1]. CPI has designed, fabricated, and delivered a 900 kW, 140 GHz gyrotron for use in this system.

The design of the gyrotron is similar to a previously developed 140 GHz gyrotron that was delivered to the Wendelstein 7-X stellarator facility in Greifwald, Germany [2], but incorporates a number of design improvements, including an upgraded collector, an improved internal mode converter design, a simplified high-voltage layout, and reoptimization of the electron gun and cavity.

The single-anode magnetron injection gun was designed to produce a high-quality electron beam, with minimal perpendicular velocity spread, at accelerating voltages in the range of 80 to 85 kV and beam currents up to 50 A. The nominal design operating point is 80 kV, 45 A. The electron beam interacts with the $TE_{28,7}$ mode of a cylindrical cavity in a 5.5 T nominal magnetic field produced by a superconducting magnet with a warm bore diameter of 20.6 mm.

An internal mode converter consisting of a tapered dimpled-wall launcher and three phase correcting and focusing mirrors converts the $TE_{28,7}$ excitation mode into a Gaussian TEM_{00} output beam, which exits the gyrotron horizontally, through a low-loss, edge-cooled, CVD diamond output window.

After the cavity interaction, the electron beam propagates to a single-stage depressed collector, which employs a combination of voltage depression (25 kV nominal, 30 kV maximum), non-adiabatic beam expansion, dynamic magnetic sweeping, and water-cooled dispersion-strengthened copper alloys to safely dissipate the residual energy of the spent electron beam.

A photograph of the gyrotron and superconducting magnet, in the CPI factory test stand, is shown in Figure 1.

Fig. 1. The VGT-8141 SN2 Gyrotron is installed in the superconducting magnet in CPI's test stand. The system is pictured prior to installation of the output waveguide and load.

II. Factory Testing at CPI

Factory testing and gyrotron conditioning were carried out at CPI during the summer of 2014. For a beam accelerating voltage of 80.5 kV (with the cathode voltage 58.5 kV below ground, the body voltage 22 kV above ground, and the collector at ground), the gyrotron output power could be varied smoothly from 560 kW (for a beam current of 25 A) to 924 kW (for a beam current of 44 A) during short pulse tests, as shown in Figure 2.

During factory testing, demonstration of the 1000-second pulse capability of the gyrotron was limited to output powers of about 500 kW, because the test stand cannot operate with beam currents above 25 A for pulses longer than 5 to 10 ms.

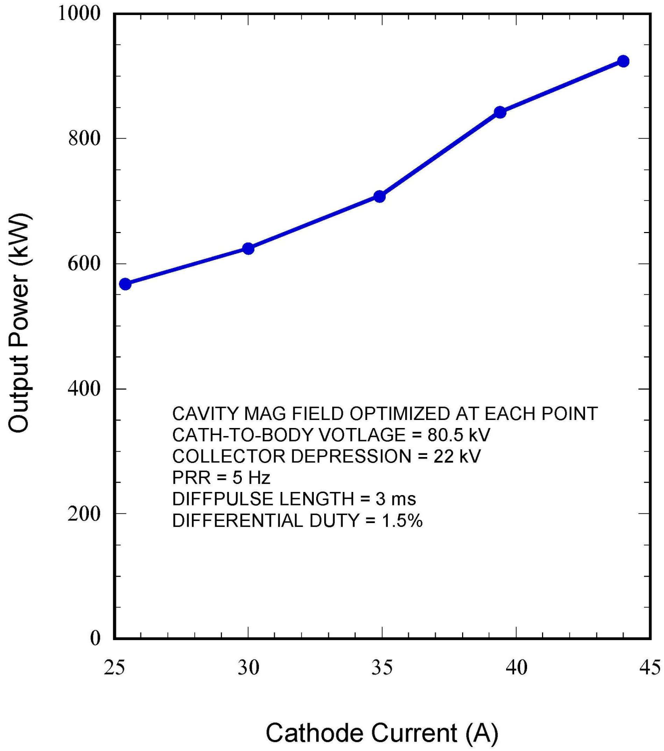

Fig. 2. Measured output power versus beam current for an accelerating voltage of 80.5 kV. The cavity magnetic field setting was re-optimized at each point.

Fig. 3. Installation of the 140 GHz VGT-8141 SN2 Gyrotron at the ECH facility for the EAST tokamak. A single-mirror "elbow" matching unit focuses the output beam onto the aperture of the facility's transmission line system.

III. Operation at the EAST Tokamak Facility

The gyrotron has been installed at the EAST tokamak facility, as shown in Figure 3. Conditioning to long-pulse operation at full power parameters has begun. Available results of such testing will be presented.

References

[1] X. Wang, et al., "Progress of high power and long pulse ECRH system in EAST," *Fusion Eng. and Design*, in press, 2015.
(doi: dx.doi.org/10.1016/j.fusengdes.2015.03.042).

[2] M. Blank, et al., "Demonstration of a High-Power Long-Pulse 140-GHz Gyrotron Oscillator," *IEEE Trans. on Plasma Sci.*, Vol 32, No. 3, pp. 867-876, June 2004. (doi: dx.doi.org/10.1109/TPS.2004.828815)