HIGH-POWER TEST RESULTS OF A 10 MW, HIGH EFFICIENCY, L-BAND MULTIPLE BEAM KLYSTRON

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Abstract

CPI has designed and produced an industrial prototype of a horizontally oriented, ≥10 MW, ≥65% efficiency multiple beam klystron (MBK) operating at 1300 MHz. The klystron, designated the VKL-8301B, was ordered by Deutsches Electronen Synchrotron (DESY) for the European X-ray Free Electron LASER (XFEL). The klystron was designed using state-of-the-art multi-dimensional design codes to ensure that all performance requirements are exceeded. Final hot test data, taken after retuning the cavity frequencies and trimming the solenoid currents for reduced beam interception, showed a peak saturated rf output power of 10.4 MW and 67.8% efficiency. The data were measured at the full 1.5% duty with 1.5 ms pulse width. The VKL-8301B prototype satisfied all required operating conditions, including operation into an output mismatch of 1.2:1 Voltage Standing Wave Ratio (VSWR) at various phases. Factory testing is completed and the prototype is expected to ship to the customer by the end of April 2009.

INTRODUCTION

Large particle accelerator projects like the XFEL, which is under construction at DESY in Hamburg (Germany) [1], or like the planned International Linear Collider (ILC) favor MBKs for their ability to generate high rf output power and efficiency at moderate electron beam energy. For the XFEL, DESY ordered a prototype of a horizontally oriented, high-power MBK operating at 1300 MHz. At 10 MW peak rf output power from two waveguide outputs, the klystron is required to provide at least 65% efficiency and more than 3 MHz instantaneous -1dB bandwidth. Average power and rf pulse length are 150 kW and 1.5 ms, respectively. This is CPI's second generation 10 MW, L-band MBK, designated the VKL-8301B. The klystron has been developed and the prototype has almost completed factory testing. This paper outlines the design and manufacturing process and reports on the test results.

DESIGN

In our design approach [2], six off-axis electron beams enable peak cathode current densities as low as 2.2 A/cm² for long cathode life, projected to be in excess of 100000 hours. Compared to our first-generation design, where higher-order-mode cylindrical cavities were used [3], we are utilizing seven ring resonators operating in the fundamental-mode. This ensures sufficient beam separation while still keeping the overall diameter of the device small in order to reduce cost.

Our in-house 1D large-signal code (LSCEX) was used to generate the initial rf design. The 2.5D code TESLA [4] enabled us to verify and refine the rf design. The code was also useful for minor adjustments in the magnetic circuit to reduce beam interception with rf. For the coaxial cavity design we utilized the commercially available 3D codes MAFIA and HFSS. The baseline beam optics design was created using our in-house 2.5D code XGun. With state-of-the-art 3D modeling software for beam transport (MICHELLE) [5] and magnetostatics (MagNet) we then validated and refined the beam optics design for good transmission of the off-axis electron beams. The simulations showed that the overall design exceeds all required performance parameters.

The VKL-8301B is going to be used in the XFEL, therefore it had to be an "industrial" version. It is

Figure 1: The vacuum envelope of the VKL-8301B prototype, serial number 002, being prepared for dress after bakeout.

horizontally mounted on a cart, which can be moved in the accelerator tunnel. The klystron features vertical adjustment as well as axial and lateral positioning on top of the cart. It also is equipped with integrated X-ray shielding.

KLYSTRON CONSTRUCTION

The parts to start building the subcomponents for the vacuum envelope were available in spring 2008. The heater-cathode assemblies provided by the vendor were running slightly less efficient than designed but still within reasonable limits. In cold test most cavity parameters were at or could be tuned to the design values, only the input and output cavity's external Q values were slightly higher than anticipated. The assembly process went relatively smoothly for a prototype klystron with this degree of complexity. The vacuum envelope was sealed in and started bakeout at the end of August 2008. Figure 1 shows a photo of the vacuum envelope after bakeout. The electromagnet was available at the beginning of November 2008. At that time the vacuum envelope was loaded into the solenoid and installed into the test set, initially for vertical testing. When the cart was available in December 2008, the klystron was set up for horizontal testing as shown in Figure 2.

TEST RESULTS

The beam transmission without rf was 99.6% at the nominal operating beam voltage. Without rf, the klystron was able to quickly process to maximum beam voltage, full duty and full pulse width.

Initial rf hot test data taken at reduced rf duty and pulse width showed a peak rf output power of 11.2 MW and

Table 1: Design parameters and measured values from the VKL-8301B prototype

Parameter	Design	Actual	Units
Peak Output Power	≥10	10.4	MW
Average Output Power	≥150	156	kW
Beam Voltage	115	118	kV
Beam Current	133	130	A
Efficiency	≥65	67.8	%
Frequency	1300	1300	MHz
-1dB Bandwidth	≥3	5.35	MHz
Gain	>46	50.1	dB
RF Pulse Duration	1.5	1.5	ms
Pulse Repetition Rate	10	10	Hz
Number of Electron Beams	6	6	- - -
Number of Cavities	7	7	- - -
Peak Cathode Loading	~2.2	- - -	A/cm²
Solenoid Power	<5500	4736	W

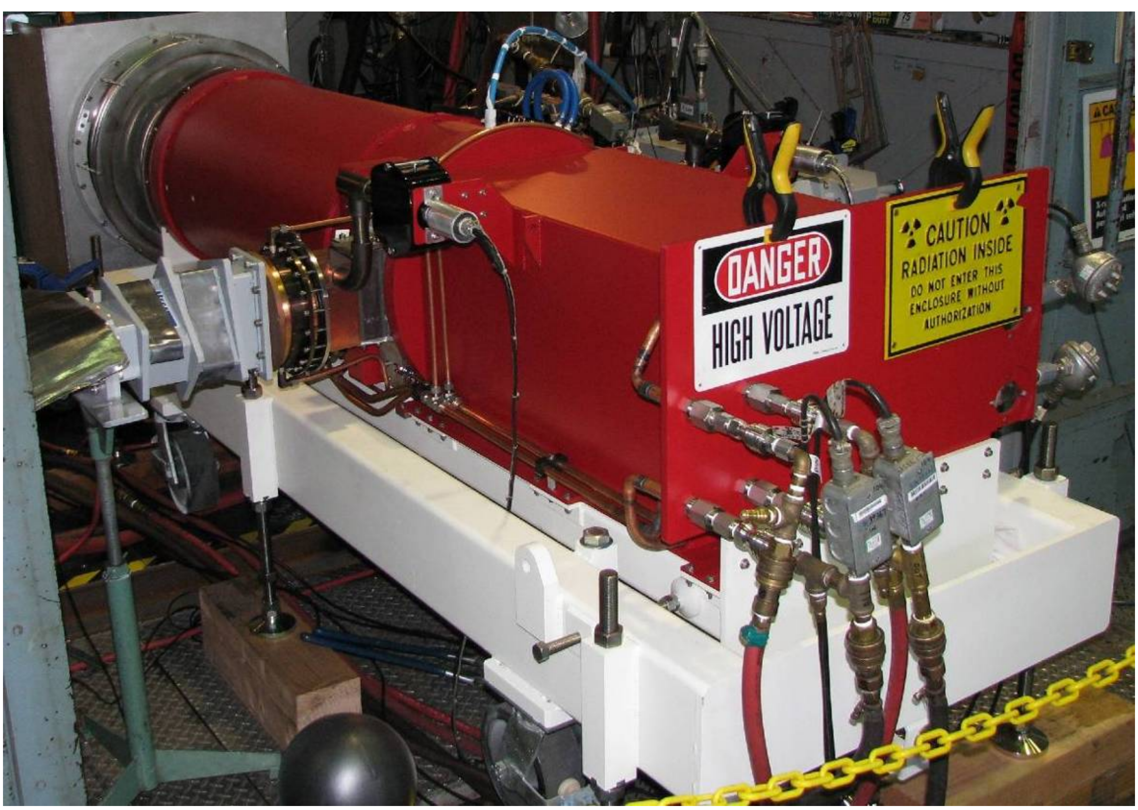

Figure 2: The VKL-8301B prototype, serial number 002, including electromagnet, X-ray shielding and cart. The photo shows the klystron during testing.

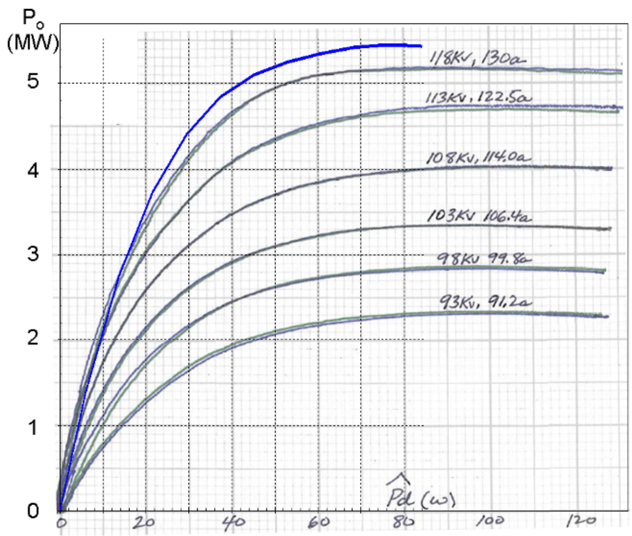

Figure 3: Transfer curves of the VKL-8301B prototype: TESLA-simulated (light blue) vs. measured (green and dark-blue for the two rf outputs at various beam voltages).

74% efficiency, which was accompanied by a fairly high electron beam interception. Retuning the cavity frequencies for a symmetric bandpass centered at 1300 MHz and optimization of the electromagnet for lower beam interception resulted in a considerable reduction of the rf body current, but also a noticeable drop in rf output power and efficiency. Design and current operating parameters are listed in Table 1. Operating into matched rf loads with the final klystron setup at 1.5% rf duty, a saturated rf output power of 10.4 MW was achieved, which corresponds to almost 68% efficiency. Figure 3 shows transfer curves measured at different beam voltages. A transfer curve simulated in TESLA is shown in comparison; however some actual electrical parameters were slightly different from what was used in the simulation. The VKL-8301B is also required to achieve at least 60% efficiency at 7 MW peak rf output. With 7.11 MW at 104 kV and 108 A beam voltage and current, respectively, an efficiency of 63.3% was achieved. Figure 4 shows bandpass curves measured at different rf drive levels in comparison with a TESLA-simulated curve. Again some actual electrical parameters were slightly different from what was used in the simulation. In order to ensure operational stability, the klystron was operated into a 1.2:1 VSWR mismatch at various phases. The VKL-8301B exhibited stable performance at all operating conditions. Consequently the klystron met all performance requirements and is expected to ship to the customer at the end of April 2009.

ACKNOWLEDGEMENTS

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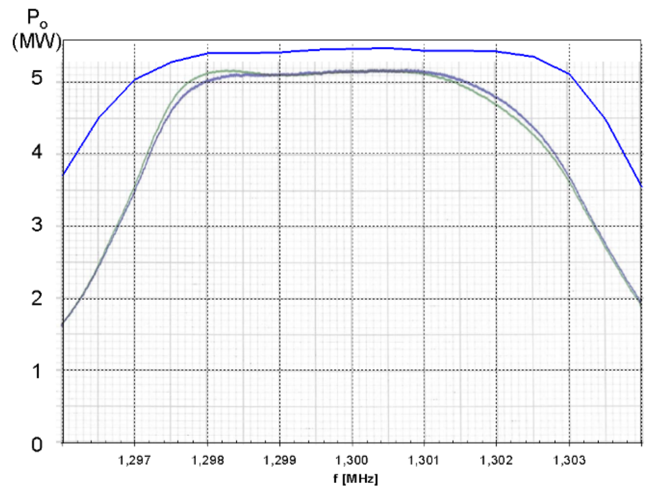

Figure 4: Bandpass of the VKL-8301B prototype: TESLA-simulated (light blue) vs. measured (green and dark-blue for the two rf outputs).

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