Recent Developments in X-band Klystrons at CETD

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Abstract: *The X-band klystrons are used as the RF power sources of the compact and high-gradient accelerators. 20-MW klystrons with the frequency of 11.4 GHz and 12 GHz were developed at CETD in 2021 and 2022, respectively. Another klystron development to increase the RF output power from 6 to 8 MW by using the high efficiency design method has been ongoing since 2018 in collaboration with CERN. Some oscillations were observed in the test of the first prototype, and mitigation measures have been developed at CERN. Designs and test results of these klystrons are presented in this report.*

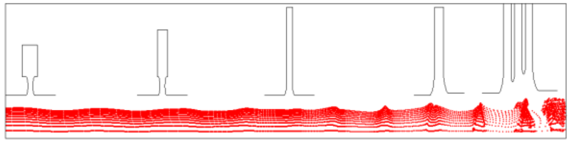
20-MW Klystrons

Introduction

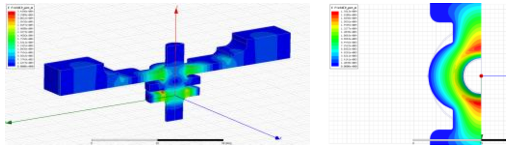
The market of the X-band klystron is expanding recently, and the output power ranged between 10 to 50 MW has been demanded. CETD developed X-band 20-MW klystrons E37116 (11.4 GHz) and E37118 (12 GHz) for industrial and scientific applications.

Design

Two types of klystrons were designed in order. The RF circuits were scaled from the existing klystron and the 3-cell output cavities operated at pi/2 mode were used to decrease the electric field strengths in both klystrons. The output power of 20 MW and the efficiency of more than 40% were obtained in FCI simulations. The dedicated electron gun and the electromagnet for these klystrons were also designed.



Electron bunching simulated by FCI



Electric field in the output cavity simulated by HFSS

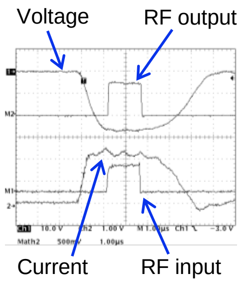
Test Results

11.4-GHz klystron E37116 was fabricated and tested at first in 2021. After the diode mode and RF mode conditionings, the output power of 20 MW was successfully obtained. The RF pulse waveform at 20-MW output was stable. 12-GHz klystron E37118 was tested in early 2022 and the almost the same performance was obtained.

Test results of 20-MW klystrons

Parameter	Unit	Spec.	E37116	E37118
Frequency	GHz	-	11424	11988.889 *
Beam voltage	kV	290 max.	270	270
Beam current	A	195 max.	183	181
RF pulse width	μs	1.5 max.	1.5	1.5
Pulse rep. rate	pps	400 max.	30	10
Output power	MW	20.0 min.	20.0	20.0
Efficiency	%	-	40.6	40.9
Drive power	W	400 max.	120	156

*This frequency was specified by the customer.



Waveforms
(Example of E37116)

20-MW klystron

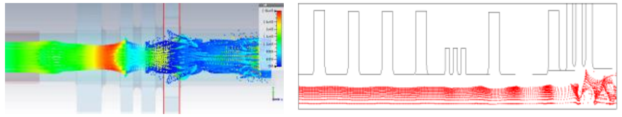
High-Efficiency 8-MW Klystron

Introduction

The high efficiency X-band klystron development in collaboration with CERN started in 2018 to increase the RF output power of the existing 6-MW klystron used for Xbox-3 test stand to 8 MW. Increasing the output power will cover the wider range of RF components tested at Xbox-3.

Design

The RF circuit design with keeping the total length has been done at CERN using KlyC and CST-3D codes and checked at CETD by FCI. The RF circuit had an input cavity, five bunching cavities, the 2nd harmonic 3-cell cavity (pi mode triplet), and the multi-cell output cavity. 8.2 MW output power and more than 56% efficiency were obtained at the voltage of 154 kV and the current of 94 A in the simulations.



Electron bunching simulated by CST (left) and FCI (right) at 8.2 MW output. CST result shows electrons at output cavity.

Test Results

The first prototype was tested in late 2021. In the diode mode operation, some oscillations were observed at far below the design voltage of 154 kV. The operational voltage without oscillations was less than 85 kV and the output power of MW level was unavailable at the voltage.

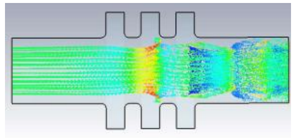
Oscillation frequencies

Voltage [kV]	Freq. [GHz]
85 - 125	22.532
107	22.016
125	21.896 21.932

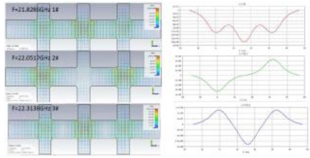
22.5 GHz instability detected at 92 kV with spectrum analyzer (left) and diode (right, circled) at klystron output

Design Modification

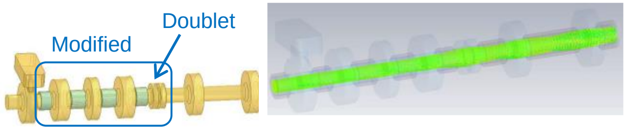
In the KlyC and CST simulations at CERN, 22.5-GHz oscillation was identified as TM01 pi/2 mode of the triplet. The triplet was substituted to the doublet (2 cells) to avoid this oscillation and unstable higher order HE modes. Oscillations at higher voltages were identified as coupled TE11 modes trapped in the first three bunching cavities. The gap lengths were modified to detune the TE11 modes in each cavity. In addition, stainless-steel drifts were used to dump them. The DC beam simulation with all the bunching cavities in CST showed no instability. The new klystron will be fabricated and tested at CETD in 2022.



DC beam instability at 92 kV by oscillation in triplet



TE11 coupled modes in three bunching cavities



Modified bunching circuit (left) and stable DC beam in CST (right)

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For questions and discussions on this poster, please send an e-mail to; toshiro.anno@etd.canon