High Power Test of an X-band Klystron in KEK

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Abstract

A brief report on the high power test of a prototype X-band klystron, XB72K#10, is given. rf power of 50 MW for 1.5 μsec pulse width with 25 Hz repetition rate was achieved. Further study was limited by the existence of self exited oscillation at 20.5GHz.

1 Introduction

Future linear collider such as JLC[1], requires a high power pulsed RF source. An X-band klystron is a possible candidate[2]. XB72K is a series of prototype X-band klystrons developed at KEK. The design work and fabrication of XB72K #10 were done in 1997[3]. The high power operation test started soon after its delivery (December 1998) and lasted till May 1999. In the present paper, we report the test of #10 klystron.

2 Design Features

We used MAGIC code, which is a general-purpose PIC code for plasma physics, as a design tool for #10 klystron. The whole of the klystron, from the gun to the output structure, is calculable by this code. Review of the location and the detune of buncher cavities of previous XB72K prototypes were done. Optimization to improve RF current brought an introduction of longer drift space and an additional idler (buncher) cavity. The total number of idler cavities of #10 is 4 (2 gain and 2 bunching cavities). Stagger tuning was employed for the bandwidth being large. The design target was 100 MHz (3dB).

Output cavity of #10 is a 4-cell $2/3\pi$ traveling wave type. The output structure was re-designed by MAGIC. Care was paid in reducing electric field strength in the output cavities to avoid rf breakdown in it under longer pulse width (1.5 μ second). Relatively low field, 77 MV/m, is the maximum field strength was realized[4]. TE11 mode in the output structure is detuned by tuning the iris of the output cavity cells. The output structure has two output ports connected to the last cell.

The basic design guideline of #10 klystron is the JLC specifications in Table 1. The designed rf power of # 10 klystron reaches 75MW at 480 kV. This voltage is nominal of our modulator and easy to achieve. Fig.1 shows the simulation result by MAGIC code on the saturated power at various operation voltages. The modulator (PFN) of the test stand for XB72K klystrons was improved to supply 1.5 μsec pulse, which meets the JLC specifications.

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Table 1
JLC specifications on the klystron.

Frequency	11.424 GHz
Power	75 MW
Voltage	550 kV
Efficiency	47 %
Gain	53 dB
Pulse Width	1.5 μsec
Repetition	120 Hz

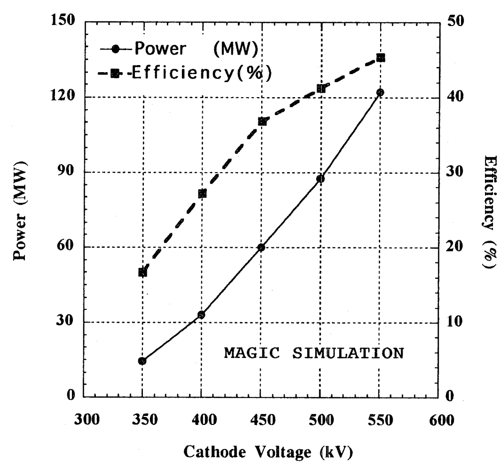

Fig. 1 Saturated power and efficiency by MAGIC. XB72K#10.

3 Measurements

3.1 Solenoid magnet

Beam focusing of #10 is by a solenoid magnet. Since #10 klystron is longer than the previous ones, the focusing solenoid magnet, which has been used for XB72K klystrons, was modified to fit #10 klystron. We put additional return yoke and the collector pole piece was moved up by 40 mm. An explicit measurement of the focusing magnetic field (on the beam axis) shows excellent reproducibility and the result agrees well to the calculation by Poisson code. See Fig.2.

3.2 RF power measuring

We installed a calorimetric measurement system as well as a crystal detector system. Each of the two rf output ports of the klystron was terminated by the ta-

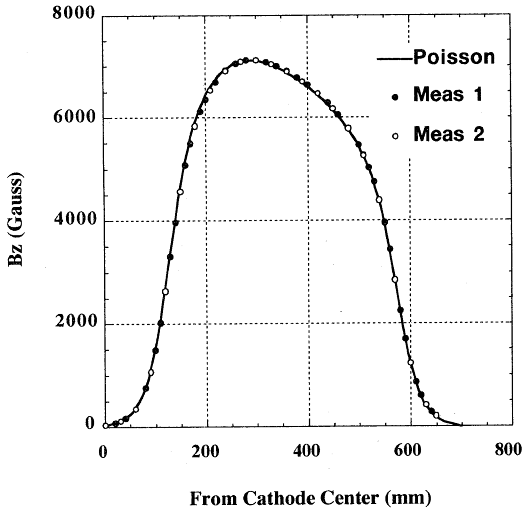

Fig. 2 Focusing field. Design and measurements.

pered SUS water load for the temperature measurement. The temperature and the flow of the cooling water were measured by a quartz thermometer and a high precision OVAL flow meter.

3.3 Perveance

All the XB72K gun, including #10, were fabricated based on the same (electrical) design. Longer pulse operation allows us to measure accurately the perveance at operation voltages. The measurement shows more than 1.3μ, which is little larger than the design value, 1.2μ. It is considered that this discrepancy comes from mainly the heat expansion of the cathode and its support.

4 High Power Test

4.1 Gun and RF Conditioning

High voltage and rf conditioning of the klystron started on Feb. 2. On Feb. 16, we achieved the rf power of 29.7 MW with 100 nsec pulse width at the cathode voltage 372 kV. The beam current was 306 Amps. The observed perveance and the efficiency were 1.35μ and 26%. The ordinary conditioning process ended up on the next day with encountering the self-excited oscillation.

4.2 Oscillation

The oscillation was firstly found at the cathode voltage, V_k, being about 370 kV. The frequency of the oscillation was 20.7 GHz. Fig. 3 is a snapshot of the scope display when the oscillation takes place. The oscillation signals were coming out from both the input port ("Pin f" in the figure) and the output port ("Output L1"). The both wave forms look very similar. The other two lines are the signal from the crystal to monitor the forward power into the input cavity ("Pin f") and CD (C-Divider) signal which measures the cathode voltage.

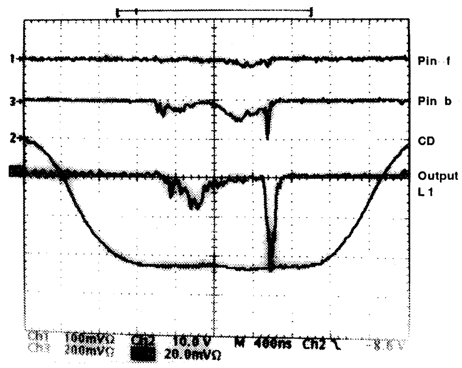

Fig. 3 Oscillation signals from the input and the output ports.

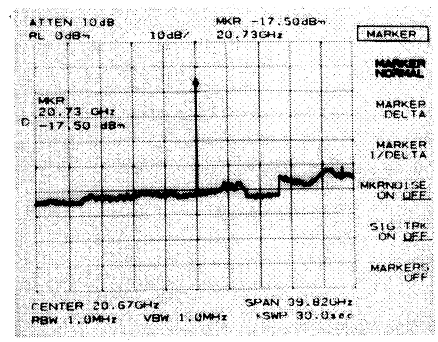

Fig. 4 Oscillation spectrum. 20.7 GHz.

A snapshot of the spectrum analyzer display is given in Fig. 4 when the oscillation signal appeared. This is the spectrum of the signal from the output port. We see 20.7 GHz only.

There was a clear threshold cathode voltage for this oscillation. The threshold voltage depends on the focusing field: stronger be the focus field, higher the threshold be. However, at $V_k = 380$ kV, the new oscillation at 20.5 GHz appeared instead of 20.7 GHz and the threshold voltage of this new oscillation does not depend on the focusing field. In Fig. 5, the plots of the observed threshold voltage vs.. current in the focusing coil is given. (Note that we have four coils in the solenoid, named A, B, C and D, from downstream to up. C and D have their own power supply while A and B are connected in a series to a single power supply. In Fig. 5, we changed AB coil current.)

With increasing V_k, the oscillation at 20.5 GHz becomes stronger and the position of the signal of the oscillation on the scope moved toward the head of the pulse. We could not find the saturation of the oscillation power by applying higher V_k. The absolute power level of these oscillations are still unknown while some attenuators for the power measurement were broken during the oscillation study. We could not accept the oscillation.

The threshold becomes high if we decrease B_c, the magnetic field on the cathode surface (design value is 40 gauss), by increasing the bucking coil current. However, we found that the gain for the operation frequency of the klystron became poor significantly at the same time. The saturated power lowered remarkably too. In conclusion, reducing B_c is effective to avoid the oscillation,

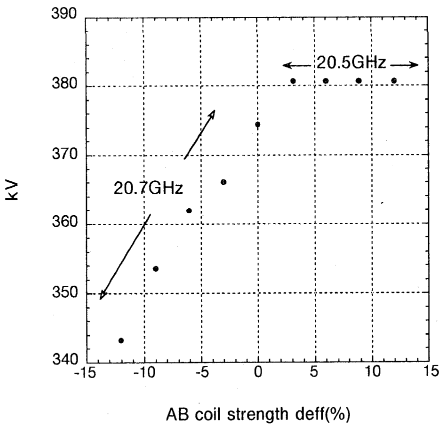

Fig. 5 Threshold voltage. Dependence on the coil current.

but not advantageous to get high rf power free from the oscillation.

Lowering the heater power was found to be effective to make threshold higher too. The beam current, I_k, or the perveance of the klystron was lowered while the gain of the klystron was not so reduced in this case. Therefore, we pursuit the best condition for obtaining high rf power by scanning the heater power. Rf modulation of the operation frequency helps a little to raise the threshold. Although the effect is small, the rf modulation violates the oscillation growth.

5 The Maximum Power

The maximum power of 50MW, for 1.5 μ second pulse width, with 25 Hz repetition rate was achieved at the cathode voltage 480 kV. The heater power was lowered in this case. The perveance was about 1.0μ. The efficiency is 31%. Fig. 6 shows the observed pulse shape of the output power. The modulator successfully produced the pulse which had 1.5 μsec (or more) pulse width at this voltage. See Fig 7. The pulse flatness was adjusted by tuning PFN within $\ll 1$ %.

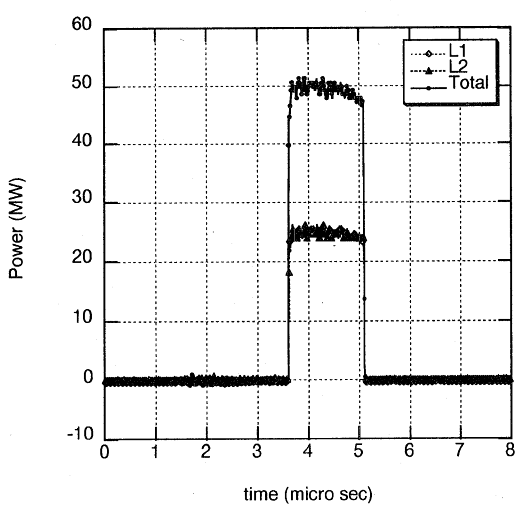

Fig. 6 Power from output port#1 (L1) and #2 (L2) and the total power.

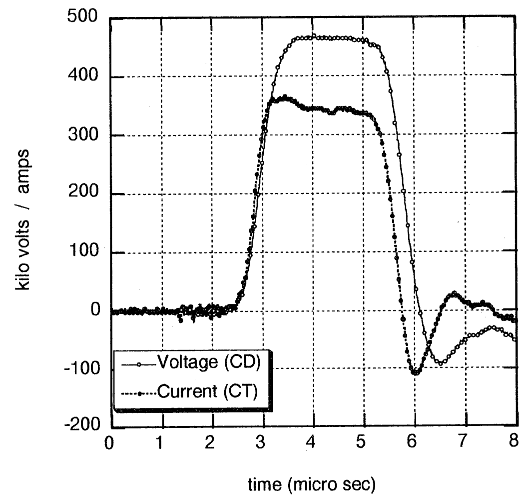

Fig. 7 Pulse waveform of the cathode voltage and current, calibrated from the output signals of CD and CT (current transformer).

6 Conclusion

The rf windows[5] installed in the output ports did not show any serious problem under the longer pulse up to 50MW 25Hz. There was no indication on the RF breakdown in the output cavity either. We need more power to test of these parts. However, the oscillation prevents us to go further and it is not easy to get more power. A suggestion was made about the short pulse operation to get rid of the oscillation. Now the discussion for further study is going on.

The longer pulse operation enables us the accurate measurement of, such as V_k, I_k or the output power than before. Calorimetric measurement can be a cross-check of the measurement of the output power by the crystal detector system. Unfortunately, quantitative comparison between simulation and experiment is not straightforward, since the klystron was operated with lower heater power.

Acknowledgment

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