FIRST OPERATING TEST OF THE 700 MHz 1 MW PROTOTYPE KLYSTRON FOR A PROTON ACCELERATOR

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The design, manufacturing process, and first operating test of a high power RF source for a proton accelerator are described. A klystron amplifier system has been developed for operation at 700 MHz, 1 MW and is composed of a triode type electron gun, six cavities, an RF output window, a beam collector, and an electromagnet. The prototype klystron was constructed and tested at a reduced duty to produce the designed output RF power.

KEYWORDS : Klystron; Accelerator; Electron gun; Cavity; RF window; Collector

1. INTRODUCTION

The main linear accelerator(linac) of the PEFP is designed to supply 100 MeV proton beams [1,2]. In the future phase the PEFP linac, above 100MeV, it will be designed and constructed with 700MHz components. In order to suitably prepare for this future phase, research and development of the 700MHz klystron has begun. This research and development is also simultaneously aimed at being able to repair the 350MHz klystrons. In the design of the klystron tube, several computer codes are incorporated to predict the performance of the tube [3]. Based on previous research and pre-prototype experiences [3,4], an overall layout was determined: the design parameters of the klystron are summarized in Table 1. The main components of the klystron tube, including the electron gun, RF cavities, collector, focusing magnet, and supporting structure, were fabricated and assembled completely.

2. METHODS

2.1 RF Interaction

The prototype is a six-cavity klystron where the third cavity is a second harmonic cavity for higher efficiency. Figure 1 shows developments of the modulated RF currents in which each line corresponds to a cavity mode. The gain and transfer characteristics were calculated using these conditions and are shown in Figures 2 and 3. To secure the specifications, the cavities were tuned to obtain higher output powers.

2.2 Electron Gun

The electron gun was a triode with a modulating anode. An M-type cathode was adopted and the gun was designed to maintain a peak cathode loading of less than $0.6A/cm^2$ and a peak electric field of less than 70kV/cm. Figure 4 shows the beam trajectories when the magnetic field on

Table 1. Specifications of the PEFP Prototype Klystron

Operating Frequency (MHz)	700
Output RF Power (kW)	1,000 (CW)
Anode Voltage (kV)	95
Modulating Anode Voltage (kV)	51
Beam Current (A)	16.6
Efficiency (%)	~ 60
Power Gain (dB)	43 (minimum)
Focusing Field (Gauss)	~250
Bandwidth (MHz)	+/ - 1.5 (-1dB)
Number of Cavities	6

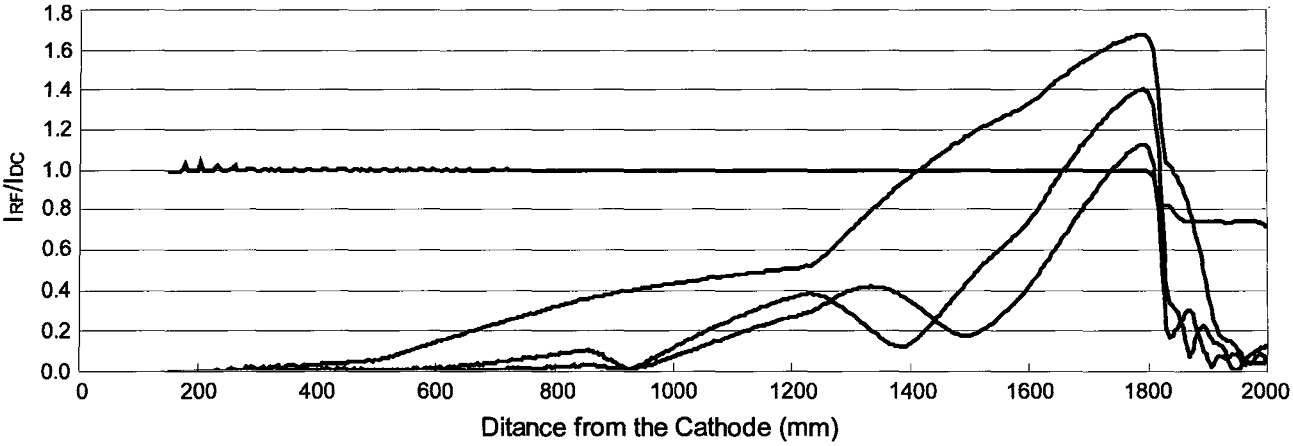

Fig. 1. Simulation of the RF Interaction. The Lines Show the Modulated RF Currents of the Corresponding Cavity Modes

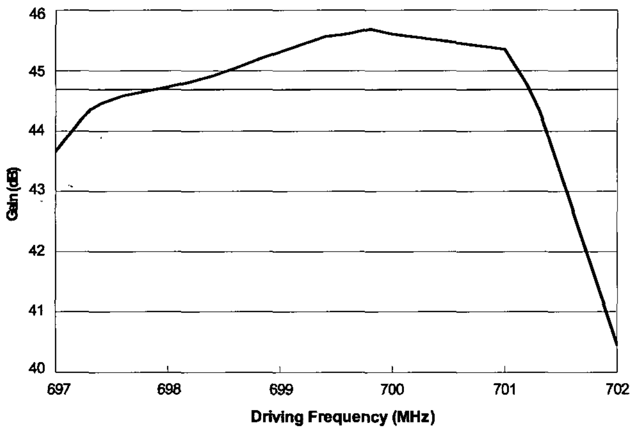

Fig. 2. RF Gain Characteristics

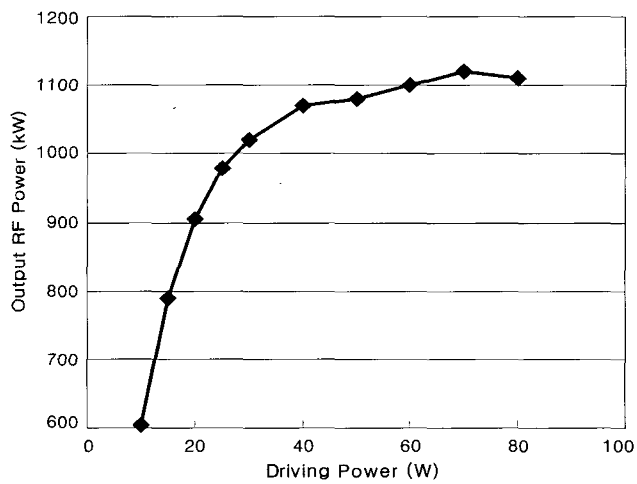

Fig. 3. Transfer Curve at Q_{ex} = 55

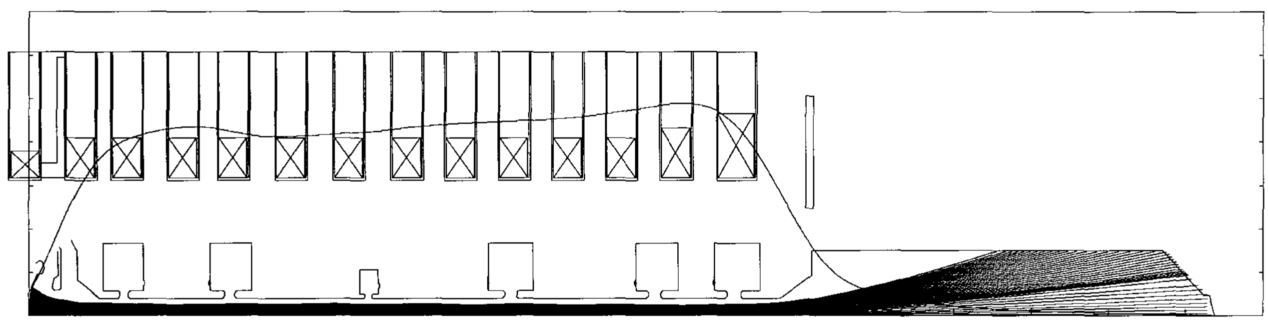

Fig. 4. Focusing Magnet and Beam Transport

the cathode surface is 31 Gauss. The magnetic field of the main drift region was 250 Gauss, 2.3 times the Brillouin value, and increased up to 300 Gauss in order to compensate for the increased space charge effects.

2.3 Output Circuit

An iris coupling scheme was chosen to extract the output power, which was incorporated into the cascade waveguide step transformer and pillbox-type RF window as seen in Figure 5. The slot size was optimized to have the requirement, according to the RF interaction simulations. The crossing area on the right side of Figure 5 corresponds to the region that satisfies this requirement. The window and step transformer were optimized together to obtain a minimum voltage standing wave ratio(VSWR) and guarantee the required bandwidth. The major specifications of the output window are summarized in Table 2.

2.4 Collector

The collector was constructed from oxygen-free high conductivity copper(OFHC). The peak power dissipation density on the collector surface was designed to have a maximum capacity of 200W/cm^2 under the nominal operating conditions.

3. FABRICATION AND PROCESSING

All parts of the klystron tube were fabricated and tested, along with the equipment for the construction and testing, to ensure that required qualities for the klystron fabrication were present. Cathode firing was performed in a high vacuum chamber of a quartz bell jar up at temperatures up to 950° C. During the firing procedure, the vacuums were maintained at less than 10^{-7} torr and the final pressure at the completion of the firing was 9×10^{-9} torr. The external Q(Q_{ex}) of the first cavity was measured at 538(the design value was 550); the tuning range of all cavities was +/ - 15 MHz and was considered adequate for the klystron tuning.

Table 2. Specifications of the Output Window

Frequency (MHz)	700
Mode	TE11
Average Power (kW)	1,000
Window Diameter (mm)	220.8
Window Thickness (mm)	7
Window Material	Alumina, >99.5 %
Peak ΔT (K)	50
Power Loss in Window (W)	100
Peak Tensile Stress (MPa)	60
Alumina Tensile Strength (MPa)	250
Safety Factor	~5

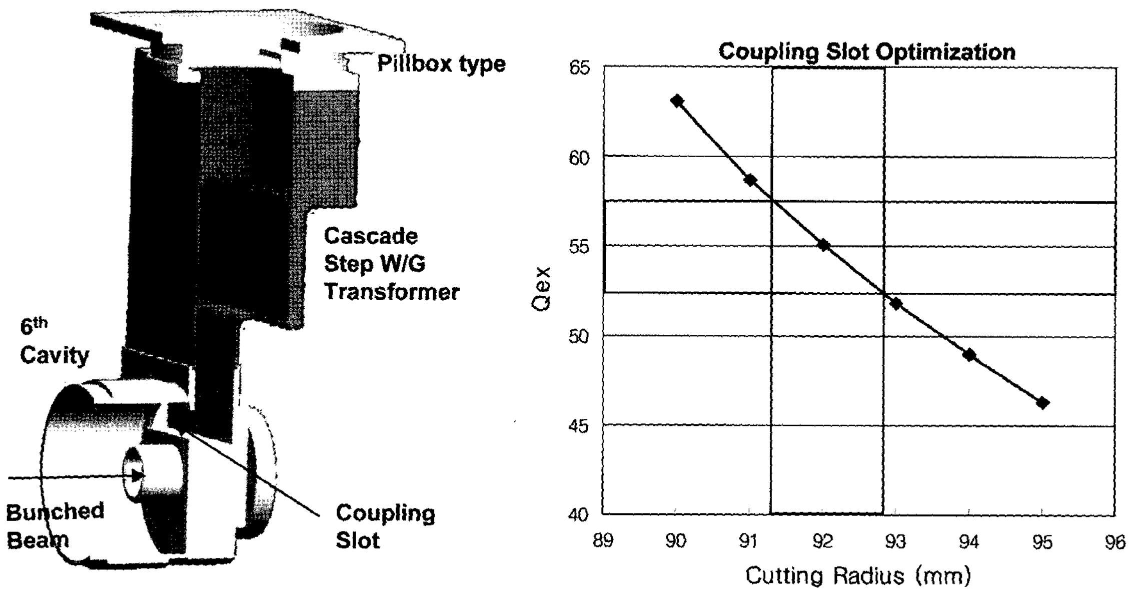

Fig. 5. Schematics of the RF Output Circuit and Dependencies of Q_{ex} on the Coupling Slot Size

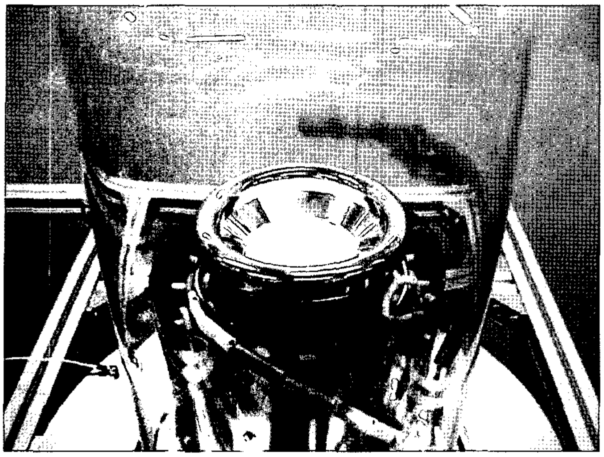

Fig. 6. Gun Firing Equipment

A capacitive tuning mechanism was adopted, which allows the adjustment of the re-entrant cavity gap. After completing the vacuum and RF tests for all cavities and parts, the parts were welded together as shown in Figure 7. The soft baking process was performed for two weeks at 250° C.

4. OPERATING TEST

Parallel to the tube development, a long pulse power supply was developed for the RF performance test at KAPRA. The long pulse power supply's power rating was 1.8MW and the pulse length was up to 2ms. Furthermore, two self-healing energy storage capacitors (100kV, 3μF each), two high power spark gaps, current limiting resistances, and

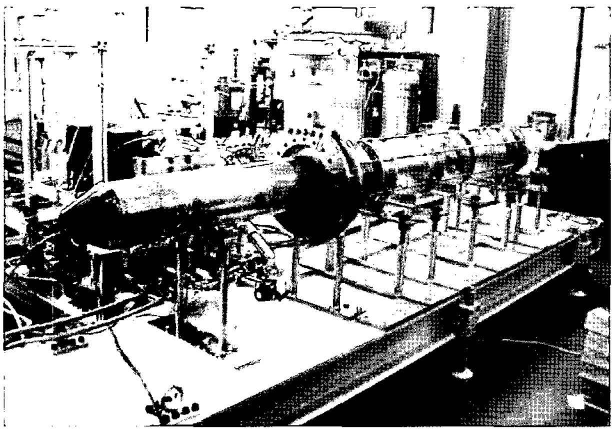

Fig. 7. 700 MHz PEFP Prototype Klystron Tube After the Final Welding

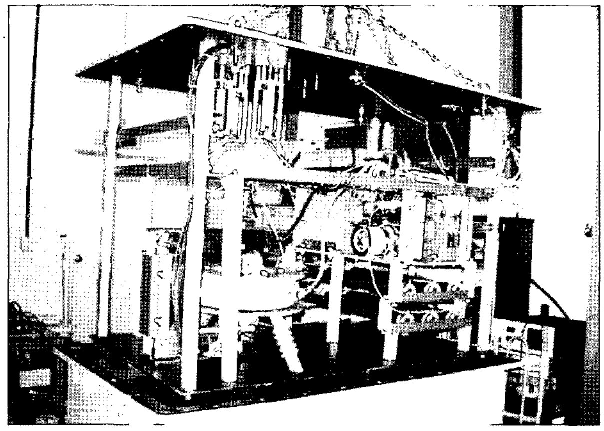

Fig. 8. Cathode Heating and Pulse Power System

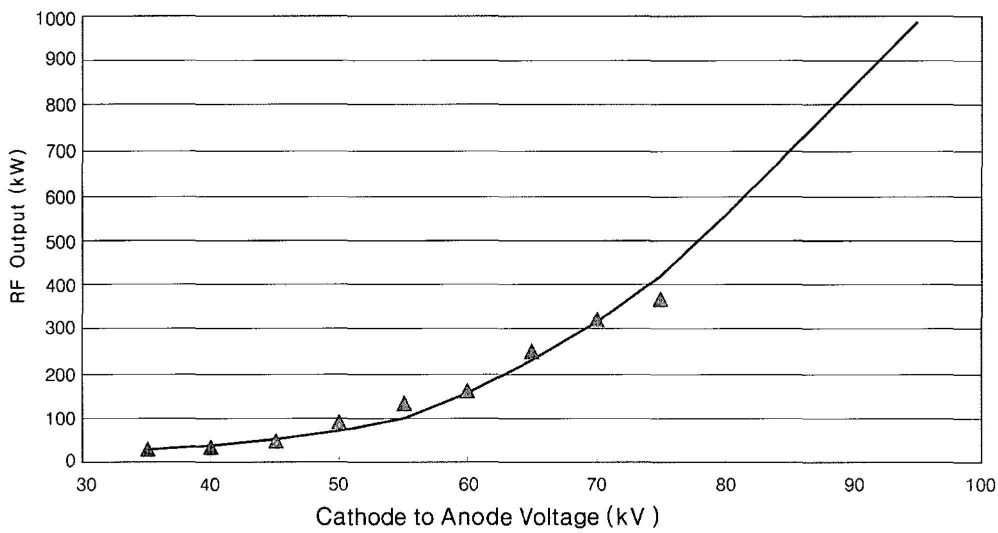

Fig. 9. Anode Voltage and RF Power

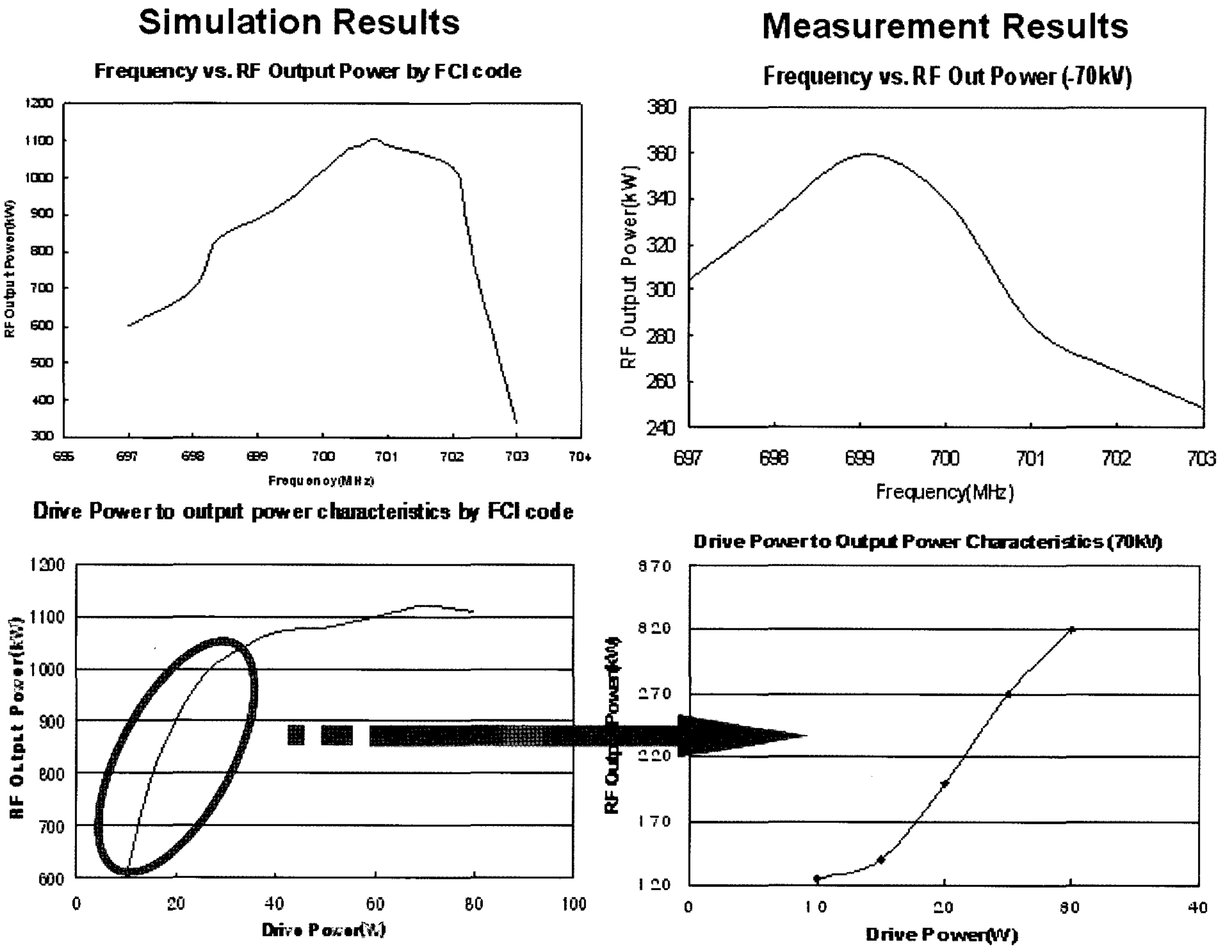

Fig. 10. Comparison of the Simulation and Experimental Results

trigger circuits were incorporated into the test klystron. Figure 8 shows the cathode heating and pulse power switching system. A 1 MW RF dummy load and the related waveguide circuits were equipped for the test operation.

The klystron amplifier system operated with up to 75 kV of anode voltage. The RF output power reached 370 kW, as shown in Figure 9. At voltages above -75kV, the trigger circuit showed performance instability and a surge current breakdown occurred in the thyristor . This circuit needs to be modified by employing a thyristor with a larger current capacity. The theoretical and experimental results for the output power versus the drive frequency and power are compared in Figure 10.

5. SUMMARY

The design, manufacturing process, and first operating test of a 700MHz klystron, a high power RF source for a PEFP proton accelerator, have been summarized. The prototype klystron was designed to meet the specifications and capacities of specific infrastructures, as well as to train domestic industries in the component fabrication and processing from designs to tests, as part of this research. Assembling the machined parts was successfully undertaken in a high vacuum. The completed klystron operated with up to 75kV of anode voltage.

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