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Research Article

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Design, Fabrication and Testing of Gun-Collector Test Module for 6 MW Peak, 24 kW Average Power, S-Band Klystron

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ABSTRACT

This paper presents a detailed design and development methodology of Gun-Collector Test Module (GCTM) for 6 MW peak and 24 kW average power, S-band klystron. Electron gun has been designed through Vaughn's synthesis, which was later optimized using TRAK code. The final optimized design was cross verified using MAGIC code. Thermal design of the collector was done first from analytical formulae and then verified with ANSYS. Then a GCTM was fabricated and hot tested. This paper also represents the hot testing results of GCTM which was found to very much close to that of the simulated values.

Key words: Klystron, Gun-collector test module, TRAK, MAGIC, ANSYS

INTRODUCTION

The high power klystrons belong to the family of microwave tube power amplifiers and they have wide range of applications in many emerging fields such as communication, radar, material processing and particle accelerators for medical, industrial and scientific applications including nuclear waste transmutation, energy production by sub-critical reactors. A 6 MW peak, 24 kW average power S-Band klystron, with specifications as given in Table-1, is under development at CSIR-CEERI, Pilani. This tube will be used as RF source for industrial linear accelerator at BARC, Mumbai.

Table -1Tube Specifications

Parameters	Specifications
Frequency (MHz)	2856.0
Saturated power (MW)	6.0
Gain (dB)	45
Band width (MHz)	±4 MHz
Efficiency (%)	45
Beam voltage (kV)	130-140
Beam current (A)	100
Magnetic field (Gauss)	1100

The main purpose of making a GCTM is to evaluate the performance of electron gun and collector under DC conditions. Firstly the electrical design of electron gun and collector is done using different simulation software. The thermal simulation of collector is done under full beam dissipation condition. In the present design TRAK and MAGIC codes have been used for electrical design while ANSYS is used for thermal design of collector. Based on engineering design of electron gun and collector, a GCTM is fabricated.

ELECTRON GUN AND COLLECTOR

Electron Gun

The basic role of electron gun in klystron is to generate an electron beam with predefined specifications so that it can interact with RF field to produce desired power. In this tube we have used Pierce type electron gun. Schematic of this gun is shown in fig.1 [1]. It mainly consists of cathode, beam focusing electrode, anode. Electrons emitted by thermionic cathode are accelerated by the concentric anode, which is maintained at a positive potential with respect to cathode. The electron beam is given laminar shape with the help of beam-focusing electrode (BFE). Due to the presence of space charge forces, the electron beam has a general tendency of spreading, application of a coaxial magnetic field (having magnetic flux's parallel to the axis of the electron beam) prevents the beam from spreading.

Collector

The main function of the collector is to collect the spent beam. The schematic of the collector is shown in fig. 2[1]. It consists of two conical portions (one in the beginning and the other in the end) and a cylindrical portion in the middle. Electrons in the beam contain high kinetic energy. A part of this energy is transferred to rf during beam wave interaction and the rest is dumped into the collector. Due to this high energy dumping collector gets heated, hence efficient thermal design of the collector plays a crucial role in the high power klystrons.

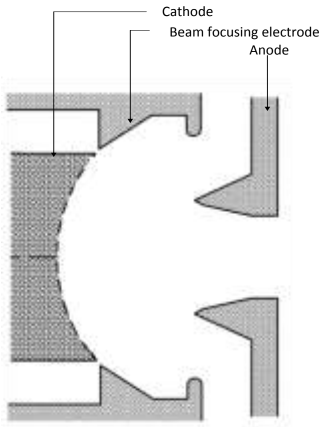


Fig.1 Schematic of Pierce type electron gun

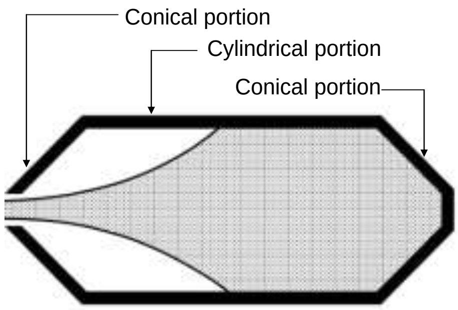


Fig. 2 Schematic of typical collector with beam spreading

DESIGN AND SIMULATION OF ELECTRON GUN

A computer code based on Vaughan's synthesis [2] has been written to get an initial approximation of the electron gun while the beam voltage, beam current and beam waist radius is fixed. Initial approximate dimensions obtained from Vaughn's synthesis have been used as input for optimization. Commercially available code TRAK has been used for this optimization. It took several runs in the TRAK code before it was finally accepted. Another commercially available code MAGIC [5] has been used to cross validate the final optimized design obtained from TRAK. The results obtained from both codes shows a good agreement. The final optimized beam trajectories from TRAK code and MAGIC code are shown in fig. 3 and fig. 4 respectively. A comparison of V-I characteristics of the electron gun obtained from the two codes has been shown in fig.5. Table 2 gives a comparison of different parameters obtained from the two simulation tools.

Table - 2 Comparison of Different Parameters Obtained from the Two Simulation Tools

Simulation tool used	Beam voltage (kv)	Beam current (amp)	Beam waist radius (mm)	Beam throw (mm)
TRAK	130	89	8.0	7.0
MAGIC	130	89	8.0	7.45

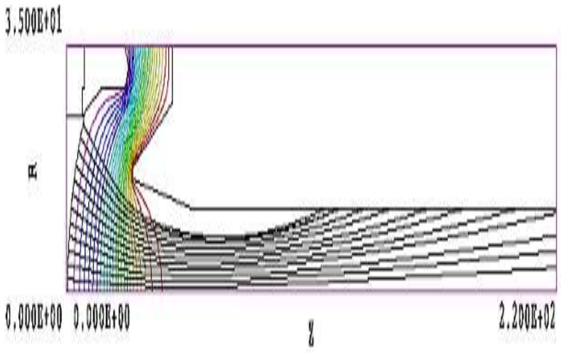


Fig. 3 Electron trajectories simulation using TRAK

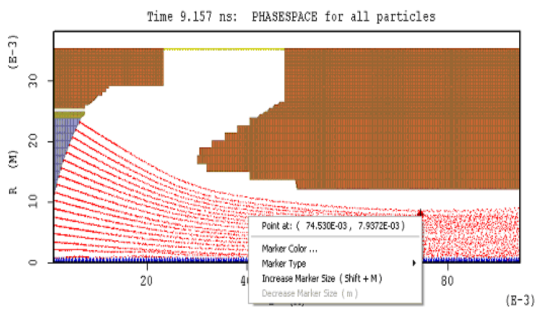


Fig. 4 Electron trajectories simulation using MAGIC

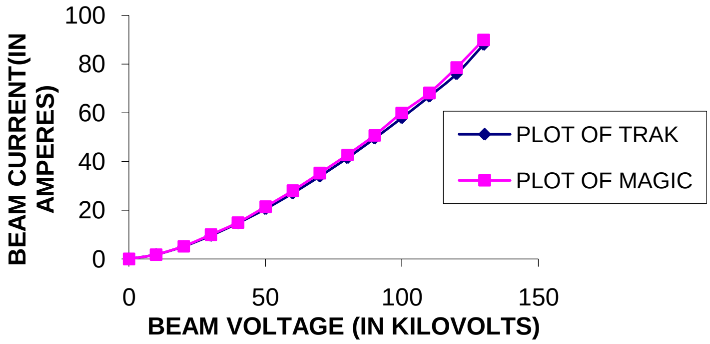


Fig. 5 Comparison of V-I characteristics computed using TRAK and MAGIC

DESIGN AND SIMULATION OF COLLECTOR

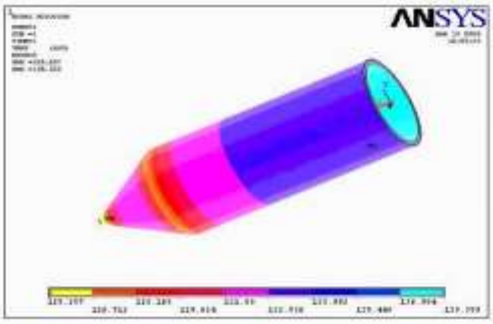
Convective heat transfer takes place between circulating fluid and a solid surface. The rate of convective heat transfer between a surface and a fluid is given by the Newton's Law of Cooling [3], [4]

$$Q = h\,A\,\theta \tag{1}$$

Where Q is rate of heat transfer (W), h is convective heat transfer coefficient ($Wm^{-2}K^{-1}$), A is surface area (m^2) and θ is Temperature difference (K)

$$Nu = h.L / K \tag{2}$$

Where Nu is Nusselt number for the flow, L is characteristic dimension of pipe (m) and K is thermal conductivity of copper ($Wm^{-1}K^{-1}$). Ducts are made on the outer surface of the collector to increase the effective surface area for cooling. ANSYS [5] is being used as simulation tool for the thermal design of collector. Depending on the different conditions of the flow, different values of convective heat transfer coefficient are obtained and are given as input to the ANSYS. Different sets of inner and outer surface temperature distribution of collector are obtained for different set of inputs using ANSYS code. Fig. 6 shows a typical result of 3-D simulation of collector, with smooth surface, using ANSYS [5]. Fig. 7 shows a cross sectional view of ducted collector after simulation. Thermal simulation results obtained from ANSYS indicates that in the worst case (when total beam is dumped in the collector without any interaction) temperature on collector surface may raise up to 86^0 C. This result was obtained with a water flow rate of 15 gallon per minute.



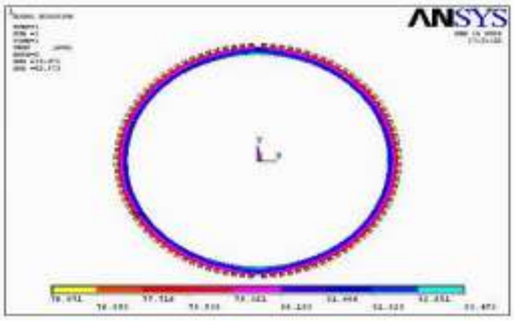


Fig. 6 Results for complete smooth surface **Fig. 7 Temperature distribution with ducted surface of collector**

SIMULATION OF GUN-COLLECTOR TEST MODULE

Once the gun and collector design have been finalized, they are combined and simulated in MAGIC to observe the electron trajectories. The simulated result is shown in fig.8, the blue colored area in the collector shows the secondary electron emission. This simulation helps us to judge the performance of GCTM before fabrication.

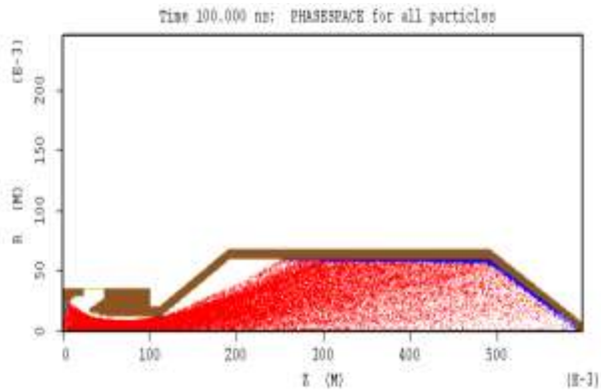


Fig. 8 Trajectories hitting on the collector with 130 keV energy

FABRICATION OF GCTM

Once the dimension of electron Gun and collector are finalized through simulation, they are fabricated from different materials depending on their functions in GCTM. M-type dispenser cathode is being used for this tube. Since high vacuum exists inside the tube, so all the parts should be leak proof. Helium leak detector is used to check the leaks for all most all the fabricated parts. TIG welding and brazing has been used to join the fabricated parts. Jigs and fixtures are used to maintain the assemblies aligned and co-axial during joining operations. This helps us to avoid beam interception. An ion pump has also been integrated with the GCTM, this act as an appendage pump. Once the total GCTM assembly has been made it is once again tested with helium leak detector (fig.9). GCTM is then vacuum processed to get a base pressure around 10^{-9} torr, before pinch off as shown in fig.10. Before it is mounted on test bench, the flow of water in the water jacket has to be checked with predefined flow rate (fig.11).

Fig. 9 Leak testing of GCTM **Fig.10 Vacuum processing of GCTM** **Fig.11Testing for water circulation around GCTM**

HOT TESTING OF GCTM

Once the GCTM is vacuum processed and found leak proof, it is mounted on a high voltage pulse modulator to carry out hot testing. In this process performance of the electron gun and collector has been tested. Collector has been lead shielded to avoid harmful X ray radiations. The GCTM has been tested at a voltage up to 130kV with pulse width of 10µSec at a pulse repetition rate of 400 (max). One screen shot of applied voltage and current by pulse modulator at full prf (400 Hz) is shown in fig. 12, also the output rf power is shown in the same figure. The actual applied voltage on the electron gun has been measured on CRO screen as shown in fig. 13 and it is found as per set voltage by the modulator. The experimentally measured V-I characteristics of the electron gun are shown in fig 14; the curve is in close agreement with the simulated characteristics of fig.5.

Fig.12 Screen shot at full PRF

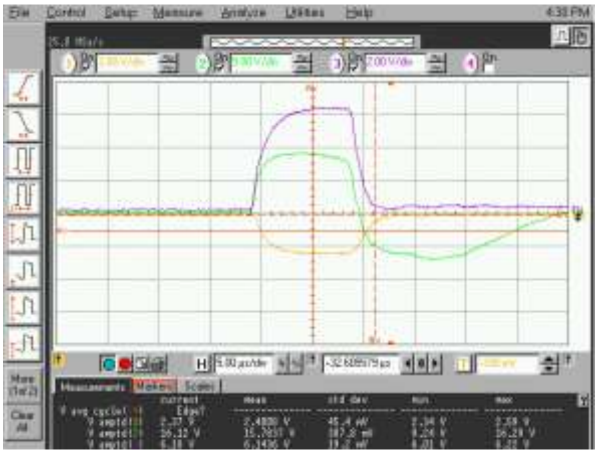


Fig.13 Observed output on CRO

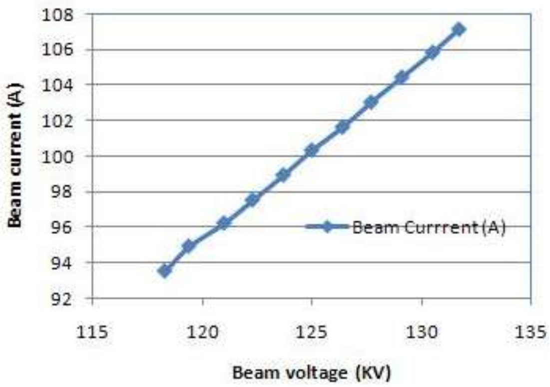


Fig. 14 Measured V-I characteristics of the Electron-Gun

CONCLUSION

Hence the Gun Collector Test Module for 6 MW peak power and 24 kW average power has been successfully designed and fabricated. It has been found during hot testing that, the electron gun is capable to hold the required high voltage without breakdown. It is also found that the designed collector is suitable to dissipate the heat successfully in dc condition without any deformation. This validates the successful thermal design of the collector as well as the electrical design of the electron gun.

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