Thermal Design and Analysis of Collector for C band 250 kW CW Klystron

O S Lamba, Ms Meenu Kaushik, Sushil Kumar, Ms Aditi Gupta,
Ms Varsha Gupta, Ms Sarita , Debasish Pal, D. Kant, L M Joshi

MICROWAVE TUBES AREA.
CENTRAL ELECTRONICS ENGINEERING RESEARCH INSTITUTE (CEERI)
PILANI: 333031
(COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH (CSIR)

Email : osl@ceeri.ernet.in

Abstract

Thermal design of the collector in high power klystron plays a crucial role in overall design of klystron. Spent electron beam, after giving a part of its kinetic energy to RF fields, strikes on the inner surface of collector and dissipates its remaining energy in the form of the heat. In case of high average power tubes, the energy deposited on the collector may damage the collector if the heat is not removed efficiently. The overall dimensions and the shape of the collector depend on the operating voltage and the average power of the beam. This paper presents the thermal design of the collector of a 250 KW C band Klystron under development. Thermal simulation has been done by using ANSYS 11.0 (multi-physics). The outer surface of the collector has been grooved to increase cooling. Design results are presented for water-cooling with different flow rates and channel dimensions.

I. INTRODUCTION

The high power klystrons belong to the family of microwave tube power amplifiers that find wide use in communication, radar, material processing and particle accelerators for medical, industrial and scientific applications including nuclear waste transmutation, energy production by sub-critical reactors and spallation neutron sources.

Functionally a klystron can be divided into three sections

(a) The electron beam forming and focusing section that produces a well focused laminar electron beam
(b) The RF section, where the interaction of the electromagnetic signal to be amplified with electron beam takes place resulting in net transfer of energy from electrons to RF signal, and
(c) An electron collector that collects the spent electron beam.

The main function of collector is to collect the spent beam. The electron beam that acquires kinetic energy through the acceleration in the gun, delivers part of its energy to RF field in the process of interaction in the RF section. The energy still left in the beam, which depends on the efficiency of RF interaction, is allowed to be dissipated on the collector resulting in heating of latter. The collector is designed to remove the heat efficiently thus produced. Thus thermal design of the collector in high power klystron plays a crucial role in overall design of klystron. Thermal simulation has been done by using ANSYS 11.0 (multi-physics). Cooling system for collector can be efficiently designed after getting the results of thermal simulation.

II. Klystron Specifications

Operating Frequency	:	5 GHz
Output Power	:	250 CW
Beam Voltage	:	60 kV
Beam Current	:	10 A
Efficiency	:	50%
Gain	:	50 dB
Collector Dissipation	:	500 kW

The collector is vital component of the klystron tube. The function of collector is to collect spent electron beam and effectively dissipate the heat generated in it. A forced water cooled collector has been designed to dissipate 500 kW power. The following aspects have been covered in the proposed topic: Choice of material, Physical dimensions, Cooling techniques.

Physical dimensions have been determined after analyzing the temperature profile of the collector using ANSYS code. The temperature rise of the surface calculated for 100 l/min. to 500 l/min. flow rate keeping the diameter 14 cm constant. The desired flow rate optimised for safe limit of temperature rise of collector. The length of collector changed from 65 cm to 100 cm in step by step and temperature range studied by changing the flow rate.Total surface area calculated keeping safe limit for thermal loading of the collector surface. The surface area increased by applying groove on the surface of collector. The temperature analysis carried out for plain as well as grooved surface. The variation of groove done from 55 to 220 on the surface. The final collector of ID 12 cm, OD 14 cm and length 85 cm having surface area 9874 cm^2 optimized for 300l/m flow rate.

III. DESIGN APPROACH

The shape of the collector surface generally has a short tube at the entry, a more strongly divergent conical part near the entry into the collector and more extended conical section at the end. The following considerations should be taken into account to design a collector for Klystron tube [1].

1. The thermal conductivity of the collecting cylinder should be high.
2. Diameter of the collecting cylinder should be small compared to its length so that the probability of secondary electrons finding their way out is low.
3. The material of which collector is made should be a poor secondary emitter.
4. The beam should be diverged by shielding the collector from magnetic field used to focus the beam in the interaction region.

The aspect ratio of the collector is chosen so as to have largest surface area to dissipate maximum heat by increasing its surface area. Some times the surface is made ducted to increase the effective surface area.

III. THERMAL ANALYSIS OF COLLECTOR

Convective heat transfer occurs between a moving 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 [2], [3].

$$Q = h\,A\,\theta \qquad (1)$$

Where Q is rate of heat transfer (W), h is convective heat transfer coefficient (Wm^{-2}K^{-1}), A is surface area (m2) and θ is Temperature difference (K)

Typical Values of Heat Transfer Coefficient h in Wm $^{-2}$K $^{-1}$ are given below.

Table-(1)

Free convection over various shapes for air	2-23
Free convection over various shapes for water	300-1700
Turbulent convection over various shapes and tubes for air	6-1400
Turbulent convection over various shapes and tubes for water	1100 - 9000

Heat transfer coefficient (h) is calculated by the relation

$$Nu = h.L / K \qquad (2)$$

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})

For different conditions of the flow different values of h are obtained and are given as input to the ANSYS and temperature distribution on geometry surface is obtained [4].

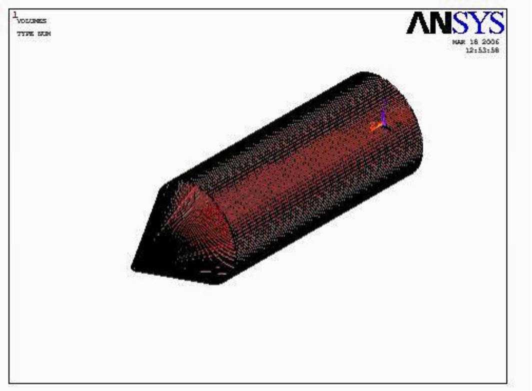

Fig. (1) Geometry of collector modeled in ANSYS

Case III : 220 Grooves Collector

Dimensions of Collector:

OD:14CM,ID :12 CM

Total Length 70(cylinder)+15(cone) : 85 CM

Total Surface Area (cm^2) :9874.86 cm^2

Total Cross Section Area : 51.5 cm^2

Total Heat Flux : 506336.29 w/m^2

Collector Dissipation : 500 KW

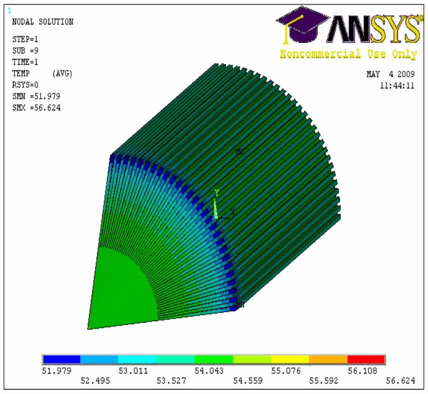

Fig. 2 Temprature profile for 300 liter/min., 220 grooves

Table2.Temp.V/S flow rate for 220 grooves

Water Flow (liter/min)	**Applied Heat Flux (w/m^2)**	**Bulk Temp.(˚C)**	**simulated temperature (˚C)**
100	**126584.07**	**30**	**60.33**
200	**126584.07**	**30**	**35.79**
300	**126584.07**	**30**	**26.62**
400	**126584.07**	**30**	**21.70**
500	**126584.07**	**30**	**18.59**

Plain Collector Geometry

OD: 14cm, ID: 12cm

Total Length 70 (cylinder) + 15(cone): 85cm

Total Surface Area(cm2) : 5056.86cm2

Total Cross Section Area 47.10cm2

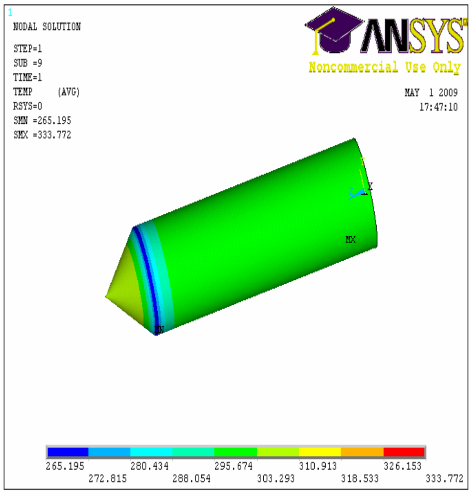

Fig. 3 Temp. with plain surface of collector

Table3.Temp.V/S flow rate for plain collector

Water Flow (liter/min)	**Applied Heat Flux (w/m²)**	**simulated temperature rise after cooling t(˚C)**	**Simulated Temperature Range**
100	1448914	628.06	598.68 to 658.06
200	1448914	374.96	351.34 to 404.96
300	1448914	303.77	265.19 to 333.77
400	1448914	229.65	210.67 to 259.65
500	1448914	197.6	179.90 to 227.60

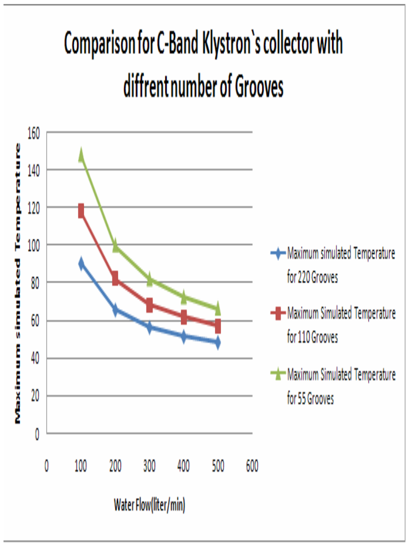

Fig. 4. Temperature profile with different grooves

CONCLUSION

Collector assembly with cooling system for 250 KW C band klystron has been designed successfully Thermal analysis of collector has been done using ANSYS code.

Thermal simulation results obtained from ANSYS clearly indicates that the grooved surface collector of diameter 14 cm and length 85 cm and water flow rate of 200 LPM kept the temperature in safe operating limit.

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