Design and development of collector for C-band 250 kW CW Klystron

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Abstract. The paper presents the design and development of collector for C-band 250 kW high power klystron. The design criteria for the collector assembly is selection of material, vacuum and high temperature compatibility, proper electron beam dispersion, minimum back scattering of electrons and thermal design for proper cooling at high power dissipation. All these aspects have been discussed for collector development in details. The collector has been designed in TRAK and then beam propagation has been analyzed in MAGIC 2D software. The thermal simulation has been done using ANSYS 11.0 (multi-physics). The outer surface of the collector has been grooved to facilitate its proper cooling. Design results are presented for water cooling with different flow rates and channel dimensions. OFHC copper material is chosen for collector which is suitable for vacuum and hydrogen brazing operations and good thermal properties for efficient cooling.

1. Introduction
Klystron is a high power microwave amplifier, which operates under ultra high vacuum of order 10⁻⁸ torr or better. Klystrons are widely used in radar communication, material processing and particle accelerator for medical, industrial and scientific applications. Klystron mainly consists of electron gun, RF cavity stack, RF window, collector and electromagnet. Each of these sub assemblies is separately designed, fabricated and evaluated. The paper mainly focussed on the design and development of collector. The function of the collector is to collect spent electron beam coming out of the tube and effectively dissipate the heat generated in it. 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 final energy exchange takes place in the output cavity. The collector is placed next to output cavity. The energy still left 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. Also electrons impinging the collector surface may produce secondary electrons which under favourable conditions may travel towards RF interaction region resulting in instabilities & other undesirable effects. It therefore is necessary to design the collector so as to trap the secondary electrons in the collector itself.
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 & more extended conical section at the end. The following considerations should be taken into account to design a collector for klystron:

- The thermal conductivity of the collecting cylinder should be high.
- 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.
- The material of which the collector is made should be a poor secondary emitter.
- The beam should be diverged by shielding the collector from a 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. Sometimes the surface is made ducted to increase the effective surface area. A forced liquid cooled collector has been designed and developed to dissipate 500 kW power. In an ideal collector, cooling technique should be implemented such that heat generated inside the collector would be removed as fast as possible to prevent temperature rise of collector beyond a safe limit. Also, it should have low weight, small size, and proper internal shape so that secondary electrons do not travel back in the drift region.

1.1. Specifications of this particular klystron

- Operating Frequency 5 GHz
- Output Power 250 kW CW
- Beam Voltage 60 kV
- Beam Current 10 Amp
- Focusing Electromagnet
- No. of cavities 6
- Efficiency 40 % (min.)
- Gain 45 dB (min.)
- Cooling Water

2. Electrostatic Design Approach

The electrostatic design optimized through electron beam dispersion in the collector. The electron beam is launched from cathode with the help of all the optimized beam parameters. Various effects like beam scattering, scalloping and beam overlapping are observed. The electron beam profile observed for 10 KeV to 70 KeV beam energy and beam was uniformly distributed over the surface. The collected power in the collector is calculated. The collector is again simulated in MAGIC2D for validation and beam profile is further analysed. When beam propagates into the collector, secondary emission and back transmission of electrons into the RF section are the major issues of concern. The results of beam dispersion are shown in fig 2.

2.1. Derived Beam Parameters

- Beam Radius 3.00 mm
- Beam current 10 A
- Beam voltage 60 kV
3. Thermal Analysis of Collector

A forced water cooled collector has been designed to dissipate 500kW power. 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 400 l/min. flow rates. The desired flow rate is optimised for safe limit of temperature rise of collector. The temperature analysis is carried out for plain as well as grooved surface.

Heat transfer occurs between a moving fluid and solid surface. The rate of heat transfer between a surface and a fluid is given by:

$$ h = \frac{Kw}{DH} \cdot Nu $$

where $Kw$ is Thermal Conductivity (Wm$^{-1}$K$^{-1}$), $DH$ is Hydraulic diameter (m) and $Nu$ is Nusselt number.

$$ Nu = 0.023 \cdot Re^{0.8} \cdot Pr^n $$

$Pr$ - Prandtl number
$Re$ - Reynolds number
$n = 0.4$ for heating (wall hotter than the bulk fluid) & $0.33$ for cooling (wall cooler than the bulk fluid)

$$ Re = \frac{Dv \cdot \rho}{\mu} $$

Typical value of heat transfer Coefficient $h$ in Wm$^{-2}$K$^{-1}$

For different condition of the flow different values of $h$ are obtained and are given as input to the ANSYS and temperature distributed on geometry surface is obtained as shown in Table 1.

3.1. Dimensions of Collector

- No. of Grooves: 110
- Output Diameter: 14 cm
- Input Diameter: 12 cm
- Collector length: 85 cm
- Total Surface Area: 9021.27 cm$^2$
- Collector Dissipation: 500 kW
Table 1 Simulated temperatures with varying flow rates.

| Water Flow (lpm) | Applied heat flux (w/m²) | Cooling coefficient (w/m²K) | Simulated temp.(°C) in ANSYS |
|------------------|--------------------------|-----------------------------|-----------------------------|
| 100              | 554245.68                | 3502.34                     | 67.31-116.63                |
| 200              | 554245.68                | 6098.37                     | 48.84-85.56                 |
| 300              | 554245.68                | 8435.27                     | 42.34-73.15                 |
| 400              | 554245.68                | 10617.89                    | 39.03-66.20                 |

Fig. 3. Temperature profile of collector

Fig. 4. Plot of water flow vs simulated temperature

Fig. 5. Plot of numbers of grooves vs simulated temperature at 500 kw power dissipation
4. Temperature variation with grooves
The outer surface of collector grooved to increase the surface area. The number of grooves increased from 44 to 219. It is observed that temperature fast decreased with increase number of grooves but after 110 grove minor changes observed in temperature as shown in fig. 5.

5. Engineering design of collector
The simulated dimensions of collector converted to the engineering drawing of collector parts for workshop fabrication. The cylindrical collector both ends are made conical to avoid back scattering of electrons after hitting the collector surface. All parts are fabricated separately and brazed in hydrogen furnaces to make vacuum tight joints. The collector assembly leak checked for leak rate of $10^{-11}$ torr litre/sec.

Fig. 6. Drawing of collector

Fig. 7. Fabricated Plain collector assembly  Fig. 8. Fabricated 110 Grooved Collector
6. Conclusion
The electrostatic, thermal and mechanical design of collector assembly with cooling system for 250 KW C band klystron has been done successfully. Thermal analysis of collector has been done using ANSYS code and we have got the surface temperature of the collector to be 42.34 °C -73.15 °C which is quite easy to maintain. 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 300 lpm kept the temperature in safe operating limit. The fabrication of collector is under progress.

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