Analytical method to estimate thermal parameters for high power gyrotron collector

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Abstract: Using basic equations, a MATLAB code, GCOLT has been developed to estimate the necessary initial thermal parameters of high power gyrotron collector.These parameters are requiredby commercially available software like ANSYS for detail thermal simulation of the collector. The optimized parameters of the collector are obtained from the ANSYS simulation and compared with the values obtained from the analytical method.

1. Introduction

Gyrotron is a high power, high frequency microwave source that can deliver power in the range of few hundreds kilowatt to few tens of mega-watt in long pulse mode operation. The main components of gyrotron are magnetron injection gun, beam tunnel, interaction cavity, non-linear taper or quasi optical launcher, collector and RF window. The electron beam emitted from the cathode experiences crossed electric and magnetic field. The electric and magnetic fields help to move electron beam in helical path. The electric field accelerates the electron beam to its final beam energy. The gyrating electron beam follows the magnetic flux lines and drift towards the interaction cavity. In the interaction cavity, the electron beam interacts with the RF in the resonator cavity and transfer its kinetic energy to the RF. Finally, the spent electron beam is collected on the wall of the collector and the RF power is collected through the window.

There are two types of collector i.e.undepressed collector and depressed collector.In case of depressed collector, the kinetic energy of the spent beam is partially converted into electrical energy and rest into heat energy, whereas in case of undepressed collector, the total kinetic energy of the spent beam electron is converted into heat energy. The heat generation rises the temperature on the collector surface. Thus, the wall loading on the collector surface should be within the technical limits i.e. $\leq 1 kW/cm^2$. This typical value reduces the possibility of failure of the collector due to the metal fatigue.In the depressed collector, the potential of the collector is reduced below the body potential to improve the efficiency of the device. The electron beam is distributed in large area instead of collecting at small area in order to avoid crystallization and deformation of the collector surface. The distribution of the spent electron beam over large area is achieved using extra magnetic system applied across the collector.

The designand development of collector requires the electrical and thermal analysis. Using EGUN software, the electrical analysis is carried out to optimize the dimensions of the collector geometry, the magnetic field strength and its position, electron beam trajectory and electron beam spread. Similarly, the thermal design analysis is required to optimize the flow rate of the coolant, thickness of the collector wall, grooves height and width,using ANSYSsoftware. The thermal transient analysis also helps to estimate the maximum temperature that the material can handle without deformation.But, for the initial electrical and thermal design of the collectorrequires some basic input parameters such as collector dimensions, depressed voltage, magnetic field strength, coolant flow rate, type of coolant, collector material, etc. To estimate above mentioned parameter, a code in MATLAB, GCOLT has been developed using basic equations [1-3]. The paper discusses the basic equations and the code to obtain the initial parameter for the thermal designof 120 GHz 1 MW gyrotroncollector.

2. Thermal analysis using analytical method

The material of the collector is OFHC copper and for effective cooling of the collector the outer surface consists of grooves. The maximum temperature handled by the OFHC copper material is 450K without metal fatigue. The spent electron spreading on the collector surface is non-uniform. Thus, the heat flux is different at different location of the collector surface. The amount of heat flows through the collector inner surface to the outer surface is to be carried out by the coolant and can be estimated from basic heat conduction equation.The heat flows through collector wall can be given by the equation,

$$Q=(2*pi*l**k*(T_{in} - T_{out})) / (\ln(R_2 / R_1)) \quad \text{watt} \qquad (1)$$

where T_{in} is the collector inner wall temperature in Kelvin, T_{out} is the collector outer wall temperature in Kelvin, R_1 is the collector inner radius in metre, R_2 is the collector outer wall radius in 'metre', ' l is the length of the collector in metre,k is the thermal conductivity of the collector material in W/ m .K. The heat carried out by the coolant can be written as,

$$Q_{out}= h*A_{out}*(T_{out} - T_C) \quad \text{watt} \qquad (2)$$

where 'h' is the heat film coefficient of the coolant in W / m^2.K, A_{out} is the collector outer surface area in m^2, T_c is the coolant temperature in Kelvin, T_{out} is the temperature of the collector outer wall in Kelvin.
Initially, the inner surface temperatureis assumed and the outer surface temperature is estimated through MATLAB code using above mentioned basic equations. The temperature from a particular point or surface varies almost exponentially i.e. e^{-mx} with distance where 'm' depends on material property and 'x' is the distance[3].The flow diagram of the GCOLT code is given in figure 1. Further, the estimated values of the heat film coefficient are verified using ANSYS. The transient analysis shows that the collector inner surface temperature is within the desire limit for the small duration operationof the device. The results obtainedfrom the MATLAB code and ANSYS analysis are given in table 1.

3. Conclusion

The results obtained from analytical estimation using MATLAB code are used for ANSYS simulation. The inner wall temperature is initially assumed whereas the outer wall temperature and the heat film coefficient are estimated using MATLAB code. The estimated values are feed to ANSYS program and obtained optimized results. The comparison between the analytical estimation using MATLAB code and ANSYS simulation shows the maximum error in outer temperature is 8.8% and minimum error is 2.7%. For inner wall temperature, the maximum and minimum errors are 9% and 0.97%, respectively. The material property variation with temperature is not considered in analytical estimation to reduce complexity in MATLAB code. If those effects are considered, errors will be lesser.

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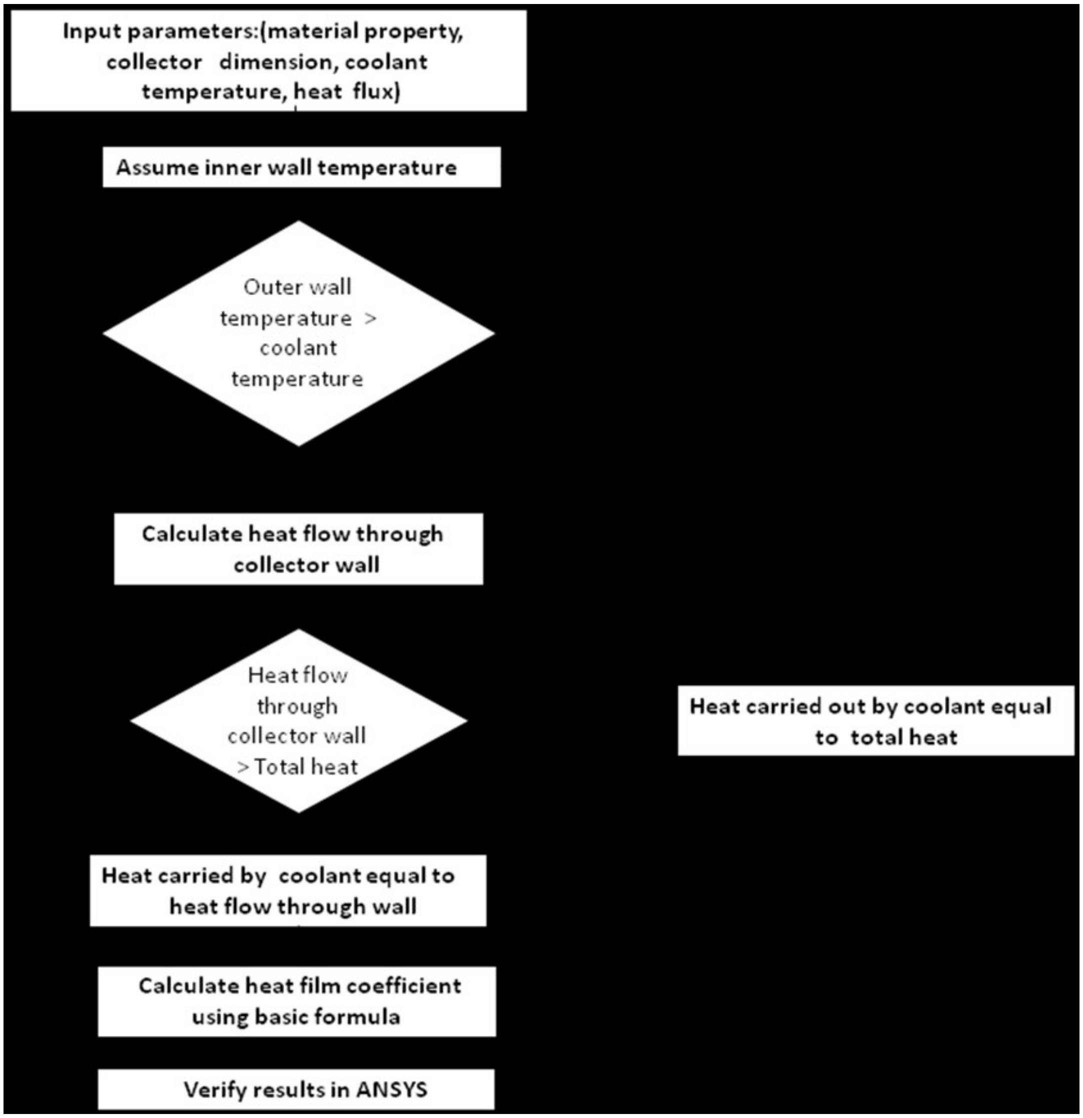

Figure 1. Flow diagram of analytical estimation of thermal parameters of the gyrotron collector .

Table 1. Comparison of inner and outer surface temperature of the collector between analytical method and ANSYS.

Assumed inner wall temperature (T_{in}) k	Heat film coefficient from MATLAB code (h) watt.$m^{-2}.k^{-1}$	Outer wall temperature from MATLAB code (T_{out}) K	Inner wall temperature from ANSYS simulation (T_{in}) K	Error in the inner surface temperature (%)	Outer wall temperature from ANSYS simulation (T_{out}) K	Error in the outer surface temperature(%)
675	275408.25	409.40	742.06	9.0	398.30	2.7
700	231432.11	429.70	752.10	6.9	415.07	3.4
750	195453.50	460.0	763.30	1.7	432.10	6.1
775	181973.43	475.73	767.47	0.97	441.10	7.1
800	181578.78	485.22	768.10	3.9	444.20	8.8