Design and Development of Test Collector Used in a Magnetron Injection Gun Assembly (MIGA) of a Gyrotron

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Abstract
The magnetron injection gun assembly (MIGA) is a very important assembly used for evaluation of a magnetron injection gun in a gyrotron. Obviously, the gyrating electron beam emitted from the cathode of MIG needs vacuum for the effective flow. Thus a component known as a test collector is attached with the MIG at one end to close and collect the electron beam. In this paper, the need of a test collector along with the designs and thermal simulation have been discussed. For the studies, two gyrotrons, namely, 42 GHz, 200 kW and 120 GHz, 01 MW gyrotrons are considered. The test collectors for these gyrotron are optimized as 85 mm and 140 mm, respectively for the inner diameters obtained through designs, thermal simulations as well as mechanical interfacing with the anode diameters of the corresponding MIGs. Using the test collectors, MIGA of 42 Gyrotron was fabricated and vacuum processed while the MIGA of 120 GHz gyrotron is at the final stage of fabrication. The paper also elaborates the experimental results of MIGA of 42 GHz gyrotron giving the designed value of 10A beam current.

Keywords
Gyrotron, Gyro-device, Electron Gun, Magnetron Injection Gun, Collector.

I. Introduction
Gyrotron is a high power, high frequency microwave source for various applications such as plasma generation, material spectroscopy, security, space exploration, etc. [1]-[4]. A number of gyrotrons have been developed throughout the world for the last six decades [5]-[7]. At CSIR-CEERI, the design and development of 42 GHz, 200 KW gyrotron under multi-institutional project sponsored by DST and 120 GHz, 01 MW gyrotron under CSIR-Network scheme, respectively, initiated in the last decade, were the pioneers in gyrotron research on device level in India [8]-[10]. Gyrotron is based upon the principle of interaction between a gyrating electron beam and a typical rf mode in the interaction structure. The gyrating electron beam with the desired beam properties is generated from a gyrotron electron gun normally called as a magnetron injection gun (MIG). Obviously, the design of any component is required to be experimentally validated. However, for the electron beam flow, high vacuum is must. Thus, a sealed magnetron injection gun assembly consisting of MIG attached with a collector is required to be fabricated and vacuum processed. MIG consists of cathode as electron beam emitter and anode as the electron beam generation facilitator achieved through the application of high voltage between cathode and anode to ensure the effective electron beam emission. The spent electron beam is collected by a component known as a collector. Due to handling of large electron beam power, the actual collector in a gyrotron is very large and heavy component, normally, covers almost half in size and weight of the complete gyrotron. Therefore, it is always preferred to have a smaller size collector for use in MIGA, hereby, called as a test collector. This paper elaborates the design and development of the test collectors for two gyrotrons, namely, 42 GHz, 200 KW gyrotron and 120 GHz, 01 MW gyrotron which are supposed to generate 650 kW and 3.2 MW electron beam power, respectively. Simple method is proposed for design of each of these test collectors for testing in pulse mode. Both these test collectors have been thermally designed and optimized through ANSYS software [11] keeping the temperatures of the cathode less than 200 deg C as well as experimental evaluation as simple as possible. These test collectors have been fabricated by using ofhc copper as materials. The inner diameters of these collectors were optimized as 85 mm and 140 mm, respectively. The paper also presents the test results of electron beam power comparable with the designed value in a developed and vacuum processed MIGA of 42 GHz, 200 kW gyrotron.

II. Design and Thermal Analysis
The design of the test component is governed by various factors such as the incident heat power, the compatibility with the inner diameter of the interfacing anode, the technical feasibility of the test facility, etc. The incident power is estimated through the expression given as [12]

\[ A = \frac{Q d}{t k \Delta \theta} \]  

where A is the inner surface area of the collector where the electron beam power is incident, Q is the heat flux, d is the thickness of collector, t is the time, k is the thermal conductivity of collector, \( \Delta \theta \) is the difference of temperature between the inner surface and outer surface of collector. The testing of gun collector module is planned for 0.05-1% duty cycle seeing the test facility availability and thus for the thermal safety of collector, 0.1-2% is taken for the beam power in the design and simulation. This has been applied for each of the gyrotrons under studies. It is of interest to mention that the inner diameter of test collector is kept the same as the actual collector designed and developed for use in the gyrotron. Moreover, the material of test collector is also kept the same as Oxygen Free High Conductivity Copper (OFHC) as planned for the actual collector to be used in the gyrotron.

The thermal analyses of the test collectors of both gyrotrons have been carried out by using ANSYS software [11]. Figs. 1-2 present the model of the test collectors of gyrotron in ANSYS under studies. A number of combinations of heat power loads and heat film coefficients have been tried out. But, it is always kept into consideration the availability of experimental facility as well as simple way of experimental evaluations. Fig. 3 show the effect of heat film coefficient on the temperatures of the surfaces of the collector 42 GHz gyrotron.
Fig. 1: Model of test collector used in MIGA of 42 GHz gyrotron (Inner diameter = 85 mm, length = 150 mm, thickness = 10 mm).

Fig. 2: Model of Test Collector Used in MIGA of 120 GHz gyrotron (inner diameter = 140 mm, length = 100 mm, thickness = 10 mm).

Fig. 3: Heat film coefficient versus temperatures of test collector surfaces of 42 GHz gyrotron for dissipated heat power = 1000 W (collector length = 150 mm, collector, thickness = 10 mm, collector inner diameter = 85 mm).

The experimental evaluation of test collector of 120 GHz, 01 MW is planned with 0.05% duty with the available facility at CEERI. Clearly, in this situation, 1600 W becomes the heat power load on the inner surface of the test collector. Using the length of collector = 100 mm, inner radius of collector = 70 mm, the heat flux is calculated through (1) and test electron beam power as 36396.7 W/m². A number of iteration simulations have been tried out. The typical results of the temperatures of the collector surfaces with respect of heat film coefficient have been presented in Fig. 4 which would certainly help in the decision of the maintenance of the ambient around the collector.

Fig. 4: Heat film coefficient versus temperatures of Test collector surfaces of 120 GHz gyrotron for dissipated heat power = 1600 W (collector length = 100 mm, collector, thickness = 10 mm, collector inner diameter = 140 mm).

III. Fabrication

The test collectors for 42 GHz and 120 GHz gyrotrons have been fabricated as per design values which have been designed as 85 mm diameter and 140 mm diameter, respectively, due to different power handling capability in the experimental evaluations of MIGs (Figs. 5 and 6). The test collector of 42 GHz gyrotron has been successfully brazed with the magnetron injection gun (MIG) and vacuum processed up to 400 deg C in the order of stable vacuum of 1.0x10⁻⁸ millibar. Fig. 7 shows a developed and vacuum processed MIGA of 42 GHz gyrotron. The process of development of MIGA of 120 GHz gyrotron is in the final stage.

Fig. 5: Test Collector of 42 GHz, 200 kW Gyrotron.

Fig. 6: Test collector of 120 GHz, 3200 kW Gyrotron.
V. Experimental Results
Experimental results have been achieved by using MIGA of 42 GHz gyrotron where, as mentioned above, MIGA is an assembly of MIG and test collector. Fig. 8 shows a typical experimental results of electron beam power at different heater power. The experimental results are obtained at 1% duty cycle of anode voltage with simple air fan flow around the device and in conformity with the design values [13]-[16].

VI. Conclusion
The test collectors have been designed to evaluate the magnetron injection guns of two gyrotrons, namely, 42 GHz, 200 kW and 120 GHz, 01 MW gyrotron, respectively. The thermal optimizations have also been carried out and then these component have been fabricated. For 42 GHz gyrotron, the test collector has successfully been joined with the MIG having insulator in between and then experimental results has been achieved to for the desired 10A electron beam current.

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