Design and Development of Electromagnet for 3 MW S-Band Tunable Pulse Magnetron

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***Abstract*- This paper presents design and development studies of an electromagnet for testing of a high-power 3.0MW S-Band 2.856 GHz tunable pulsed magnetron using CST microwave studio. Based on the design and optimized parameters a prototype of electromagnet with hinge type plates have been developed and tested. The electromagnet has been tested with constant current source up to 28 A of current and the required magnetic field of 1600 Guass with the required field profile between the pole pieces has been achieved at the operating current of 25-26 A. For cooling of the electromagnet external water cooling arrangement has been made and the water flow rates has been kept at 5L/m. The in-house developed 3 MW magnetron has been tested with the developed electromagnet and the results are acceptable .**

I. Introduction

LINAC based X-Ray machines are extensively used for industrial, medical and Security applications. These LINAC based X-ray machines use high power microwave sources such as Klystrons and Magnetrons. Magnetrons being inherently efficient, compact and small size provides economical solution. Magnetron is a cross field device basically a diode, with a magnetic field parallel to its axis. It provided the impetus for the development of microwave radar during World War II [1]. The first, two-pole magnetron was developed in 1921 by Albert Hull at General Electric's Research Laboratories, New York, as an outgrowth of his work on the magnetic control of vacuum tubes, but it was only an interesting device until 1940. In 1929, K. Okabe working with H. Yagi at the Tohoku College of engineering also used a magnetron in which the anode was divided in two segments and its lowest operating wavelength was 12 cm. [2-3]. Prior to World War II, frequencies up to several hundred MHz could be generated by conventional triode, tetrodes etc, but significant amount of power was not possible above few hundred MHz [4]. During World War II, there was an urgent need for generation of high power microwave for radar transmitters which geared up the development of magnetron to its present status [5].

CSIR-CEERI has successfully developed and delivered a series of high power pulse magnetrons in S-band with a pulse output power from 500 kW to 3 MW. The magnetic focusing system is one of the main component of these magnetrons. The function of the DC magnetic system is to provide magnetic field parallel to the axis of cathode. The magnetic field causes electrons attracted to the positive outer part of the resonant structure, to spiral outward in circular path rather than moving directly to the anode. Like cathode, the magnetic field in magnetron also plays a different role as compared to the linear beam tubes. It plays a direct role in beam-wave interaction process unlike linear beam devices where DC magnetic field is used only to focus the electrons. All these magnetrons uses either a permanent magnet or a solenoid type electromagnet. By using a electromagnet user has a better control over the operating region as the user can operate in a broad operating region of operation by changing the magnetic field. This paper describes the method to design and development of an electromagnet for the testing of a high power S-band pulse magnetron. The required magnetic field for this magnetron is about 1600±50 Guass and it has a axial mounted cathode support. The paper has been divided into four sections including the introduction in section I. Section II describes the electromagnet design and modeling parameters using CST Microwave studio. The simulation and experimental results have been discussed in section III followed by the conclusion in section IV.

II. Design and Modeling

A solenoid is a coil of wire designed to create a strong magnetic field inside the coil. By wrapping the same wire many times around a cylinder, the magnetic field due to the wires can become quite strong. The number of turns *N* refers to the number of loops the solenoid has. More loops will bring about a stronger magnetic field. Ampere's law can be applied to find the magnetic field inside of a long solenoid as a function of the number of turns per length *N/L* and the current *I*. According to amperes law for solenoid coil the maximum magnetic field of single coil at the centre of the coil is given by the equation (1).

$$B = \frac{\mu_0 NI}{L} \tag{1}$$

and the current density for *N* turns

$$J = \frac{NI}{A} \tag{2}$$

where B is magnetic field (in gauss), N is number of turns in coil (in integer), I is current flowing in the coil (in Amperes), L is length of the coil wire (in mm) and μ is permeability of vacuum (amperes per meter) respectively.

Depending on the requirement of the magnetic field (~1600 Guass), the cross section of the rectangular wire has been ed. The material for pole pieces and yoke has been taken as oft iron. The bobbin material has been taken as copper. As he magnetron has a axial mounted cathode support one of the pole of electromagnet has been taken as hollow to pass the cathode support from there. Due to the circular hole in one of the pole piece makes its design more complex. The dimensional and operating parameters of the developed electromagnet are as given in table 1. Depending on the dimensional parameters an electromagnet has been modeled in CST Microwave studio. The cross sectional view of the model is as shown in Fig.1.

TABLE 1
DIMENTIONAL AND OPEATING ELECTROMAGNET

Parameters	Values
Material of Yoke and Pole	Soft Iron
Coil Material	Copper wire with rectangular cross section
Number of turns North pole coil (solid) South pole coil (hollow)	 253 287
Operating Current	28 A (Max.)
Air Gap Lenght	78.5 mm
Cooling duct diameter	6mm
Power Supply	Glassman Europe LP 35-35

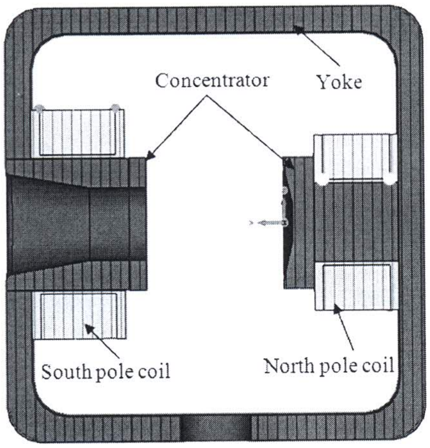


Figure 1. Cross sectional view of the electromagnet.

III. SIMULATION RESULTS AND DISCUSSION

The magneto static solver module of the CST microwave studio has been used to simulate the magnetic field inside the modeled electromagnet. As one of the pole piece is hollow in nature, a special shaped concentrators have been designed to concentrate the magnetic field in the air gap between the pole pieces. The number of turns in both the coils have been optimized to achieve the required magnetic field and the filed profile between the pole pieces. The vector plot of the magnetic field lines are as shown in Fig.1.

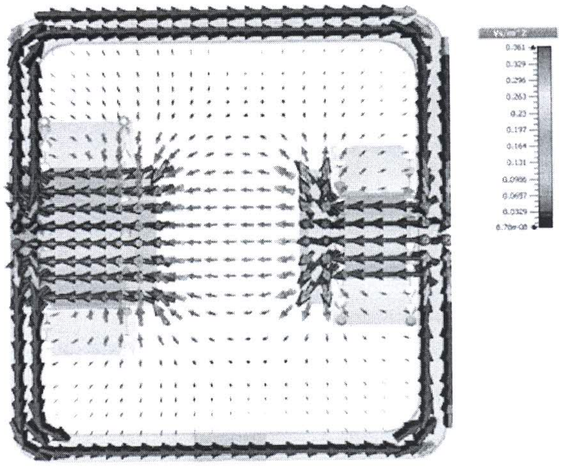


Figure 2. Vector plot of magnetic field lines inside the concentrator and yoke.

The lab prototype of the electromagnet has been developed depending on the simulated model as shown in Fig.3. Again the designed electromagnet has been simulated with different values of coil currents starting from 5 amperes to 28 ampere. The experimental results have been compared with simulated results and the measured values of EEV developed electromagnet MG 6053. The comparison of the results is as shown in Fig. 4. The data have been taken at the axial and radial center of the pole pieces.

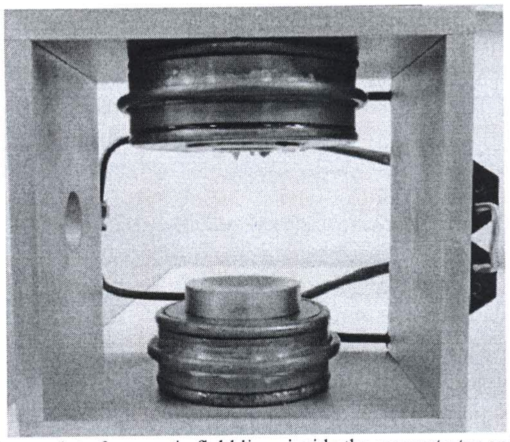


Figure 3. Vector plot of magnetic field lines inside the concentrator and yoke.

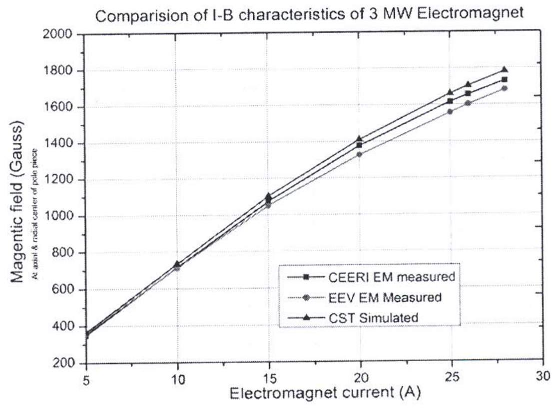
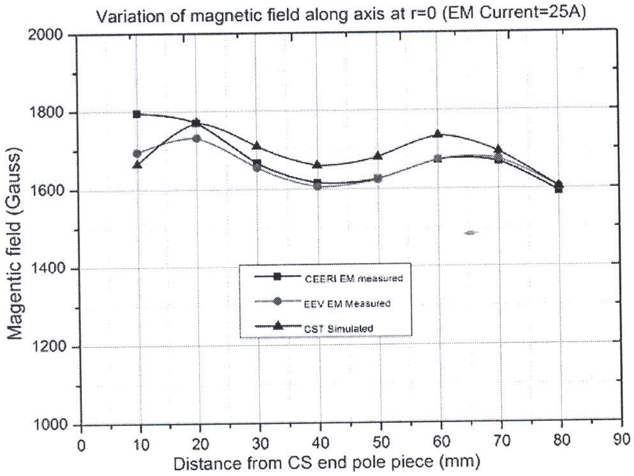
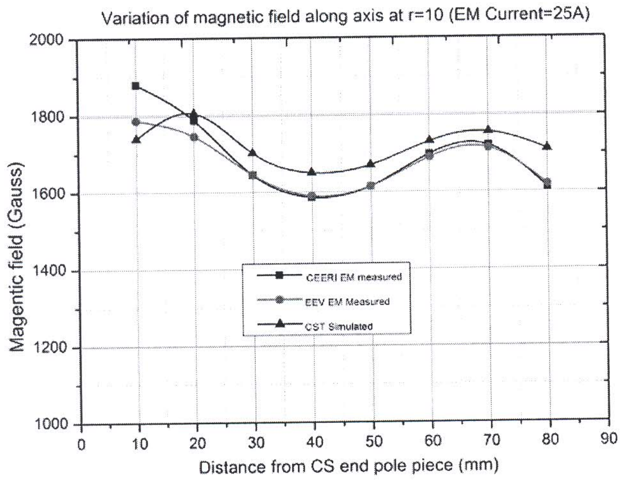


Figure 4. Comparision of magnetic field at the center of pole pieces.

e value and profile of the magnetic field in the interaction egion of the magnetron is very important parameter for the efficient operation of the magnetron. Hence the magnetic field has been simulated and measured at different values of radial position starting from the cathode support (CS end) at the operating current of 25 Amperes. Figs. 5(a-b) show a comparison between simulated different experimental results.



(a)



(b)

Figure 5.Comparision of magnetic field at different radial position (a) at r=0, (b) at r=10mm.

IV. CONCLUSION

An electromagnet has been designed and developed for the testing of high power S-band 3 MW pulse tunable magnetron. The 3MW magnetron lab prototypes developed by CSIR-CEERI have been tested with CSIR-CEERI developed electromagnet up to 46-47 kV and the power measured is ~3.0 MW (same as with using EEV Electromagnet). The 3 MW magnetron developed by CSEI-CEERI is as shown in Fig 5. The electromagnet voltage and current were 25 V and 23.5 A respectively. Fig.6 show the hot test bench of the high power magnetron with all the other power supplies and measuring equipments.

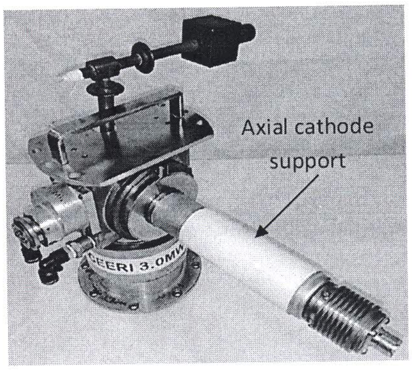


Figure 5. Lab prototype of 3 MW S-Band pulse tunable magnetron

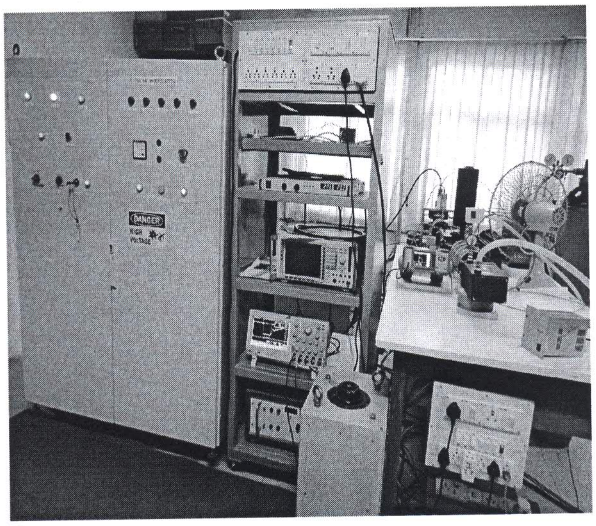


Figure 6. High power pulse magnetron test bench

ACKNOWLEDGMENT

The authors are thankful to the Director, CSIR-CEERI Pilani for granting permission to publish this paper. This work has been carried out as a part of Bhabha Atomic Research Center(BARC) sponsored project " Design and Development of 3 MW S-band tunable pulse magnetron." Authors are also also thankful to their colleagues for continious support and help.

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