HIGH POWER, 140 GHz GYROTRON

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Abstract

The design and construction of a pulsed 100 kW, 140 GHz gyrotron is described. Initial gyrotron operation is expected in early 1982. Advances in gyrotron theory have also been carried out in support of this experimental research. The application of gyrotrons to plasma diagnostics is also under investigation.

Introduction

The MIT gyrotron development program is devoted to the investigation of advanced concepts for high power, high frequency gyrotrons. The primary experimental goals are to demonstrate new techniques for achieving efficient, single mode emission, to improve output coupling, and to develop new diagnostics of gyrotron performance. The choice of 140 GHz is based primarily on restrictions associated with the electron cyclotron resonance heating of fusion plasmas [1]. Gyrotrons with frequencies above 100 GHz will be required by fusion devices with magnetic fields above 3.5T for ω_c heating. This frequency is significantly higher than the 28 GHz [2] to 60 GHz that characterizes the present industrial efforts. In addition, our design goal of 100 kW pulsed power is greater than the output power of any previous gyrotron that has been operated above 100 GHz [3].

The MIT gyrotron is characterized by a number of unique features. A wide range of modes can be investigated with a single electron gun by simply changing the dimensions of the resonant cavity. This includes the study of whispering gallery modes (TE_{511}, TE_{611}, TE_{711}) as well as azimuthally symmetric modes (TE_{021}, TE_{031}, TE_{041}). In the latter case, the gun has been designed so that the electron beam interacts with the second radial maximum of the RF field rather than the first radial maximum as in industrial tubes.

This is shown in Fig. 1, which illustrates the beam field interaction for the TE_{021} and TE_{031} modes. This schematic shows the relative sizes of the cavity cross section, annular beam and electron gyro-orbit, as well as the relative intensities of the RF radial maxima. Placement of the electron beam at a higher radial maximum may be necessary in high power, high frequency gyrotrons in order to reduce space charge effects and electron velocity spread, and therefore minimize their deleterious effect on the efficiency. However, this placement of the beam requires a wider input beam tunnel and introduces the possibility of RF leakage into the gun region, which could adversely affect the beam optics. Special care has been taken in the design of the beam tunnel region in order to minimize this problem. Optical and quasi-optical techniques will also be utilized both to diagnose the gyrotron performance and to improve the power output coupling. [4]

A number of new problems emerge as gyrotron technology is extrapolated to high power and frequency. The most problematic is the need to operate in higher order modes in order to maintain a resonable wall heat flux [4]. Such a cavity might be sufficiently overmoded that it could be difficult to excite the desired mode, or multimoding may occur. Fig. 2 exemplifies this problem for operation in the TE_{031} mode. The starting currents required to initiate the TE_{031} and its neighboring modes have been plotted as a function of the resonator magnetic field [5]. Efficient operation requires a field of approximately 54 kG [6]. The mode chart indicates that the TE_{231} mode will be excited first unless its Q can be sufficiently lowered via damping techniques to ensure that TE_{031} has a lower starting current at this field.

Description of Experiment

Fig. 3 is a simplified schematic of the experimental setup. The major components are the Bitter magnet and gun coils, the electron gun situated within the gun coils, a vacuum system connected to the pumping port, and the gyrotron tube. A gate valve is located between the gun and tube in order that a vacuum can be maintained in the gun when it is disconnected from the tube. This prevents the cathode from being poisoned by the air and increases its longevity. The gyrotron internal components consist of a beam tunnel between the gate valve and resonator, the resonator, a linear up-taper which serves as a transition to an overmoded output waveguide, and a quartz vacuum window through which the radiation is emitted. The anticipated operational characteristics are listed in Table 1.

The cavity magnetic field is provided by a water-cooled Bitter magnet capable of producing up to 110 kG. This magnet has a field homogeneity of $\pm$ 0.5% over the resonator region, which is adequate for maintaining the beam-RF field resonance. The magnet has a 10.5 cm diameter bore, which allows the gyrotron to be manuevered until proper alignment is achieved. In addition to bore size, another advantage of the Bitter solenoids is the ease with which they can be restacked to provide novel magnetic field profiles for efficiency optimization. Attached to the Bitter magnet are a pair of auxiliary coils that will be used to shape the field in the gun region.

The electron gun has been designed and constructed under subcontract by Varian Associates. It represents the first complete design of a gun for a high power, high frequency gyrotron. A magnetic compression of 25 is required in order to obtain $v_{\perp} / v_{\parallel} = 1.5$ in the cavity region. Good beam quality has been achieved with a velocity spread less than $\pm$ 3.5% according to particle simulation codes. This low velocity spread has been obtained by designing the gun so that a laminar flow of electrons occurs. However, a number of potential difficulties have been uncovered during this study. It has been found and verified by adiabatic theory that the beam thickness can be large at high frequency. This tends to decrease the strength of the coupling between the beam and RF wave. In addition, the beam quality is sensitive to operating parameters such as anode voltage and beam current, and thus a power supply capable of stable operation must be used.

Design of the Resonator

When designing the resonator, the major goals were to optimize the efficiency and to lower the diffractive Q, Q_D of possible parasitic modes. Operation in the TE_{031} mode was chosen for the first experiment. The cavity consists of a cylindrical straight section 5λ long preceded and followed by linear tapers. A slope of approximately 0.2° was chosen for the input taper so that the RF field would have a tail that would prebunch the electrons and improve the efficiency. The length of this taper was chosen so that the TE_{031} mode would be trapped, while q > 1 modes would not be confined as effectively and thus have lower Q's [7]. The output taper angle of 4° was chosen based on the ed to keep mode power conversion to other TE_{0p1} modes below 10% and to obtain a Q_D of 1500 needed to maximize efficiency [6]. Assuming a sinusoidal RF field profile, a total efficiency of 30% is anticipated. The Q_D of about 1500 is about a factor of 3 higher than those of present devices primarily because of the lower field intensity at the second radial maximum (see Fig. 1).

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Table 1 - Experimental Parameters

Frequency	= 140 GHz	Beam current	= 5 to 7.5A
Field in resonator	= 54kG	Beam voltage	= 65KV
Field at gun	= 2.2kG	Beam radius (in cavity)	= 1.82mm
Pulse length	= 2μsec	Total efficiency	= 30%
$v_\perp/v_\parallel$	= 1.5	$\Delta v_\perp/v_\perp$	$\leq \pm 3.5\%$
Peak power	= 100kW	Repetition rate	= 5Hz

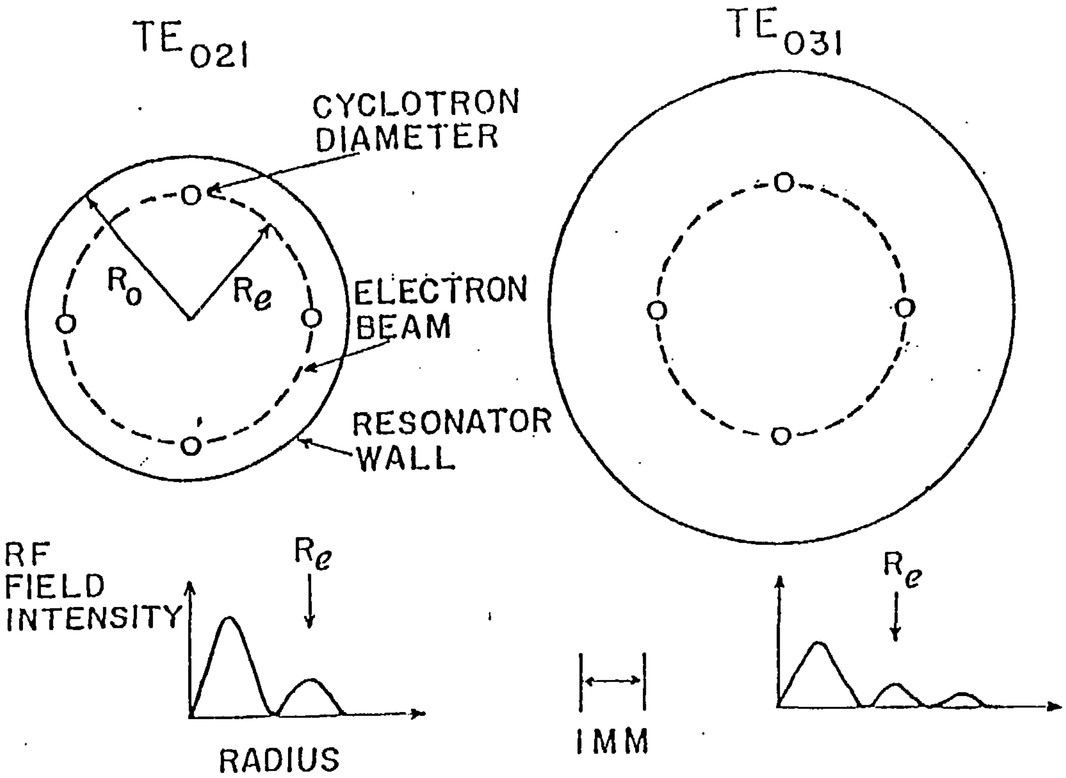

FIG. 1. 140 GHz RESONATOR EXPERIMENTS

MODE SPECTRUM FOR 140 GHz GYROTRON

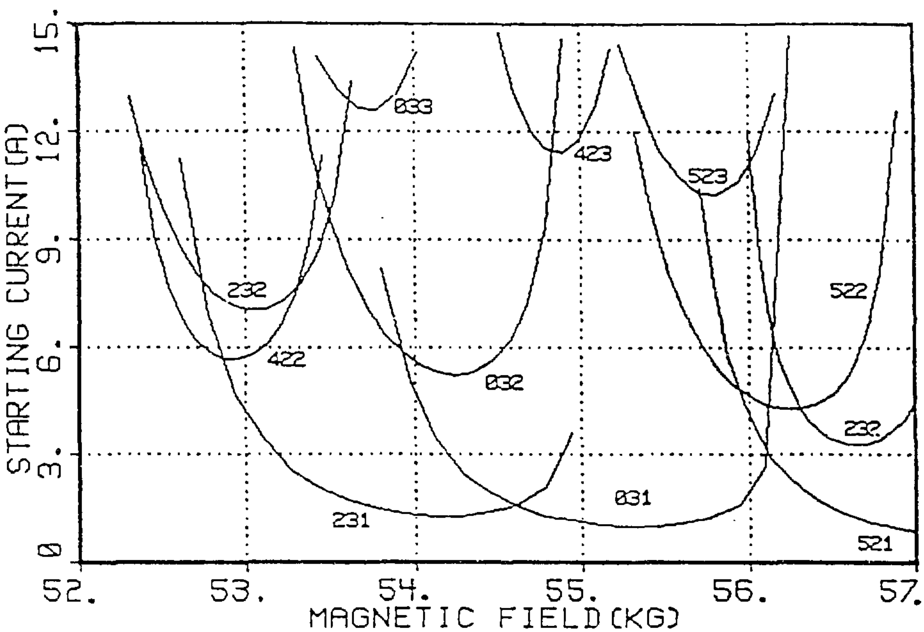

FIG. 2.

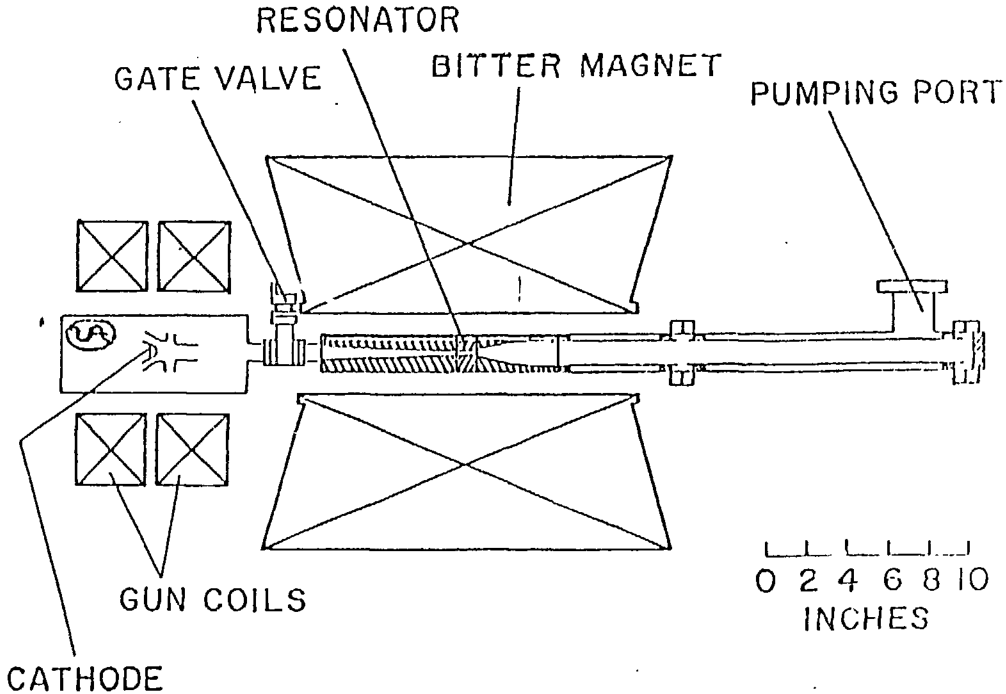

FIG. 3: M.I.T. 140 GHz GYROTRON (PRELIMINARY)