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SEMIANNUAL PROGRESS REPORT NO. 1
ON
FREQUENCY MULTIPLICATION IN HIGH-ENERGY ELECTRON BEAMS

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1. General Introduction (N. A. Masnari)

The basic objectives of this research program are to investigate:

a. interaction of high-energy electron beams with quasi-optical circuits and plasmas (Cerenkov radiation),

b. electron beam-plasma interactions using cold-cathode discharges,

c. nonlinear electron beam-plasma theory, and

d. instabilities in non-Maxwellian plasmas.

This report covers the first six months of effort on the program which was initiated on October 1, 1966. The following sections of the report summarize the status of the various projects and include discussions of results and plans for future investigations.

2. Relativistic Electron-Beam Device

Supervisor: J. E. Rowe

Staff: G. T. Konrad

The object of this phase of the program is the generation of millimeter wavelength radiation by use of a tightly bunched relativistic electron beam. The device to be used for this purpose consists of (1) a 100 kv electron gun capable of producing a beam 2 mm in diameter and carrying a current of 0.1 ampere, (2) a coupled-cavity bunching circuit resonant at approximately 7.5 GHz, (3) a high-voltage anode for accelerating the bunched beam to approximately 600 kv, and (4) a water-cooled beam collector.

The high-voltage anode, in addition to being used for accelerating the beam, also contains an elliptic cavity coupler. The bunched relativistic electron beam passes through a quartz cone which is placed along one focus of the cavity. In so doing the beam radiates power at the harmonics of the bunching frequency by the Cerenkov effect. In particular, the coupling and detecting circuitry have been optimized for the 15th harmonic, which corresponds to a wavelength of 2 mm. At the other focus of the elliptic cavity is located an antenna, which is terminated in a radiating horn for transmitting the 2 mm wavelength radiation to a detector.

Attempts were made on a previous program to operate this device, but poor vacuum conditions precluded the attainment of sufficiently high voltages. At the present time all components of the device are being carefully cleaned and a new vacuum pump has been placed on order and is scheduled for delivery in the near future. Upon arrival of the pump, the device will be prepared for operation and testing will commence shortly thereafter.

3. Beam-Plasma Interactions

Supervisor: R. J. Lomax

Staff: J. D. Gillanders

A computer program has been written to plot the roots of a dispersion relation. This program follows the roots by Runge-Kutta integration of the derivatives of the dispersion relation, after locating the roots by iterated application of a first-order Taylor series correction.

The program was checked out by reproducing the results obtained by Simpson[1] using a different method. The program was then run with finite values of collision frequency and electron temperature included. Small values of collision frequency (on the order of 0.01 times the plasma frequency) have noticeable effects on the gain without noticeable change of the real part of the propagation constant. For larger values of collision frequency (up to half the plasma frequency) both the gain and propagation constants are considerably changed. More definite data is now being collected and studied.

A plasma electron gun of the type described by Boring and Stauffer[2] has been built and tested. This gun has the advantage of not requiring differential pumping which is normally required when a conventional gun is used for beam-plasma studies in the intermediate pressure range around 1 Torr. A system to couple to the beam and plasma generated by this gun is now being built and will be used to study the interaction problem.

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1. Simpson, J. E., "An Instability of a Beam-Generated Plasma in a Uniform Magnetic Field", Tech. Report No. AFAL-TR-66-3, Stanford University, Stanford, California; November, 1965.

2. Boring, K. L. and Stauffer, L. H., "A New Non-Thermionic Electron Gun", Proc. Natl. Electronics Conf., pp. 535-544; 1963.

4. Time-Dependent Nonlinear Analysis of Electron-Beam Plasma Interaction

Supervisor: J. E. Rowe

Staff: A. Lin

Much of the initial effort on this program has been involved with an evaluation of previous beam-plasma interaction studies. In particular, Dawson's reports[1,2,3] have been thoroughly reviewed. The two-dimensional plasma phenomena will be investigated in the near future by using the charge-filament model in which motion is permitted in two directions. An initial position and velocity will be assigned to each filament and the trajectories of all filaments will be followed on a computer by solving the exact equations of motion.

5. Instabilities at Cyclotron Harmonics in a Non-Maxwellian Plasma

(W. D. Getty)

A plasma column in a uniform axial magnetic field can support electrostatic waves that propagate in a direction perpendicular to the magnetic field. The details of these waves have been studied for the Maxwellian plasma by Bernstein[1] and for the

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1. Dawson, J. and Smith, C., "Some Investigations of Plasma Instabilities in One-Dimensional Plasmas", Plasma Physics Lab., Princeton University, Princeton, N. J., Report Matt-152; November, 1962.

2. Dawson, J. and Smith, C., "Some Computer Experiments with a One-Dimensional Plasma Model", Plasma Physics Lab., Princeton University, Princeton, N. J., Report Matt-151; January, 1963.

3. Dawson, J., Shanny, R. A. and Greene, F. M., "Numerical Experiments in Plasma Physics", Plasma Physics Lab., Princeton University, Princeton, N. J., Report Matt-441; July, 1966.

1. Bernstein, I. B., "Waves in a Plasma in a Magnetic Field", Phys. Rev., vol. 109, No. 1, pp. 10-21; 1958.

non-Maxwellian plasma by Crawford and Tataronis[2], Gruber, Klein and Auer[3], and Speck and Bers[4]. In the case of the non-Maxwellian plasma it is found that under certain conditions these transverse electrostatic waves become unstable at frequencies related to the cyclotron frequency of the electrons and its harmonics. The conditions under which instabilities are obtained pertain to plasma density, transverse propagation constant (i.e., plasma column diameter), plasma electron energy and magnetic field strength. The experiment to be described in this report is an attempt to observe these instabilities. The main problem is the production of a sufficiently dense plasma with an appropriate non-Maxwellian velocity distribution.

The instability of the electrostatic wave is of great interest from the point of view of plasma physics because it is a velocity space instability and may be excited and observed under relatively "clean" conditions. It is interesting from the engineering point of view because in principle it makes possible the generation of high microwave frequencies by exciting a high cyclotron harmonic by the instability. In the experiment it is planned to obtain conditions under which the second harmonic becomes unstable as well as the fundamental.

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2. Crawford, F. W. and Tataronis, J. A., "Absolute Instabilities of Perpendicularly Propagating Cyclotron Harmonic Plasma Waves", Jour. Appl. Phys., vol. 36, pp. 2930-2934; September, 1965.

3. Gruber, S., Klein, M. W. and Auer, P. L., "High-Frequency Velocity Space Instabilities", Phys. Fluids, vol. 8, pp. 1504-1509; August, 1965.

4. Speck, C. E. and Bers, A., "Instabilities in Quasi-Static Waves Across B_o", Quarterly Progress Report No. 79, Research Laboratory of Electronics, Massachusetts Institute of Technology; October 15, 1965.

The experimental device is essentially a glass tube containing a triode electron gun and a collector. The glass walls of the tube are electrostatically shielded for stray charge by a cylinder and screen. The entire tube is immersed in a uniform field of 70 to 100 gauss. An electron beam of 10-mm diameter is emitted from the cathode and accelerated by the grid-anode structure to 150 volts energy. The beam current is controlled by the grid independently of the final accelerator voltage, and can be varied from zero to 60 ma. The beam passes through the shielded drift region and is collected. In order to control the ion density in the drift tube, three electrodes have been provided for controlling the space potential along the tube. The center electrode will be biased slightly negative to provide a potential well for ions. Provision is made for control of the background gas pressure up to 10^{-3} Torr. The gas used is hydrogen.

The transverse energy of the electrons is provided by a "corkscrew" winding which transfers a predetermined fraction of the electron axial drift energy into transverse motion. The resulting beam will be monoenergetic in both the axial and transverse directions. It will have approximately 120 eV axial energy and 30 eV transverse energy. The guiding centers of the electrons will be uniformly and randomly spaced across the beam cross section. With the corkscrew turned on, the beam diameter will be approximately 15 mm.

The parameters of this experiment have been chosen in an attempt to reach conditions predicted by Gruber, Klein and Auer[3] to be unstable. This particularly applies to the beam current, beam voltage, magnetic field strength, and beam diameter. The background gas pressure control and the provision for ion trapping has been included to keep the electron beam approximately neutralized. It is therefore intended to have a two-component system consisting only of the electron beam and neutralizing ions. The eventual plan is to operate under "overneutralized" conditions when a background beam-generated plasma will be present.

Two tubes have been built for this experiment. The first tube, which contains only the electron gun and collector, was intended to be a test of the electron gun construction. The gun worked satisfactorily, producing up to 60 ma cathode current with an accelerating voltage of 150 volts and a grid voltage approximately 50 volts positive with respect to the cathode. The second tube contains the ion-trapping electrodes in addition to the electron gun. Improvements have been made in the gun construction and in the cathode (which had insufficient life in the first tube) and the device will be ready for further study in the immediate future.