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A LOW VOLTAGE REPEATER FOR STUDIES OF E-BEAM WAVE INTERACTIONS

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Summary

A long pulse (350 nsec.), low energy (40-80 kV), electron beam repeater has been built for the study of various electron beam wave interactions. Our primary interest is in the fast upper hybrid mode, which we wish to excite such that its phase velocity is equal to the speed of light and hence, is suitable for electron acceleration. The repeater is capable of a 1 Hz pulse rate at current levels of 1.4 kA, well above the space charge current limits of the experiments. Electron beam confinement is provided by a pulsed axial magnetic field of 300 to 1500 Gauss. A study of beam characteristics using radial electric field probes, Faraday cups and Rogowski coils is underway. Results are presented showing the equilibrium beam plasma parameters as a function of the operating conditions. Techniques used for the wave growth are discussed and first results indicated. The wave frequency is chosen to be below the electromagnetic cutoff frequency of the empty guide. Results from the experiment will enable us to scale future experiments for 0.5 MeV, 2.0 kA beams supporting upper hybrid waves in the K-Band. These high frequency waves on these more intense beams may lead to a high gradient (200 MV/m) electron accelerator.

Introduction

A new collective wave electron accelerator proposal has been described elsewhere in the proceedings of this conference (Anselmo and Nation)[1]. The proposed accelerator uses the fast upper hybrid mode for electron acceleration. In order to excite this positive energy mode on the beam, we are proposing to use a parametric excitation technique similar to that employed with FEL's[2], with the idler mode the negative energy upper hybrid or space charge mode. The fast upper hybrid mode is especially attractive as it is the only mode which cuts the light line in a bounded plasma. We have previously reported a successful demonstration of this technique with the parametric excitation of fast and slow space charge waves (Anselmo and Nation, 1985)[3]. Further details on the results of this investigation are also presented else where in these proceedings[4]. In view of the uncertainties in the excitation of these modes we have initiated a program to rapidly explore different techniques for the growth using a low voltage modest 1 Hz repetitive line. In this paper we present a description of the facility and its operating characteristics together with a brief report of the results from the initial wave excitation experiments. Work is also in progress (Seyler)[5] to determine the linear and non linear characteristics of the waves. We also observe that with some modifications, the repetitive line system will be useful for the study of slow space charge waves on very weakly relativistic electron beams. An 80 kV electron beam propagating in a strong magnetic field at a current close to the vacuum limit will support waves with phase velocities low enough to pick up protons with energies as low as a few hundred keV and could well be useful for an high current ion injector.

Experimental Requirements

In order to excite beam cyclotron modes, we have to define the beam parameters needed using the basic theory of the propagation of the waves on an unneutralized electron beam. The theory has been reviewed elsewhere inthese proceedings. The goal of the experiment is use a particle beam of reasonable size, current and energy to rapidly and reasonably easily identify the best techniques to excite the desired modes. In view of the success and simplicity of parametric, three wave techniques, we have chosen to use a fixed period wiggler to couple energy from the negative energy slow upper hybrid or slow space charge modes to the positive energy fast upper hybrid modes. We have the capability of using either an axisymmetric electrostatic or magnetic wiggler. The experimental parameters are largely set by constraints on the wiggler given the beam energy. The size of the device in the transverse direction is dictated by the wiggler period to be used. Once the wiggler periodic length becomes comparable to or less than the the guide diameter, the strength of the wiggler field on axis is significantly diminished. We also require that the guide diameter be small enough such that the excited modes will be below electromagnetic cutoff in the pipe. We choose to set the drift tube diameter to be approximately equal to wiggler period. This simple constraint more or less sets the most important design parameters. The simple approximate, but adequate, dispersion relation

$$\omega = k_z v_d \pm \Omega_c$$

and the Manley-Rowe relations

$$\omega_{\text{fast}} = \omega_{\text{slow}} \quad \text{and} \quad k_{z\ \text{slow}} = k_{z\ \text{fast}} - k_{z\ \text{wiggler}}$$

set the other parameters of the experiment. Furthermore, to ensure we do not interact strongly with the electromagnetic

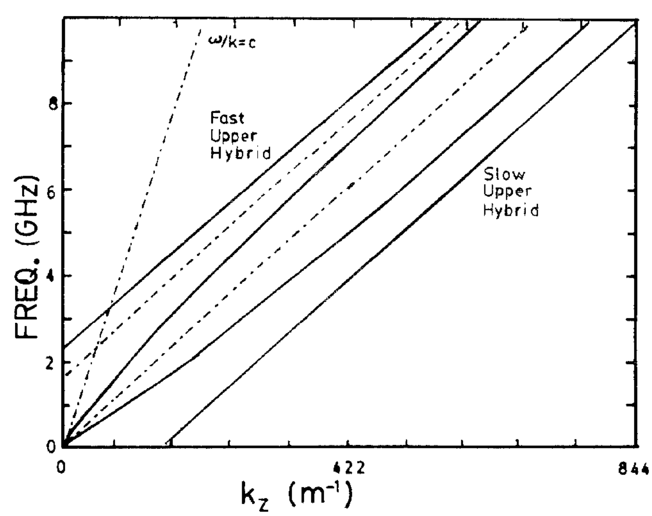

FIGURE 1. Dispersion relation for hybrid wave experiment.

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TABLE I

Experimental Parameters	
Beam Energy	35–45 keV
Beam Current	15–25 A
Pulse Duration	350 nsec
Guide Field	700–1500 Gauss
Wiggler Period	2.0–2.5 cm
Guide Diameter	2.7 cm
Beam Diameter	1.0 cm

modes in the guide, the operating frequency should be less than or approximately equal to empty guide transverse magnetic cutoff frequency. These conditions are simply given by

$$\omega_{co} \approx \frac{eB_0}{m}\left(\frac{1+\beta}{1-\beta}\right)^{1/2} \approx ck_{\text{fast}} \quad \text{and} \quad \lambda_{\text{wiggler}} \approx 2b$$

In addition to these considerations, conditions for beam stability also set a limit on the ratio of the beam plasma to cyclotron frequency. The experimental parameters chosen for this experiment are summarized in Table 1. In figure 1 we show a dispersion relation for the beam system appropriate to the parameters given above. Note that the hybrid modes are closely approximated by the simple Doppler shifted cyclotron oscillations and that the dispersion is small. This introduces an additional problem still to be resolved, that is, we shall probably need to find a means of selecting the operating frequency if we are to maintain a narrow bandwidth operation.

Experimental Configuration

The electron beam is driven from an artificial Blumlein consisting of a number of 3600 pF capacitors connected to each other and to the load via short inductive sections of delay line. The surge impedance of the line is about 18 Ω, a value far lower than that needed to drive the required beam. Most of the stored energy in the line is fed into a copper sulphate load placed across the diode. This also serves to control the cathode

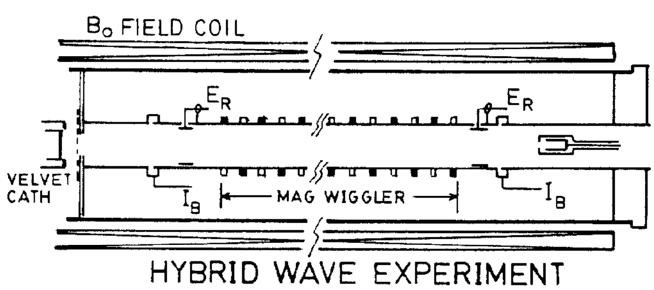

FIGURE 2. Schematic of experimental setup.

voltage throughout the pulse by providing the generator with a constant load. The line is control switched using a pressurized sparkgap. The firing of the line is limited by the time taken to charge an small bank of electrolytic capacitors used to provide the solenoidal magnetic field over the one meter length of the experiment. The use of available power supplies limit the repetition rate to about 1 Hz. Plans are currently in hand to up grade the field system to provide up to an 8 kG. magnetic field over a two meter length using two one meter long coils. With this upgrade we shall also be able to work on the higher current slow space charge wave injector mentioned above. A further refinement of the system is the use of two artificial Blumleins to drive the electron beam. The lines can be separately switched so that they can be operated in series to give an 80 kV, 36 Ω pulse forming line. Presently, we have not utilized this capability. A series of seven such lines have been previously stacked in this manner[7]. The output of the Blumlein feeds a vacuum diode which uses a synthetic velvet cathode emitting surface

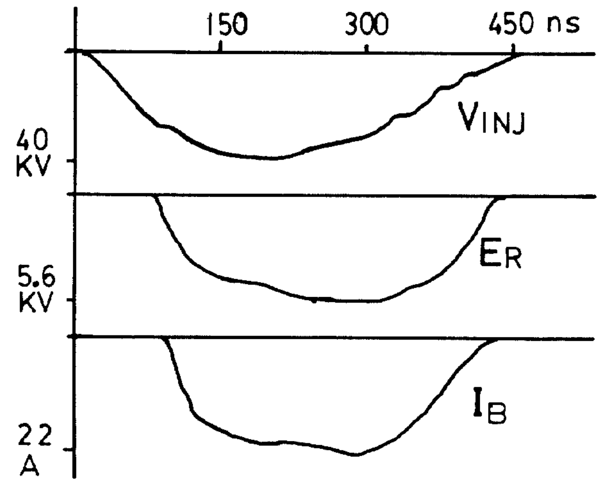

FIGURE 3. Experimental voltage and current waveforms.

to generate the beam. The cathode emitting area is considerably larger than the aperture in the anode plane so that we are only using the central and coolest portion of the beam. The beam enters the drift tube via a highly transparent screen anode. Figure 2 shows the experimental arrangement and figure 3 shows the typical output traces from the generator. The beam current is measured in the drift tube using a Rogowski coil.

We have devoted considerable effort to the alignment of the beam along the axis of the drift tube and to making the magnetic axis coincident with the geometric axis of the pipe. Off axis motion of the unneutralized beam leads to a rotation of the electrons in the relatively weak axial magnetic guide field about the tube axis and gives the beam, at a fixed axial position, a helical profile. The charging voltages for the Blumlein capacitors and for the field supply are digitally controlled and can be set to about 0.5%. This accuracy is required to simultaneously satisfy the momentum and energy conservation requirements for the three wave interaction. Two different

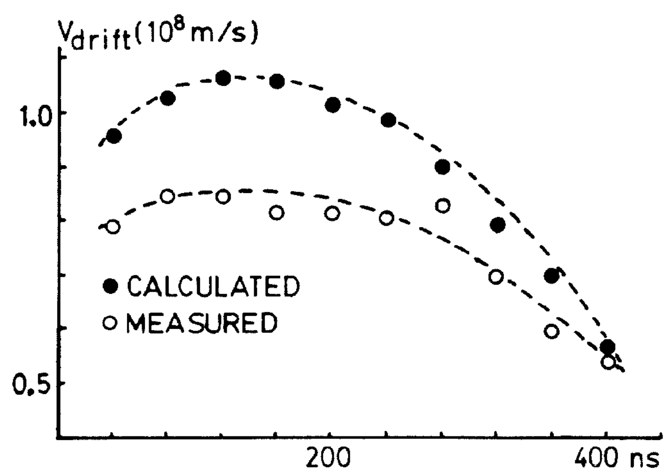

FIGURE 4. Beam drift velocity vs time.

wiggler configurations have been tested. The first, an axisymmetric magnetic wiggler, provides a gentle transition between the uniform axial field and the wiggler section. It is driven by a separate power supply and can produce an axial field variation at the outside edge of the beam of plus or minus 10% of the uniform guide field. The second wiggler configuration uses an electrostatic wiggler produced by placing a D.C. charge on conducting rings located close to the drift tube wall. The peak voltage available is 10% of the diode injection voltage. In both cases the wiggler has a period of either 2.0 or 2.3 cm and is only 40 cm. in length. We expect to excite a 3 GHz wave at a phase velocity close to the speed of light so the wiggler length is only three wavelengths, a value probably too small to ensure good wavegrowth.

Experimental Results

We have studied the beam parameters for a variety of operating conditions. We have obtained our best beams and most stable operation when we have operated at conditions close to those given in table 1. We monitor the beam radial electric field using a capacitive probe located at the drift tube wall and Rogowski coils to measure the beam current. The capacitive probe measures the beam line density so that the ratio of these two signals provides a direct measure of the beam drift velocity. Figure 4 shows the time variation of the average drift velocity of the electrons. We also use a small aperture Faraday cup to measure the radial variations in the beam current density. This is converted to a density variation using the drift velocity values given above. In figure 5 we plot the density variation with radius for the beams used. Table 2 summarizes the results for the beam equilibrium. Values of the square of the ratio of the cyclotron to plasma frequency of ~3 are needed for beam stability.

TABLE II

Beam Equilibrium Parameters

Radial Potential	5 kV
Drift Velocity	.23–.28 c
Beam Density	2.0–3.1 $\times 10^{10}$ cm^{-3}
Plasma Frequency	8–10 $\times 10^{9}$ rad/s
Cyclotron Frequency	1.6–2.4 $\times 10^{10}$ rad/s
ω_c^2/ω_p^2	3.5–7.6

In comparison, we wish to keep the cyclotron frequency as low as possible in order to take advantage of easy beam wave diagnostics at frequencies in the 3 GHz range. We have only carried out preliminary experiments on wavegrowth to date. Both wigglers have been used. Detection systems consist of magnetic pick up loops and capacitive probes feeding crystal detectors via band pass filters. Some signals have been observed during the rise and fall times of the beam but to date no signals have been recorded during the flat portion of the beam pulse. The current detection systems would only give signals of about 1 mV for 1% modulations of the beam current; this value is at the threshold of our detection sensitivity.

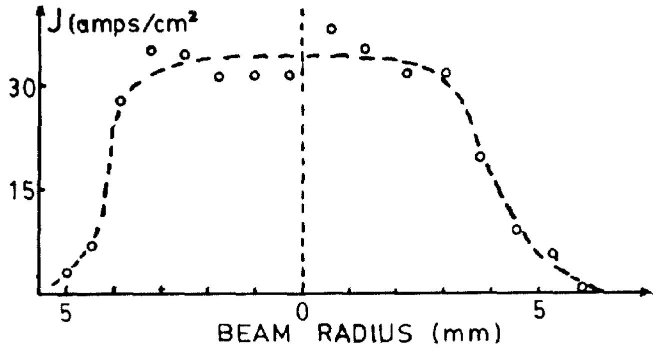

FIGURE 5. Beam current density vs radius.

Future Work

We plan to extend the experimental length to about 2 m and the active wiggler length to 1.5 m in the immediate future. Work is also in progress to initiate operation at higher beam voltages of up to 80 kV. The larger magnetic field capability planned will also allow work on the slow spacecharge wave configuration. We shall continue work with both wigglers and are also considering the use of cavities to preselect the wave frequency. Since the physical realization of the wave is a series of propagating radial constrictions on the beam it seems most likely that the magnetic wigglers should be the most effective means of exciting the required waves.

Conclusions

In conclusion, we have developed a low cost particle beam generator that can be used to explore the interaction of beam supported waves with azimuthally symmetric wigglers. The control and repeatability of the charging systems allows us to examine beam operation in confined flow near the limits set by different theories. The repetitive nature of the device will allow us to rapidly explore excitation techniques for the fast beam cyclotron and low phase velocity slow space charge modes.

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