Instability of the Fast Cyclotron Wave in a Spiral Beam-Plasma System

MEMOIRS OF THE FACULTY OF ENGINEERING
FUKUI UNIVERSITY
VOL.26 No.2 1978

Instability of the Fast Cyclotron Wave in a Spiral Beam-Plasma System

T. Idehara*, M. Tanaka* and Y. Ishida*

The excitation of the fast cyclotron wave is observed in a magnetized plasma penetrated by a spiral electron beam. For the excitation to occur, the beam energy component perpendicular to the magnetic field is larger than about 20 percent of the total energy, which is consistent with the theoretical consideration.

The instability of the wave in a beam-plasma system and its nonlinear development have been investigated with a great interest by many authors. In the case where an electron beam is injected parallel to the external magnetic field into a plasma, the space charge wave of beam has the negative energy and becomes unstable, as the result of the coupling with the plasma wave.[1)] This is called the Cherenkov excitation, which is the most dominant process in the system. However, in the case where a beam is injected obliquely to the external field and has the energy component $E_\perp$ perpendicular to the field, the fast cyclotron wave of beam may also have

---

* Department of Applied Physics

the negative energy and be excited, which is called the cyclotron excitation. In this letter, it is reported that the latter excitation is observed when $E_\perp$ is larger than about 20 percent of the total beam energy E_b $(=E_\perp + E_\parallel)$ and the experimental result can be explained consistently by the theoretical consideration.[2)]

In order to investigate the propagation of waves and their instability due to the interaction of an electron beam with a plasma, it is desired that a Maxwellian plasma is produced and an electron beam is injected into this plasma, parameters of beam being varied independently on those of plasma. Considering such a requirement, we have set up the apparatus which is consisted of three regions, that is, the dc discharge region, the plasma diffused region (or the region of the beam-plasma system) and the beam-generated region. This apparatus has be shown in a previous paper.[1)] The plasma produced by dc discharge in Ar gas (pressure $p_1=1\sim2\times10^{-2}$ Torr) is diffused into the second region ($P_2=1\sim2\times10^{-3}$ Torr) along the line of magnetic force. An electron beam is produced by the Pierce gun in the third region ($P_3=0.8\sim1.0\times10^{-4}$ Torr), and is injected into the second region. The ratio of the beam energy component to the total energy $E_\perp/E_b$ can be varied continuously by varying the beam injection angle θ with respect to the line of force. The parameters of the beam-plasma system are as follows, the plasma density $n_p=5\times10^8 \sim 8\times10^{10}$ cm^{-3}, the electron temperature $kT_e=5\sim10$ eV, the beam density $n_b=1.5\sim4.5\times10^8$ cm^{-3}, the beam temperature $kT_b=0.3$ eV, the total beam energy $E_b=100 \sim 350$ eV, the beam energy component $E_\perp=0\sim80$ eV and the electron cyclotron frequency $\omega_c/2\pi=$ 308 MHz.

The test wave is excited by the coaxial probe situated in the center

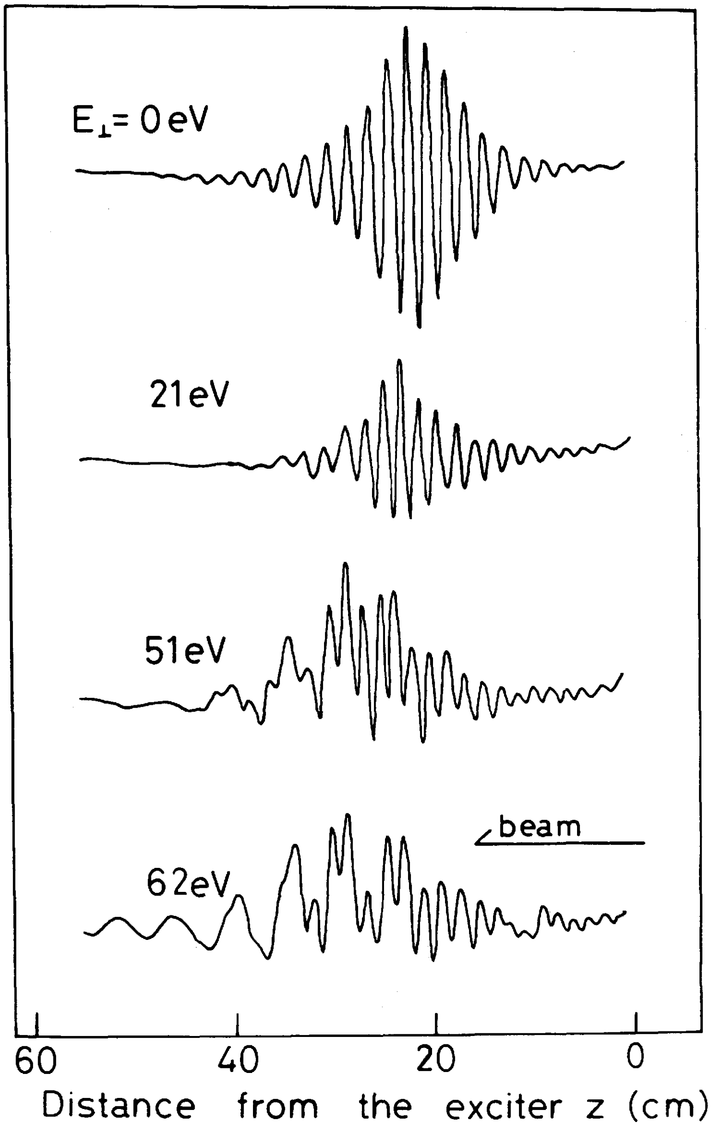

Fig. 1. The propagating wave patterns of test wave with the beam energy component $E_\perp$ as a parameter.

of the beam-plasma system (z=0) and detected by the other probe movable axially. By using the interferometer system, the propagating wave patterns along the field (along the axial direction z) are observed. They are shown in Fig. 1, with the beam energy component $E_{\perp}$ as a parameter. In the case of $E_{\perp}$ =0 eV which is shown in the upper trace, only the Cherenkov excitation can occur and the space charge wave of beam grows along the direction of streaming of electron beam. The wave number $k_{\parallel 1}$ of growing wave satisfies the relation $\omega=k_{\parallel 1}v_{\parallel}$, where $\omega/2\pi$ and $v_{\parallel}$ are the wave frequency and the velocity component of beam parallel to the external field, respectively. This result is the same as that of the previous paper.[1)] On the other hand, for the sufficiently large value of $E_{\perp}$, the other wave of smaller wave number $k_{\parallel 2}$ is seen, overlaping on the space charge wave of wave number $k_{\parallel 1}$.

The similar wave patterns are observed for the fixed value of $E_{\perp}$ (=52 eV) with the exciting frequency $\omega/2\pi$ as a parameter. The wave numbers ($k_{\parallel 1}$ and $k_{\parallel 2}$) of both waves and the amplification factor $k_{\parallel i}$ for the wave of smaller wave number $k_{\parallel 2}$ are estimated from the patterns and plotted in Fig. 2 as functions of $\omega/2\pi$. It is seen that $k_{\parallel 2}$ satifies the excitation condition of the fast cyclotron wave $\omega=k_{\parallel}v_{\parallel}+\omega_c$, though $k_{\parallel 1}$ does the Cherenkov excitation condition $\omega=k_{\parallel}v_{\parallel}$.[1)] Therefore, the former wave may be considered to be the fast cyclotron wave of beam excited in the spiral beam-plasma system.

For the various values of beam parameters $E_{\perp}$ and E_b, the similar experiments are done, the results of which are shown in Fig. 3. Solid circles show the occurence of the excitation of fast cyclotron wave.

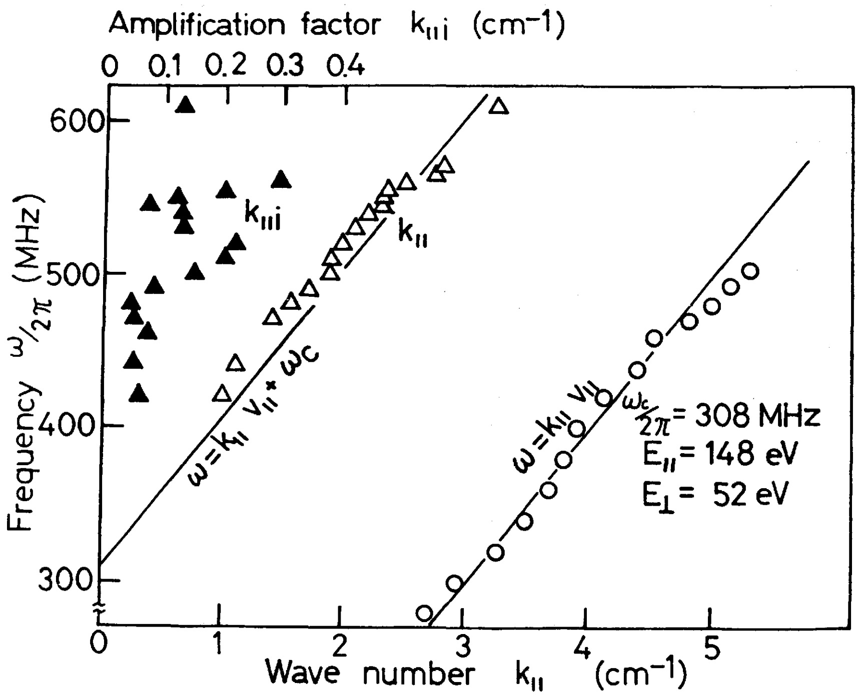

Fig. 2 The wave number $k_{\parallel}$ and the amplification factor $k_{\parallel i}$ as functions of the wave frequency $\omega/2\pi$. Hollow circles and hollow triangles show the wave numbers corresponding to Cherenkov and fast cyclotron excitations. Solid triangles show the amplification factor corresponding to the latter excitation.

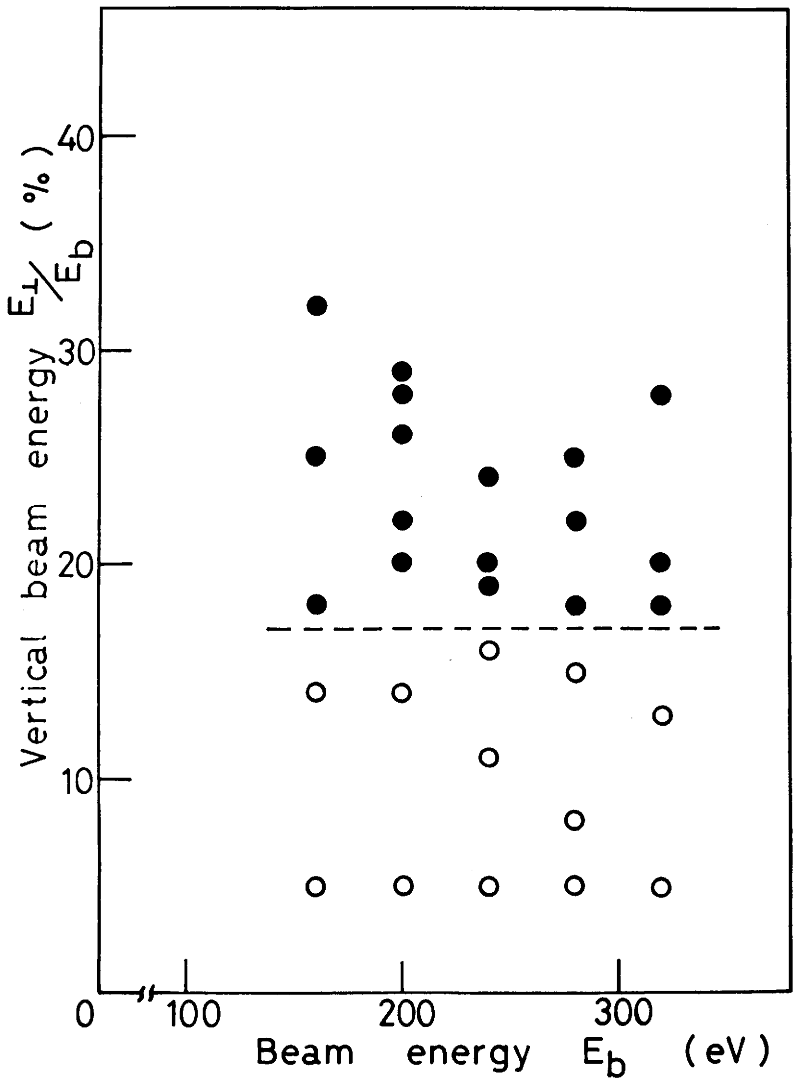

Fig. 3 The conditions for the fast cyclotron excitation to occur. Solid circles show the occurence of the excitation.

When the ratio $E_\perp/E_b$ is larger than about 20 percent, the excitation does occur. This fact is consistent with Seidl's consideration,[2] which shows that the threshold value of $E_\perp$ exists for the fast cyclotron wave to become unstable. For example, if the distribution function of spiral electron beam is assumed to be

$$f_b = \frac{1}{\pi v_{\perp 0}^2} \left(\frac{v_\perp}{v_{\perp 0}} \right)^2 \exp\left(- \frac{v_\perp^2}{v_{\perp 0}^2} \right) \delta(v_\parallel - v_{\parallel 0}), \qquad (1)$$

the threshold value of E is determined from the condition,

$$\frac{k_\perp^2 v_{\perp 0}^2}{2 \omega_c^2} > 1.6, \qquad (2)$$

where $k_\perp$ and $v_\perp$ show the wave number component and the beam velocity component perpendicular to the external field. From the observation of wave patterns propagating radially, it is known that the value of $k_\perp$ of the unstable wave lies in the region of $10<k_\perp<20$. For these values of $k_\perp$ and $\omega_c/2\pi = 308$ MHz, the experimentally obtained values of $E_\perp$ corresponding to the occurence of fast cyclotron wave excitation satisfy the above condition (eq. (2)).

It is concluded that the fast cyclotron wave of beam becomes unstable when the spiral electron beam is injected into the plasma, and the threshold value of $E_\perp$ for the instability is explained consistently by the theoretical consideration.

This work was partially supported by the Grant-in-Aid from the Ministry of Education of Japan.

References

1) For example, T. Idehara, N. Miyama and Y. Ishida, J. Phys. Soc. Japan 42 (1977) 1730.

2) M. Seidl, Phys. of Fluids 4 (1970) 966.