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Study of energy transfer by electron cyclotron resonance in tokamak plasma

Ghoutia Naima Sabri*[a], Tayeb Benouaz[b]

[a]*University of Bechar, B.P417,Bechar 08000,Algeria*
[b]*University of Tlemcen,B.P 119,Tlemcen 13000, Algeria*

Abstract

A theoretical study of energy transfer by electron cyclotron resonance to tokamak plasma is presented. Then the predictions of linear theory including relativistic effects on the wave absorption are examined. Electron-cyclotron (EC) absorption in tokamak plasma is based on interaction between wave and electron cyclotron movement when the electron passes through a layer of resonance at a fixed frequency which depends on the magnetic field. This technique is the principle of additional heating (ECRH) and the generation of non-inductive current drive (ECCD) in modern fusion devices. The power absorbed depends on the optical depth which in turn depends on coefficient of absorption and the order of the excited harmonic for O-mode or X-mode.

Keywords: Energy; transfer; electron cyclotron; resonance; tokamak; heating.

1. Introduction

The need to have a secure and clean supply of energy for our growing industrial civilization has led us to search for alternative supplies of energy. Energy produced from thermonuclear fusion reactions had been known for some decades in the sun and stars, is likely safe and don't produces greenhouse gas emissions and its radioactive wastes is less expensive to manage.

These reactions require special conditions of temperature (100 million degrees) and pressure. In this case, the more promoter configuration to realize them is tokamak which is a machine governed by Lawson

* Corresponding author. Tel.: +213-773146965; fax: +213-49815244.
E-mail address: sabri_nm@yahoo.fr.

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criterion [1], $nTt_E \geq 5.10^{21}\ m^{-3}keVs$ and to achieve these high temperatures, it is necessary to heat the plasma. The ohmic regime is a primary natural mechanism of heating. Unfortunately, this effect is proportional to the resistance of the plasma which tends to collapse when the temperature increases. We therefore use additional heating systems. Radio-frequency heating is one of important of these systems. This phenomenon occurs if the waves have a particular frequency (the same as charged particles frequency), their energy can be transferred to the charged particles in the plasma, which in turn collide with other plasma particles, thus increasing the temperature of the bulk plasma.

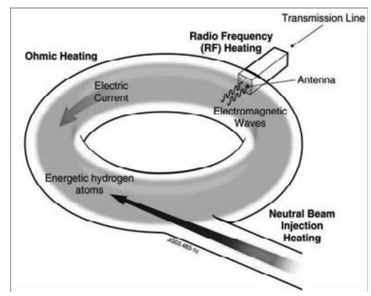


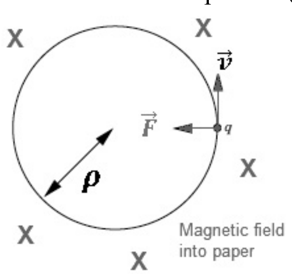
Fig. 1. (a) Tokamak machine- ITER; (b) Heating methods

According the frequency range, there are three main types of radio-frequency heating [2]:

- The heating at the ion cyclotron frequency (ICF): a few tens of megahertz (MHz).
- The heating at hybrid frequency: a few gigahertzes (GHz).
- The heating at the electron cyclotron frequency (ECF): the hundreds of (GHz).

2. Electron Cyclotron Frequency

If the particle is an electron $q = -e$; its frequency of rotation ω_{ce} is called the electron cyclotron frequency given by $\omega_{ce} = 2\pi f_c = \frac{e\,B}{\gamma m_e}$. Where $\gamma = 1/\sqrt{1 - (v/c)^2}$ [3], the relativistic Lorentz factor, $\gamma = 1$ for a non-relativistic plasma (v << c).



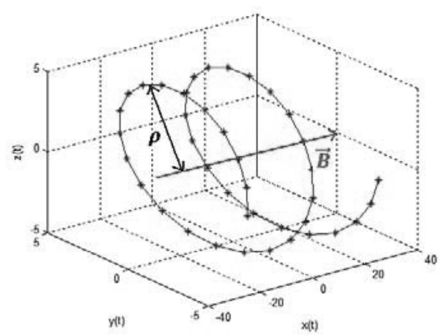


Fig. 2. (a) Effect of magnetic field on charged particle (b) spiral trajectory of charged particle

The radius of the circular rotation is called Larmor radius given by