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RESEARCH ARTICLE

Behavior of Antenna Spectral Form Factor for Wave Mode for Plasma Heating

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ABSTRACT:

Since we know plasma is the fourth state of matter. It is collection of ionized charged particles. To create and confine the plasma particles, we need a toroidal device, called tokamak. To create plasma in the center of the device we need toroidal as well as poloidal magnetic fields. Through such fields poloidal as well as toroidal currents will be created in the device. Plasma be heated with the help of following methods:

1. Ohmic Heating
2. Radio Frequency Heating
3. Neutral Beam Injection Heating

Antenna spectral form factor depends on the antenna geometry and the antenna current distribution and is independent of the plasma coupling conditions. The form factor determines the relative contributions of various ranges of k_z.

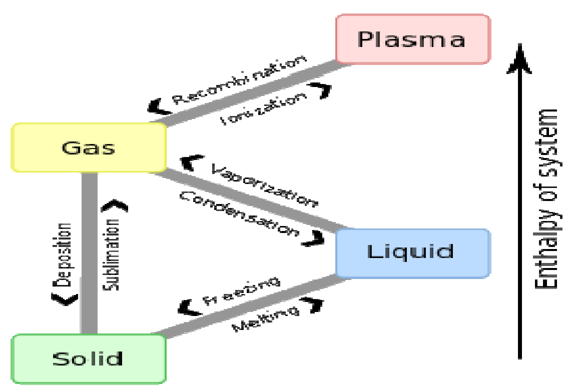
KEY WORDS: Tokamak ; ICRH ; Wave mode ; Controlled fusion ; Antenna length ; Spectral Form Factor ; Refractive index

I. INTRODUCTION:

A plasma is a hot ionized gas consisting of approximately equal numbers of positively charged ions and negatively charged electrons. The characteristics of plasmas are significantly different from those of ordinary neutral gases so that plasmas are considered a distinct "fourth state of matter." Plasma is a quasi-neutral gas of charged and neutral particles which exhibits collective behavior.

The word plasma comes from the Greek and means “something moulded”. It is described as the inner region, remote from the boundaries, of a glowing ionized gas produced by electric discharged in a tube, the ionized gas electrically neutral.

If sufficient energy is provided, a molecular gas. It will gradually dissociate into atomic gas as a result of collision between those particles whose thermal kinetic energy exceeds the molecular binding energy at sufficiently elevated temperatures an increasing fraction of the atoms will acquires enough kinetic energy to overcome the binding energy of the outermost orbital electrons.



A. PLASMA HEATING

When sufficient energy is provided to a molecular gas. It will gradually dissociate into atomic gas. Which result in collision between those particles whose thermal kinetic energy exceeds the molecular binding energy at sufficiently elevated temperatures.

For initial heating, a conductive plasma is heated by passing current through its resistance. This resistance decreases with increasing in temperature. To initiate a sustained fusion reaction, it is necessary to use different methods to heat the plasma. These methods are RF heating, Electron Cyclotron Resonance Heating (ECRH), Ion Cyclotron Resonance Heating (ICRH), and Neutral Beam Injection (NBI) heating.

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B. TYPES OF HEATING

Plasma be heated with the help of following methods:

1. Ohmic Heating.
2. Radio Frequency Heating.
3. Neutral Beam Injection Heating.

1. OHMIC HEATING

Ohmic Heating is the process in which an electric current is used to heat any material. In this process the current is passed through the conductor which results in the emission of heat. Ohmic heating alone cannot be used for plasma heating as plasma loses it efficiency with increasing temperature.

2. RADIO FREQUENCY (RF) HEATING

Radio frequency (RF) heating is one of the most successful auxiliary heating method for plasma. Till now different frequencies with different ranges have been tried in different experiments related to plasma. Ion cyclotron resonance frequency (ICRF) range has been very successfully used in tokamaks for different power levels. The rate of electrical oscillation which corresponds to frequency of radio waves and alternating current carries radio signals. These oscillations may be from 3 KHz to 300 GHz. Cyclotron is a type of Particle Accelerator, which accelerate charged particle, in the direction outward from centre along spherical path. These particles are held to spherical trajectory by static and magnetic fields and rapidly varying electric field.

It is an economic source of plasma heating and can be handled easily because:

a) The depth of penetration of radio frequency (RF) depends on its frequency.
b) Through this processes heating of material can be confined to a limited area and which results in high heating rates.
c) High heating reduces the possibility of oxidation.
d) Heating can be done in vacuum as well as in presence of any gas.
e) Continuous energy is not required.
f) Heating process is pollution free.

3. NEUTRAL BEAM INJECTION (NBI) HEATING

It involves injection of high-energy beam of neutral atoms like deuterium (isotope of hydrogen), into the core of the plasma. These energetic atoms transfer their energy to the plasma, raising the overall temperature.

C. WAVE MODES

On heating plasma different waves are formed which can be categorized as following:

- Slow wave: are sensitive to fundamental resonance and not excitable in toroidal geometry.
- Fast wave: are not sensitive to fundamental resonance but excitable in toroidal geometry.
- Ion Bernstein wave: are perpendicular to propagating warm waves of plasma, the solution for each species, near to harmonic of the cyclotron frequency.

I. THEORY

Elementary wave coupling theory is the technical parts of the launching systems is power coupling. The electron frequencies are much higher than all other frequencies due to the smallness of m_e / m_i.

The simplest case of launcher and coupling is that of electron cyclotron waves in large machines. In this case, the wavelength of the vacuum wave ($k_0 = \omega / c$ is the vacuum wave vector) $\lambda = 2\pi / k_0$, is very small as compared to the plasma cross-section. The wave is launched as a propagating wave pencil that will progressively convert to a plasma wave. Because of the smallness of the wavelength, the boundary conditions at the conducting wall of the machine, as well as on the launching structure, does not play explicit role. The wave can be accurately described in the geometric optics limit and the only boundary conditions that matter are the initial launching angle and reflections at the wall, if any.

If the vacuum wavelength becomes comparable to the antenna structure, the scale length of variations of edge plasma parameters or the plasma radius, the launcher environment and the plasma will affect the coupling process and a full boundary-value problem has to be solved to describe it.

In Antenna –plasma coupling, properties of plasma in central region are weaker than that of edge region. This property is used to for selecting the average density and ion temperature. These parameters can be determined by using :-

- Uniform model for various combinations of parameters.
- Kinetic effects of wave absorption in non-uniform plasma.
- Reflection form boundary to study fast-wave antenna coupling.
- Antenna is orthogonal to the magnetic field, which couples to fast-wave.

The Antenna Spectral Form Factor for Wave Mode depends only on the antenna geometry and the antenna current distribution. This form factor is independent of the coupling conditions to the plasma. The form factor is therefore is a weighting function which determines the relative contributions of various ranges of k_z in $Z_s (k_z)$ to the actual antenna input impedance. The Spectral form factor for $2l_y = 0.2$ m and for various l_z, showing the expected trend of spectrum broadening for smaller l_z. The corresponding antenna input impedances have been evaluated from the equation.

II. CALCULATIONS AND FORMULAS

A general theory of plasma wave, finite temperature effects and spatial gradient effect is complicated specially for fast wave and Ion Bernstein wave. Using Maxwell's equations (SI units) and Fourier Transformed in time, we get a propagation vector. The propagation vector provide the solution for the wave mode having antenna length in y-direction i.e. $2\,l_y$=0.2 m.

The antenna spectral form factor can be calculated by the formula as below

$$F (k_z) = (\pi^2 . l_z^2 . S^2 (k_z)) / (32. l_y) \qquad \text{……………….(1)}$$

where the antenna spectral function is defined by

$$S (k_z) = \cos (k_z l_z) / (k_z^2 l_z^2 - \pi^2 /4) \qquad \text{…………….(2)}$$

l_y and l_z are half-widths of the antenna in the y- and z-directions.

The equation (1) depends only on the antenna geometry and antenna current distribution and is independent of the coupling conditions to the plasma.

Plots For Various antenna length in z direction
Antenna Spectral Form Factor for different half width antenna.

Figure 1; Graph of n_z verses l_z (half-widths of the antenna in the z- direction) for l_z = 0.1m , 0.2 m, 0.3 m.

Figure 2, Graph of n_z to l_z (half-widths of the antenna in the z-direction) for l_z = 0.4m, 0.5m, 0.6m

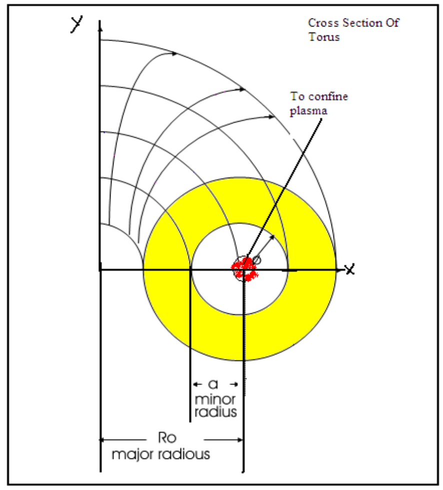

Fig.3 Cross section of Torus

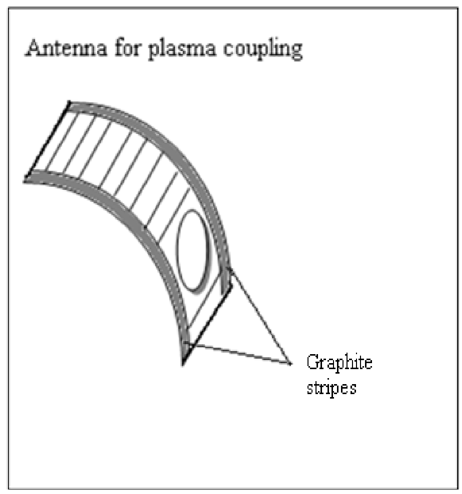

Fig. 4 Antenna for plasma coupling

Table 1 Aditya Tokamak parameters

Tokamak parameter	Aditya Tokamak
Major radius (m)	0.75
Minor radius (m)	0.25
Toroidal magnetic field ,T	1.5
Poloidal magnetic field ,T	0.5
Applied rf at center of the device ($1.5\omega_{ciHf}$), MHz	$34.451584272 \times 10^{6}$
Deuterium percentage	0.0%
Ref.-index in z-direction	7.5
Edge ion density (m^{-3})	1.0×10^{17}
Edge electron density m^{-3}	1.0×10^{17}
Maximum ion density m^{-3}	1.0×10^{17}
Max. electron density m^{-3}	1.0×10^{17}
Edge ion temperature (eV)	150.0
Edge electron temp. (eV)	150.0
Max. ion temperature eV	150.0
Max. electron temp. (eV)	150.0
Antenna length in y-direction l_y (m)	0.1
Antenna length in z-direction l_z (m)	0.25
Distance between plasma to wall ν (m)	0.04
Distance between plasma to antenna δ (m)	0.02
Antenna current I (amp)	100.0

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IV. CONCLUSION:

The dispersion relation given by equations has been changed if we add the polodidal magnetic field and n_y i.e. the refractive index in y-direction. Since the analytical solution of the roots is very complicated, so we have developed a computer code for solving the roots of the polynomial in n_x. The data has been changed on addition of these terms and there is a partial change in the ion Bernstein wave, fast wave and slow wave. Due to complexity in the analytical solution for antenna plasma matching part, we have neglected n_y. The form factor which depends only on the antenna geometry and antenna current distribution and is independent of the coupling conditions to the plasma. By using Aditya Tokamak parameters table1and taking l_z = 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.5 m, 0.6 m we get the plots, which help in antenna design. Figure 1, 2

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