BEHAVIOR OF ANTENNA INPUT SPECTRAL IMPEDANCE FOR REACTANCE IN ADITYA TOKAMAK GEOMETRY

DR. APARNA BORKAR , DR. M.S. GUPTA

Abstract : Several waves often propagate in a plasma at a fixed frequency. They usually do not interact with each other because they have different wavelengths. The power associated with one branch may however be transferred to the other in a process called linear mode conversion. The slow ion-Bernstein wave (IBW) is studied at the second harmonic cyclotron resonance, taking into account the specific geometry of the Aditya tokamak. At very high frequency optical transmission is also possible. Some matching circuitry has to be incorporated in the transmission system in order to prevent the reflected power to come back to the generator. The transmission line is connected to antenna that will couple the power inside the machine's vacuum chamber. The behavior of reactance has been seen through the plot.

Keywords : Plasma heating, Tokamak, Ion- Bernstein wave, Input spectral Impedance.

Introduction : The most commonly known state of matters are – Solid, Liquid, Gas. But there is also 4^{th} state of matter called _'PLASMA' which is mostly found in universe. Plasma is a mixture of electron gas and a hot ionized gas consisting of approximately equal parts of charged positive ions and negative electrons.Fig.1. Since plasma is an electrically charged particle, it is characterized by a strong influence of electric and magnetic field, which is different from characteristic of a neutral gas. Hence it is the 4^{th} state of matter.A tokamak is a torus shaped device which is used to confine a plasma, by using magnetic field. To achieve a stable plasma equilibrium, magnetic field is introduced that move around the torus in a helical path.Fig.2. The helical path is generated by adding toroidal field and poloidal field. The toroidal field is generated electromagnetically which travel around the torus in circle. And the poloidal field is generated by electrical current which flows inside the plasma, induced with the second set of electromagnets, and it travels in circle orthogonal to toroidal field.

Plasma is a quasi-neutral gas of charged and neutral particles which exhibits collective behavior. It has as a collection of mobile, charged and neutral particles which shows a collective behavior by way of long range interaction and can sustain oscillations of different types. So to confine the plasma the fusion processes can be used. The plasma is heated in controlled fusion by coupling RF power to plasma waves in the ICRF (ion cyclotron rang of frequencies). By heating plasma different waves are formed which can be differentiated as: Slow wave, fast wave and Ion Bernstein wave. The Slow wave are sensitive to fundamental resonance and not excitable in toroidal geometry where as Fast wave are not sensitive to fundamental resonance but excitable in toroidal geometry. IBW (Ion Bernstein wave) are perpendicular to propagating warm waves of plasma, which is the solution for each species, near to harmonic of the cyclotron frequency. Amongst these waves the Ion Bernstein waves (IBWs) have been proposed as useful for heating and improving transport in tokamak plasmas.

Theory : For plasma heating in tokamak by ICRF, is the processes of coupling of external RF power to the plasma. This can be implemented by introducing RF current carrying conductors placed near the plasma wall.

In an ionized gas plasma antenna, a gas is ionized to create a plasma, which have very high electrical conductivity. So it is possible for RF signals to travel through them so that they act as a driven element to radiate or to receive them. Alternatively the plasma can be used as a reflector or a lens to guide and focus radio waves from another source.

The coupling of ion cyclotron range of frequencies power from a slow wave antenna to the plasma with finite temperature is examined theoretically and compared to an independent computer calculation. It is shown that such antennas can be highly efficient in transferring most of the antenna power directly to ion Bernstein waves, with only a very small fraction going into fast waves.

The antenna - plasma coupling characteristics in the presence of poloidal magnetic field, the developed theory for α - species (ions, electrons, and helium) has been modified. The component of electromagnetic field has been derived for the different region. These regions are, in the plasma, between the plasma-antenna and between the plasma and the wall. In this paper we have discussed about the component of electromagnetic field between the antenna and the wall.

The numerical analysis of such developed theory shows that the poloidal magnetic field affects the plasma characteristics and power partition for the wave modes. Fig.2. Thus we see that the poloidal magnetic field should not avoid from the Aditya tokamak geometry.

The absorption and propagation of the wave in the ion-cyclotron range of frequencies for radio frequency heating have been investigated using kinetic theory. Generally cubic dispersion relation in the form of the square of the refractive index with coefficient of plasma parameters, contains two modes satisfying the cold plasma theory and the remaining one correspond to the ion Bernstein wave. Sy. W. N.-C., et al [1] had developed a dispersion relation and theory for characteristics of antenna plasma coupling for JIPPT-IIU tokamak plasmas.

Calculation : In this paper we have discussed about the component of electromagnetic field between the antenna and the wall. Particularly, the intrinsic spectral impedance especially for reactance has been discussed. For calculation of Intrinsic spectral impedance, mathematical modeling of The Maxwell's equations are used.

For antenna-plasma coupling, spatial Fourier transform may carried in y- and z- directions. For simplicity, k_y=0. This will lead to overestimate for coupling to slow waves.

ξ is introduced as dimensionless variable as

$$\xi = \frac{x\omega}{c} \quad \text{.................................(1)}$$

The formal solution for the electromagnetic field in the vacuum is determined by the boundary conditions.

And at antenna $\xi = \delta$

Whereas

At the conducting wall $\xi = \beta$

The component of electromagnetic field between the antenna and the wall parallel to the current is given by

$$E_z = -Z_s(n_z) j_A \quad \text{.......................(2)}$$

Where,

$$Z_s(n_z) = -i\mu_0 cn\left(\frac{\sin(n\beta - n\delta)}{\cos n\delta}\right) \times \left[\cos n\delta + n\frac{\sin(n\beta - n\delta)}{\cos n\delta}\,\frac{\vec{v}.(\vec{n}\times\vec{Y})}{\vec{X}.(\vec{n}\times\vec{Y})}\right]$$

.................(3)

$$\vec{j}_A(Z) = \frac{\pi I}{4l_y}\cos\left(\frac{\pi I}{4l_z}\right)H(Z, l_z)\vec{e}_z \quad \text{.....(4)}$$

l_y and l_z are half-widths of the antenna in the y- and z- direction, which are fixed for slow wave.

I = Average antenna current

$H(Z, l_z)$ = Heavyside step function for $-l_z \le z \le l_z$

$$\vec{J}_z(k_z) = (-\pi Il_z).(S(k_z)\vec{e}_z) \quad \text{............. (5)}$$

Where j can be calculated by eliminating the constants for vacuum electromagnetic fields,

$$j = c\mu_0 j_A \quad \text{............................ (6)}$$

And

$$J = nj\frac{\sin(n\delta - n\beta)}{\cos n\beta} \quad \text{............................ (7)}$$

And $n = 1 - n_z^{\,2}$

At the position of the antenna and the wall, $Z_s(n_z)$ is independent of the shape, size and other spectral characteristics of the antenna. $Z_s(n_z)$ is called the intrinsic spectral impedance of the antenna. It measure the inherent ability of the antenna to couple the power to the plasma as a function of the plasma parameters.We have calculated intrinsic spectral impedance of the antenna, which is defined by the equation (3), which includes the equations (1), (2), (4), (5), (6) and (7).

Units :

The Aditya Tokamak parameters are used for the calculation. We used SI (MKS) units for calculation. Table1shows the different values of these parameters in SI units.

Figures And Tables

Figure 1 Formation of plasma from gas fields.

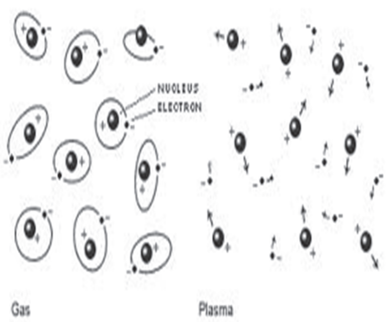
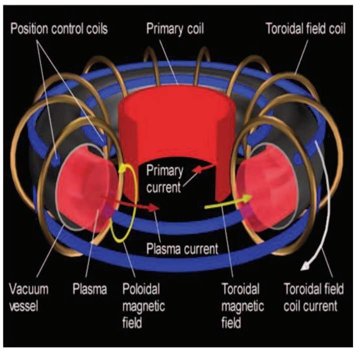


Figure 2 Formation of plasma by electromagnetic



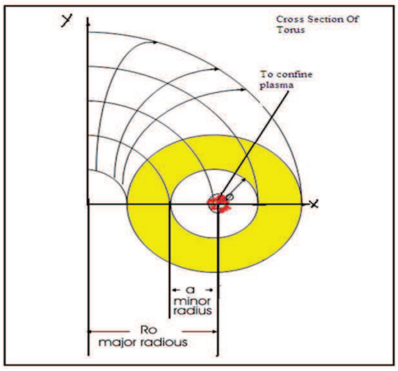


Figure 3 Cross section of Torus

Table 2(a), the distance between the antenna and conducting wall

Distance between plasma to wall v (m)	0.04
Distance between plasma to antenna δ (m)	0.02

Table 2(b), the distance between the antenna and conducting wall

Distance between plasma to wall v (m)	0.03
Distance between plasma to antenna δ (m)	0.01

Table 2(c), the distance between the antenna and conducting wall

Distance between plasma to wall v (m)	0.05
Distance between plasma to antenna δ (m)	0.03

Figure 4 Intrinsic spectral impedance versus refractive index for reactants for Aditya tokamak

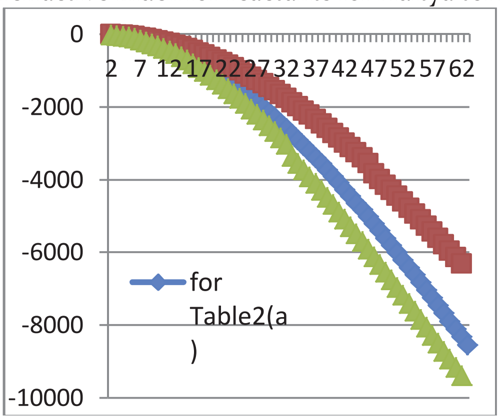


Table 1 Parameters of Aditya Tokamak

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	34.451584272×10^6
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
Antenna current I (amp)	100.0

Conclusion : From the complicated equations we can calculate intrinsic spectral impedance, partition to ion Bernstein wave, fast wave and slow wave and its characteristics. Since the analytical solution is very complicated, so we have developed a computer code for the characteristics of ion Bernstein wave, fast wave, and slow wave. From the developed computer code we can vary the antenna length in y- and z-direction, applied radio frequency, toroidal magnetic field, edge ion density, maximum ion density, edge electron density, maximum electron density, edge ion temperature, maximum ion temperature, edge electron temperature, maximum electron temperature, deuterium percentage etc. On varying these parameters the maximum efficiency can be obtain. By using Aditya Tokamak parameters,Table1, Table 2(a), 2(b), 2(c), the plots are developed for intrinsic spectral impedance for different values. By changing the distance between the antenna and conducting wall we get these results. This shows that by adjusting antenna position, reactants shows deflection. Figure4.

Acknowledgement :
We thank Kruti Institute of Technology and Engineering, Raipur, for providing material required to complete this paper. Our special thanks for Dr. S. V. Kulkarni, IPR, Gandhinagar, Gujarat, India

References :

1. SY,W.N.-C.,T.AMANO, ANDO R., FUKUYAMA, A., Slow-Wave Antenna Coupling To Ion Bernstein Waves For Plasma Heating In ICRF. Nucl. Fusion, Vol.25, No.7(1985).
2. STIX,T.H., The theory of plasma , McGraw-Hill, New York (1962) 10 to 50.
3. J. Phys. Soc. Jpn. 48 (1980) 95.
4. JACQUINOT, J., McVEY, B.D.SHARER, J.E. Phys. Rve. Lett. 39 (1977)88.
5. SWANSON, D.G., NGAN, Y.C., Phys. Rve. Lett. 35(1975)517.
6. ONO, M, STIX T.H. , WONG, K.L. HORTON, R. in Heating in Toroidal Plasma (Proc. 2nd Joint Verenna Grenoble Int. Symp. Como.1980)Vol. 1 commision of the European Communities. Directorate GeneralXXII. Fusion pgorgamme, Brussels (1980)593.
7. PURI , S. Phys , Fluid 22(1979).716.
8. ONO,N., WURDEN, G.A.,WONG, K.L., Phys. Rev. Lett. 52(1984)37.
9. WATARI,T., ONO,M., ANDO R., FUJITA, J., HIROKURA, Y.,et al, ibid. p. 419.
10. SY,W.N.-C.,COTSAFTIS, M., Plasma Phys 21 (1979) 985
11. FUKUYAMA, A., NISHIYAMA, S., ITOH. K., ITOH,S.-I. Nucl. Fusion 23 (1983) 1005.
12. BHATNAGAR,V.P.,KOCH,R.,MESSIAEN,A.M., WEYNANTS,R.R., Nucl Fusion 22 (1982) 280.
13. Figure 1-2 taken from net (hot plasma diagram

***

Principal, Kruti School Of Business Management,H.O.D. Department of Mathematics,
Kruti Institute of Technology & Engineering, Knowledge Village, Nardaha, Raipur (C.G.),India.Pin-492001
Mob. 09926114431, 09424204333. E-mail : appi.borkar@gmail.com

I/c H.O.D. Department of I.T., Department of Mathematics, Govt. N.P.G. College of Science,
G.E. Road, Raipur (C.G.), India. Pin- 492010,Mob. 094255-08074, E-mail : ms_gupta1965@yahoo.co.in