ISSN: 2582-8118 *Volume 2, Issue 2; March 2022*

INTERNATIONAL JOURNAL OF RESEARCH AND ANALYSIS IN SCIENCE AND ENGINEERING

Web: https://www.iarj.in/index.php/ijrase/index

7. Properties of Radio Frequency Heated Argon Confined Uranium Plasmas

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ABSTRACT

To help with the development of the technology required to create a self-critical fissioning uranium plasma core reactor, an experimental examination was carried out using 80 kW and 1.2 MW RF induction heating facilities. Plamas core nuclear reactors' features were studied by injecting pure uranium hexafluoride (UF6) into steady-state argon confinement plasmas and heating them with radio frequency (RF). The goals were to: 1) keep the uranium vapour concentration as high as possible in the plasma while minimising the deposition of uranium compound walls; 2) develop and test materials and handling techniques for use with high-temperature, high-pressure gaseous UF6; and 3) develop complementary diagnostic instruments and measurement techniques to characterise the uranium plasma and residue deposited on the tesserae. A fused-silica cylindrical test chamber contained the plasma in all tests, which was a fluid-mechanically-confined vortex. The perimeter of the test chamber was 5.7 cm in diameter and 10 cm long.

KEYWORDS:

Radio-Frequency, RF, Plasma, UF6 , tokamak, Argon Confined, Uranium Plasmas.

Introduction:

In a plasma, the atoms have been significantly ionised, resulting in a gas with a high level of ionisation. Consequently, it is a good conductor of electricity and is susceptible to the effects of magnetism. In a fused silica peripheral wall test chamber with an argon-contained, steady state, rf-heated plasma, pure uranium hexafluoride (UF_6) was injected.

To find the best confinement properties and the least amount of uranium compound wall coating, preliminary tests were carried out utilising an 80-kW rf facility with various test chamber flow configurations. [1]

Using lengthy injection durations of pure UF6 into an argon-contained, high-temperature, high-pressure, rf-heated plasma, the test findings showed that flow schemes and diagnostic procedures for fluid mechanical confinement and characterization of uranium within an rf plasma discharge were suitable. [2]

For studying the impact of rapidly changing plasmas on electromagnetic wave propagation, a plasma sheath generator and diagnostic system have been built to imitate reentry plasma sheath circumstances.

The plasma chamber has a width of 400 mm and a length of 240 mm, with a clear aperture of 300 mm in diameter. Densities of electrons per cubic centimetre produced are in the range of 1010 to 1015.

The plasma is created by capacitively coupling an 800 W RF generator to an internally cooled stainless steel electrode through an RF matcher and matcher. [3] At different frequencies, the waveform generator produces amplitude modulation of the RF power.

The fluctuating power levels produce electron density modulations in the ensuing plasma. The source and detector of probe radiation are a pair of 10 GHz microwave horn antennas located on either side of the chamber. Splitting the microwave power to the source horn, one component is supplied straight to an oscilloscope for high-speed recording. [4]

The plasma-induced phase shift between the two signals yields the path-integrated electron density with its whole time-dependent fluctuation when mixed with the signal from the pickup horn antenna. There is a lot of shielding in place to prevent microwave reflections and to prevent electronic pickup. The low frequency modulation of the electron density, as well as higher harmonics and plasma disturbances, can be clearly seen in the data. [5]

The power source, the r-f power amplifier, and the resonator, which consists of a capacitor section and an induction coil encircling the plasma, are the three basic components of r-f induction heating equipment. Resonator parameters can have a significant impact on the performance of the power amplifier. A resonator's ability to contribute power to a plasma largely depends on the features of its power amplifier. [6]

There are enormous scientific hurdles to overcome in order to generate, on Earth, genuine nuclear energy through the major role that the fundamental strong nuclear force plays in the fusion events. Because fusion reactions are not a natural process that can occur on Earth, they are the primary impediment to developing a viable alternative source of energy. [7]

Deuterium, a renewable and abundant source of energy, could be used to protect the biosphere in the event of a power outage. For the majority of fusion research, magnetically-trapped toroidal plasmas are used in toroidal machines1 (tokamaks), see Fig. 1.

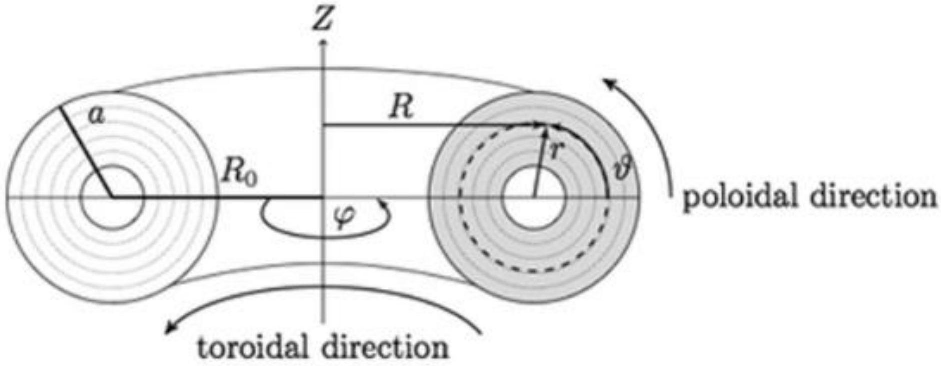

Fig. 1 shows the axisymmetric toroidal column of plasma, magnetically contained in a tokamak machine by a solenoid enclosing the column. The major and minor radial coordinates are R and r, respectively, the column axis is R0, and the last closed magnetic surface is a (LCMS).

Application of radio frequencies in tokamak plasmas:

For a tokamak plasma device to work, the Ohmic heating coils are used as a transformer, and the plasma is the secondary current. The produced secondary current in the plasma raises the plasma's initial temperature (both ions and electrons) via the Ohmic heating process. The plasma current generates a poloidal field, which is essential to maintaining plasma equilibrium. [8] A decrease in Ohmic heating efficiency as plasma temperature rises results in a slowing and saturation of the electron temperature increase at around 1–2 keV. In order to raise the temperature of the DT fusion reactor (about 10 keV), external heating must be provided. Keep in mind that -particle (He3), a byproduct of DT reactions in the DT-based fusion reactor, will be used to create heat for the core of the reactor system. [9] As a result, steady-state functioning necessitates compensating for the decreased plasma current due to reduced Ohmic current efficiency, even though a large percentage of the current is given by self-generated "bootstrap" current.

Objectives:

- To investigate the propagation of long-wavelength electromagnetic waves in plasma.
- To learn more about plasma fusion using radio frequency wave scattering.
- For the investigation of multi-megawatt radio frequency power electron distribution function and gaussian antenna spectrum
- To examine the axisymmetric toroidal column of plasma in a tokamak machine's plasma chamber

Research Methodology:

The systematic and theoretical analysis of the procedures used in a particular field of study is known as methodology. Theoretical analysis of a branch of knowledge's methodologies and principles is included. Paradigm, theoretical model and phases as well as quantitative or qualitative methodologies are common concepts included. In the current study, secondary data was acquired from a number of sources, including books, educational and development periodicals and government publications as well as printed and online reference resources.

Result and Discussion:

To yet, ITER (International Thermonuclear Experiment Reactor) tools are unable to effectively cover plasma's outer radial half, which is now in the construction phase4. NB and electron-cyclotron RF power sources are used, and their efficiency and adaptability are limited, especially when they approach the pedestal radial layer. [10] The lower hybrid current drive (LHCD)9,10 potentially be used to address this problem because major issues that have plagued this concept for a long time in tokamak trials have now been resolved. For example, the LHCD concept9 is shown schematically in Fig. 2, having been demonstrated experimentally on the Princeton Large Torus (PLT) and extrapolated successfully on the Frascati Tokamak Upgrade (FTU) to plasma densities suitable for reactor use. [11]

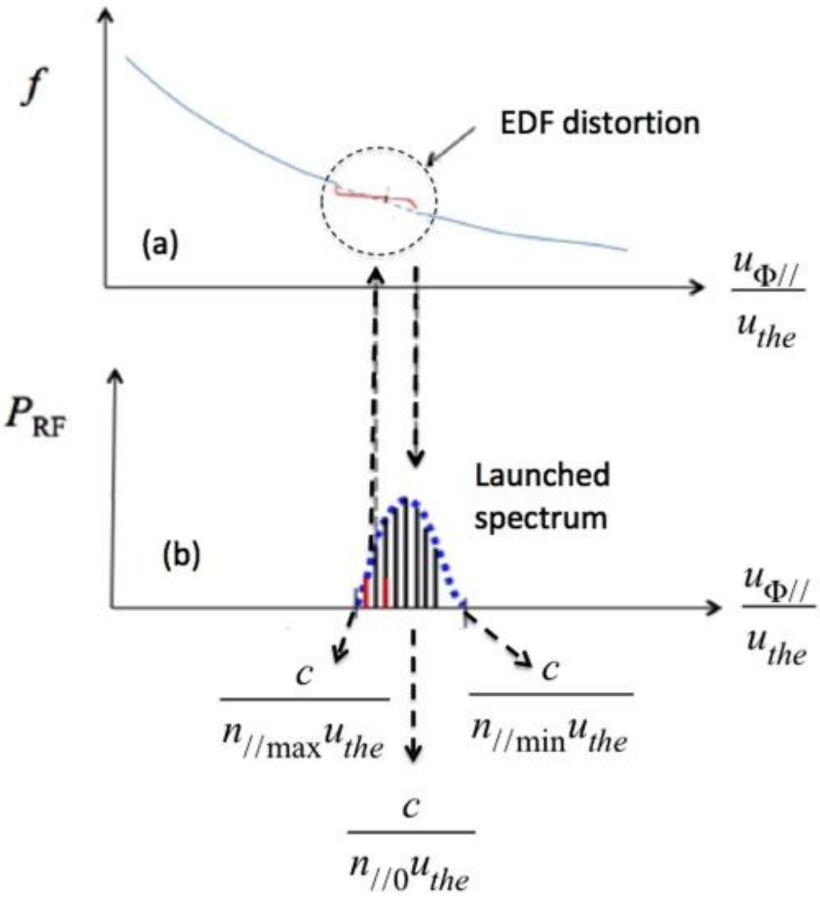

Fig. 2 (a) shows the dispersion of electrons in space (EDF). Radio-frequency power (in arbitrary units) connected to plasma at many gigahertz can produce the LHCD effect9 with a Gaussian antenna spectrum.

An understanding of how radio-frequency (RF) waves propagate (or "dissipate") in the turbulent fusion furnace interior is critical to sustaining an efficient, constantly operating power plant. [12]

RF waves heat the plasma fuel and propel its current across the toroidal interior when they are transmitted by an antenna in the doughnut-shaped vacuum chamber common to magnetic confinement fusion devices known as tokamaks.

It is possible that conditions within the chamber will alter (or "scatter") the wave's trajectory, which could impact the process' efficiency. [13]

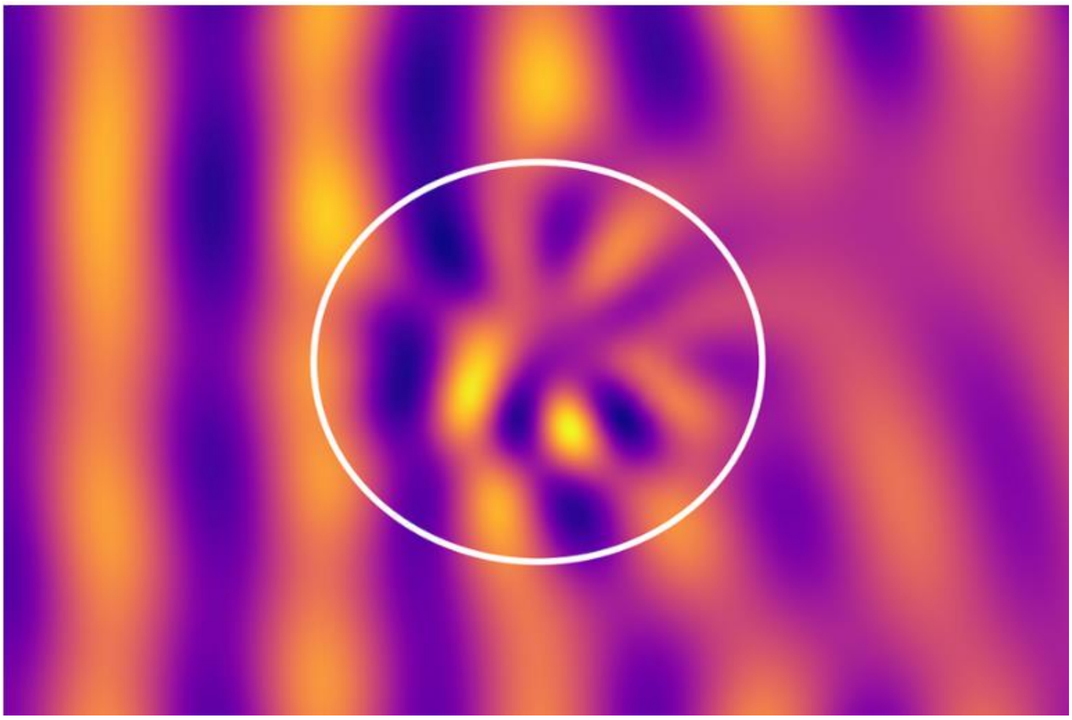

Fig. 3 shows how radio-frequency wave scattering enhances fusion calculations.

In order to heat and drive current in magnetically confined plasmas, various RF forms (ranging from 50 to 500 MHz) and microwaves (ranging from 2 to 100 GHz) have been produced. [14]

The in-plasma heating method relies heavily on resonance between RF and plasma particles (e.g., ions and electrons), with wave energy effectively being turned into particle energy.

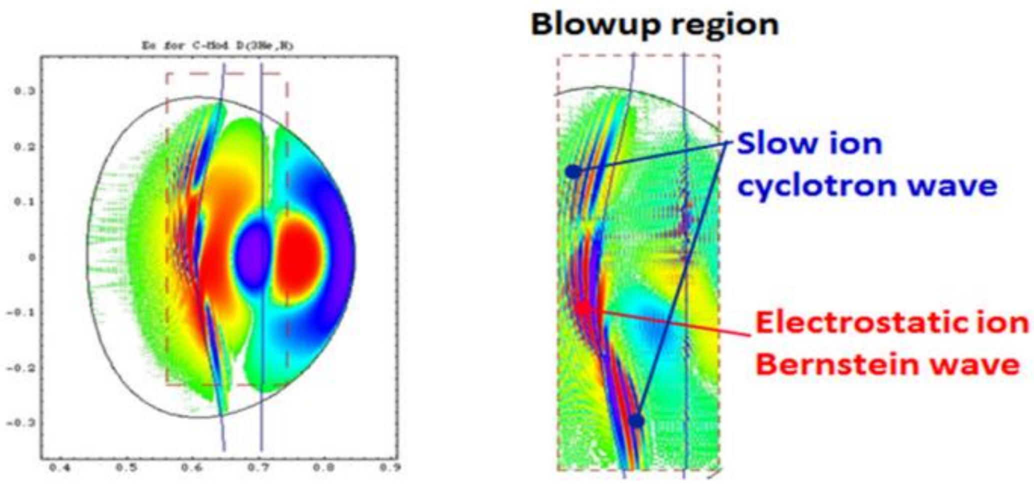

Fig. 4: Propagation of long-wavelength electromagnetic waves (fast-wave branch) from the low-field side and conversion into electrostatic waves (ion Bernstein waves) at the hybrid resonance layer in the plasma's core

An adequate launching antenna can be located at the plasma edge for ICH heating at a frequency range of 50 to 500 MHz once resonance properties in the machine (e.g. the second harmonic ion cyclotron or the hybrid resonance layers in the plasma) are known. [15] A full-wave modelling programme is used to create the 3D findings displayed in Fig. 4.

Conclusion:

While in d-c plasmas, the peak temperature occurs directly on the centerline, in r-f induction heated plasmas, radiation causes the peak temperature to occur in an annulus around the centerline instead. The ratio of the total discharge power to the reactive power in the r-f induction coil can be used to characterise the power transfer from the magnetic field to the discharge for a uniform electrical conductivity discharge. A resonator's maximum voltage and current limit its ability to perform at a high level. When the discharge radius approaches the coil radius, the coupling coefficient approaches unity. Increasing the reactive power for a given discharge power when the radius of the discharge is smaller than the radius of the coil requires a large increase in reactive power.

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