MAGNETIC/ELECTROSTATIC CONFINEMENTS IN He AND Ar DISCHARGES IN A SMALL TOROIDAL DEVICE CECI

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Abstract

Experimental research on the atomic mass effects on the plasma produced in a toroidal magentic confinement device is surveyed as well as the influence of radial electric field on the plasma through $E \times B$ rotation. Emphasis is made on the connection with improved confinement. The experimental results show that discharges with higher mass gases are more stable and long lived due to MHD stability and electrostatic confinement properties. The RFP configuration is also investigated by exploring the process of relaxation and reverse field generation, based on the mechanism of turbulent fluctuations. It is clear the difficult in to obtain the RFP configuration in this device for discharges with higher mass gases due to the low fluctuation levels achieved, contrary to the lower massive gases case, that present a turbulent behaviour.

Introduction

CECI is a low aspect ratio toroidal device (A-3), with major radius of R=12cm and minor radius of a=4.2cm which the typical plasma parameters obtained in its discharges are: (ne ~ 10^{12}-10^{13}cm^{-3}, Te ~ 30 - 50eV, Ti ~ 5eV, Ip ~ 3-5kA, p ~ 10^{-4}-10^{-3} Torr, using H, He, N, Ar). By the control of an external power charge system for the magnetic field coils it is possible to reach different topology for the magnetic confinement fields B_ϕ (toroidal) and B_θ (poloidal) inside the discharge chamber, forming Tokamak, ULQ (Ultra Low q) and RFP (Reversed Field Pinch) configurations.

In this paper a comparative study on the atomic mass effects on the plasma produced in CECI is described, observing that discharges in gases with higher mass are more stable and long lived due to the favourable MHD conditions and electrostatic confinement proporties. For this type of devices the MHD stability depends on magnetic Reynolds number R_m, and since R_m is roughly proportional to $(m_i)^{-1/2}$, there is a dependence on m_i, the mass of the ion species that constitute the plasma. Properties of confinement in CECI were also investigated through measurements of a plasma flow using a floating directional probe. The plasma flow which is related to the plasma potential through the force balance equation has been observed in CECI as was observed previously in other magnetic confinement systems, for example, θ pinch, RFP [1], Tokamak [2]. On the other hand, it has also been shown that when the plasma confinement is improved by some specific operational mode, a negative plasma potential develops [2]. These facts suggest that the presence of the plasma flow (or potential) is closely related to the confinement capability of the plasma device.

Plasma Confinement Device and Diagnostics

The plasma in CECI is generated by collisional ionization of the working gas (H, He, N, Ar) with electrons emitted thermionically by an electron gun source. The produced plasma is mainly confined by a combination of a poloidal magnetic field, B_θ, generated by the plasma current, and a toroidal magnetic field, B_ϕ, generated by external coils, that reaches 400 Gauss at maximum. A vertical magnetic field (B_v) controls the plasma column position, which results in an increase of the plasma current duration for over 20%.

A 2mm thickness copper shell used for conserving the toroidal magnetic flux covers the pyrex discharge chamber except for a 0.5cm brake which can be used conveniently as a window for spectroscopy and also for loop voltage measurement. An ion flow was measured in the beginning of the discharge in CECI using a floating directional probe.

The schematic view of CECI device is shown in Fig. 1.

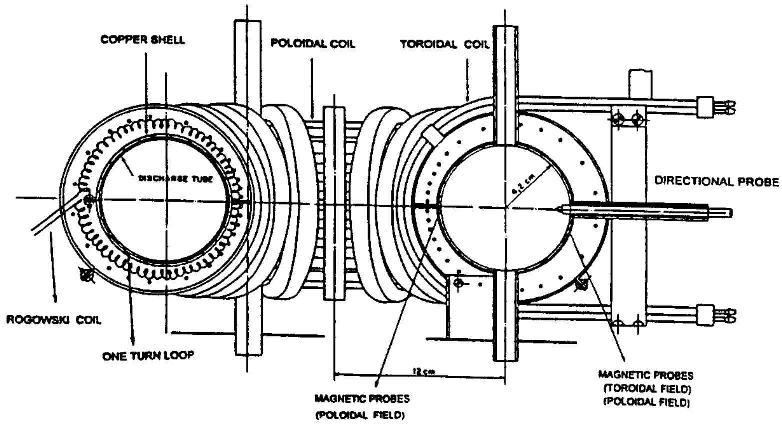

Fig.1 - Schematic view of CECI device

Experimental Results and Discussions

A detailed comparative study of the atomic mass effects on the plasma produced in CECI with respect to plasma current intensity, fluctuation levels of light emission lines, magnetic confinement modes and plasma flows related to the properties of electrostatic confinement, was carried out by surveying with H_2, H_e, N_2, and Ar gases. The emphasis was given to Ar and He discharges. The former is used in Remote Radiative Colling in tokamaks like JT-60 and JET and the later is commonly used in minority heating ICRF experiments.

Under similar discharge conditions of $B_\phi \sim 100$Gauss, voltage in poloidal capacitor bank of $V_\theta \sim 6$kV, voltage in vertical capacitor bank of $V_v \sim 6$kV and optimum pressure value for each gas, the values for plasma current and plasma lifetime are: H ($I_p < 1$kA, $\Delta t \sim 50\mu s$), He ($I_p \sim 1$-2kA, $\Delta t \sim 150\mu s$), N ($I_p \sim 2$-3kA, $\Delta t \sim 100\mu s$) and Ar ($I_p \sim 5$kA, $\Delta t \sim 100\mu s$).

An inspection of the line emission of HeII and ArII in plasmas with same density and temperature has revealed that fluctuation levels for argon plasmas are considerably lower than for helium plasmas. In a discharge using helium, the fluctuation of the light emission signal of HeII (λ = 4686Å) as the one shown in Fig.2 is very high in comparison with the signal of ArII (λ = 4351Å) shown in Fig.3. The waveforms shown for helium case were obtained discharging CECI for three times under the same operation conditions. The on/off character of HeII line emission is evident for all cases although there is no coincidence of those events contrary to the plasma current similarities. This turbulent behaviour of helium plasma was not repeated in argon discharges. In a toroidal device with much larger dimensions and better plasma parameters, REPUTE-1, from Tokyo University, a similar behaviour was observed, when operated in RFP mode. The MHD activities in REPUTE-1 were analyzed for different gases (H_2 He, N_2, Ar). The obtained power spectrum density revealed that for gases with larger magnetic Reynolds number (R_m) the MHD spectrum has a continuous turbulent structure [3]. Since $R_m \propto (m_i)^{-1/2}$, the results obtained in CECI are in agreement with experimental findings from REPUTE-1. For these types of devices, higher the magnetic Reynolds number, more turbulently will behave the plasma.

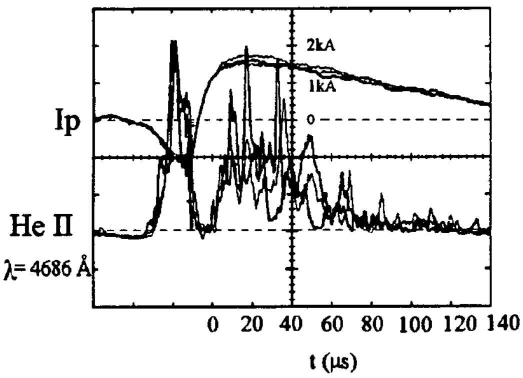

Fig. 2 - Plasma current (above) and fluctuation level in a helium discharge (λ = 4686Å)

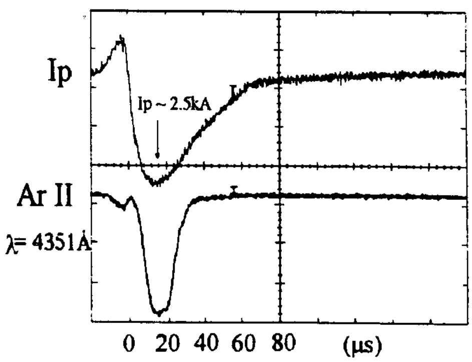

Fig.3 - Plasma current (above) and fluctuation level in an argon discharge (λ = 4351Å)

The F-θ diagrams for helium and argon discharges in CECI in low-q regime of operation are shown in Fig.4 and Fig.5 respectively, where $F = B_\phi(a)/\overline{B}_\phi$ is the reverse field quocient and $\theta = B_\theta(a)/\overline{B}_\phi$ is the pinch parameter of plasma.Here, $B_\phi(a)$ and $B_\theta(a)$ are the toroidal and poloidal field on the torus wall respectivelly, and $\overline{B}_\phi$ is the average DC polarization toroidal magnetic field. The high values of plasma current reached in argon discharges even for low values of B_ϕ indicate high θ values. In spite of that, the RFP configuration is rarely obtained in these cases, contradicting Taylor's theory. The main question on the physics of RFP is about the mechanism of sustainement of equilibrium magnetic confinement. Taylor's theory gives the properties of relaxed states, but no information is given about the relaxation process and reversed field generation (dynamo effect) . Several mechanism have been proposed, some of that are based in instabilities and turbulence [4], [5]. From an experimental point of view, marginal stability analysis of measured RFP field profiles indicates that they are close to marginal stability and it appears that as the profile diffuses towards instability, tearing modes are excited which drive the dynamo and relaxation back towards marginal stability [6]. This observation is confirmed in [5]: the dynamo effect has been understood as a cyclic process that involves plasma relaxation, diffusion and instabilities growing. This model is based on the observation that the field configuration oscillates in the vicinity of minimum magnetic energy state. From Fig.3, the signal of ArII (λ = 4351 Å) in CECI indicates a low turbulent plasma behaviour. Based on the process described previously about the sustainement mechanism in a RFP discharge, the short duration of RFP configuration for argon case can be understood in spite of the high θ values reached.

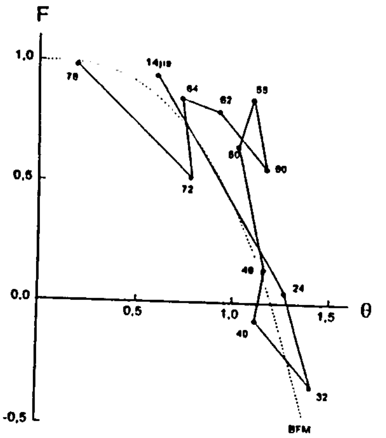

Fig. 4 - F - θ diagram for helium discharge

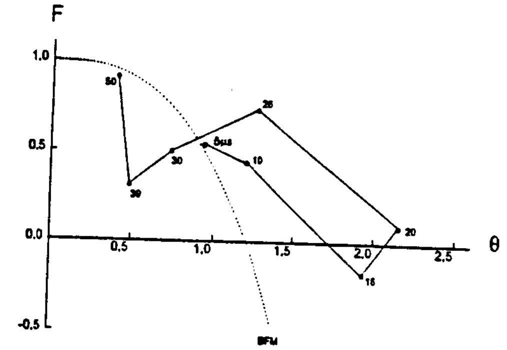

Fig. 5 - F - θ diagram for argon discharge

Among the different field configurations possible in CECI discharges, those ones in which $B_\theta >> B_\phi$ are outstanding.For helium case, when $\overline{B}_\phi \sim 50$Gauss, the values of the toroidal and the poloidal magnetic fields measured by magnetic probes are B_ϕ (a) ~ 5 Gauss and B_θ(a) ~ 80 Gauss respectively. The plasma current of 1.3 kA obtained gives the safety factor of q << 1 on the plasma surface which means that the plasma is unstable for MHD. For this case, taking into account the ion temperature of $T_i \sim 5$ eV, the ion Larmor radius is $r_L \sim 9$cm against the 4.2cm of torus radius. So, the ions can not be confined only magnetically, but with the aid of electrostatic fields. In such a plasma, the plasma flow at 20mm from the center of the discharge tube was measured. An ion counterflow to the plasma current was observed by using a floating directional probe as a double probe. The azimuthal profile of the ion saturation current at 20μs after discharge is shown in figure 6. Here the basic probe position for an azimuthal angle is defined for the negative electrode of probe to face the upstream side of plasma current. The current density of ion conterflow (j_{count}) is about 0.7A/cm^2 at 20μs and 0.3A/cm^2 at 32μs, while the plasma current densities at 20μs and 32μs are roughly 4A/cm^2 and 20A/cm^2 respectively. Figure 7 shows the azimuthal distribution of the ion saturation current at 32μs after discharge by using now the floating directional probe as a single Langmuir probe with directionality.

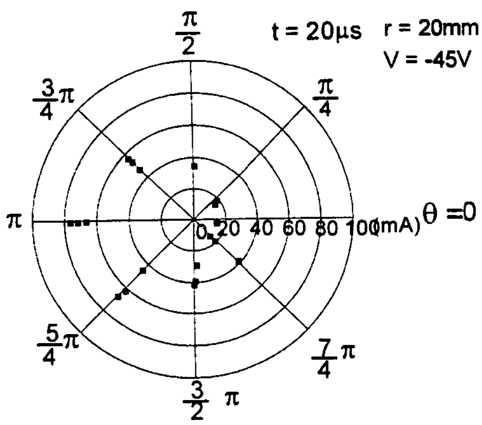

Fig.6 - Azimuthal profile of the ion saturation current at 20μs after discharge

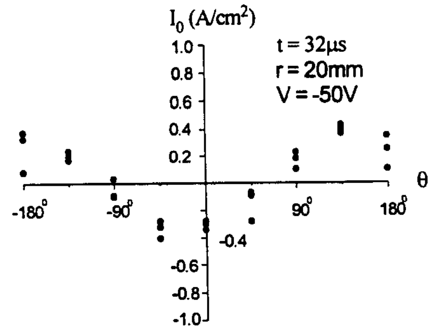

Fig.7 - Current density of ion counterflow at 32μs after discharge

It is noticed here that an ion current component in the plasma current can be neglected because of a very large mass ratio that m_i/m_e = 7300, where m_i and m_e are masses of a helium ion and an electron. Consequently, to produce the above directional ion current there is an accelerative mechanism for the ions. The ions are lost to the torus wall soon in the beginning of the discharge due to the high ion Larmor radius (r_L), while electrons, which have r_L ~ 3mm, remain confined. Experimental results show that in helium plasmas a negative potential develops soon in the beginning of discharge. This unbalance of charges in the plasma edge causes a radial electric field directed toward the center. The electric dirft of the guiding center v_E can be obtained through the measurement of j_{count} at 20μs, as follows:

since $j_{count} = n_e.q.v_E \quad \therefore \quad v_E \sim 4.5 \times 10^4$ m.s.$^{-1}$.

The $E_r \times B_\theta$ results in the ion counterflow, where E_r is the radial electric field and B_θ is the dominating poloidal magnetic field. The value of E_r/B_θ that corresponds to V_E allow the determination of E_r intensity. Since $V_E = 10^8 E_r / B_\phi \therefore E_r \sim 5$ V/cm. Careful analysis of the results obtained in helium discharges at CECI apparatus with respect to plasma characteristics of density, temperature and magnetic fields, show clearly the importance of electrostatic confinement in this device. Since ion thermal velocity is about 3.5×10^5cm/s and the dimension of the chamber is about 4 cm, the helium ions take about 20μs to reach the wall. The toroidal magnetic field of B_ϕ ~ 50G can not confine them for more than 12μs. In spite of that a plasma lifetime of about 100μs is obtained. In argon discharges, under similar conditions, with much more massive Ar^+ ions, better plasma parameters are reached. This fact suggests the possibility of a better confinement in argon discharges with higher electric field since the Larmor radius for Ar^+ ion is more than 40cm, against the 4cm of tube radius. This mass effect positively influenced the discharge in CECI. The experimental results show that in helium as well as in argon plasmas, a negative potential develops soon in the beginning of the discharge. The unbalance of charges in the plasma edge brings up an electric field, and an ion counterflow (measured with directional probe) to the plasma current which is due to the E × B drift results. Discharges with higher mass gases are more stable and long lived in CECI due to MHD conditions and electrostatic confinement properties . In spite of that it is more difficult to obtain RFP because dynamo effect needed to achieve this configuration depends essentially on turbulences in plasma.

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