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Breakdown experiment on ADITYA tokamak

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Abstract : Breakdown studies have been carried out by varying the fill pressure, applied loop voltage and external vertical field. The optimum pressure is found to be around 7.0 × 10^{-5} torr which corresponds to minimum volt-secs consumption and loop voltage. Results are compared with model calculations.

Keywords : Tokamak, breakdown, discharges.

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1. Introduction

In a tokamak discharge, volt-seconds are consumed during the breakdown of the neutral gas, in driving the toroidal plasma current and in confining the plasma. In order to have longer discharges and higher plasma current, it is essential to minimize the volt-secs consumed during breakdown phase. The volt-second consumption during the breakdown is affected by various factors namely, the fill gas pressure, the applied loop voltage, error magnetic fields etc., which determine production and loss rates of the electrons. Papoular [1] has studied the effect of poloidal field and toroidal drift on the breakdown and the subsequent current growth. The role of convective losses in the phase preceding the formation of rotational transform was studied on CASTOIR tokamak [2]. Sometani and Fujisawa [3] have studied breakdown in JFT-II tokamak in presence of applied vertical fields. In the following, we report the results of the breakdown studies carried out on ADITYA.

2. Experimental set-up

The ADITYA tokamak [4] has a major radius of 0.75 m and minor radius of 0.25 m. For the present studies the toroidal field is 0.24 Tesla on the axis.

The breakdown studies were carried out by varying fill gas pressure from 1.0 × 10^{-5} torr to 3 × 10^{-4} torr, and the peak loop voltage from 10 to 24 volts. The loop voltage is produced by discharging a capacitor bank (408 μF, 10 kV) charged to different voltages in the range of 3 kV to 8 kV. In the absence of plasma, the loop voltage is a cosine function of time with a quarter period of 7 ms. The breakdown is indicated by change in the slope of loop voltage. The signatures of the breakdown are also seen in the rise of the plasma current measured by Rogowskii Coils, and the optical signal measured by photo-diodes and photo-transistors. Hard X-rays measured by 3" × 3" NaI(Tl) scintillator are also monitored during these studies.

3. Results and discussion

3.1. *Dependence on pressure and applied loop voltage :*

The experiments show that successful discharges can be obtained for the peak loop voltages in the range of 10 V to 24 V for initial gas fill pressure in the range of 2.5×10^{-5} torr to 3.0×10^{-4} torr. The loop voltage for ADITYA rises very fast (in less than 100 μs) to its peak value and then decays with a time constant decided by the parameters of the capacitor bank and the ohmic coils. The breakdown, therefore, always occurs on the falling part of the voltage curve as sufficient volt-secs are not available in the rising phase of the loop voltage. As the loop voltage built-up is achieved by the rising of the current in the ohmic primary, the error fields at the beginning of the discharge, due to the current flowing in the ohmic circuit, are very low (< 5 Gauss).

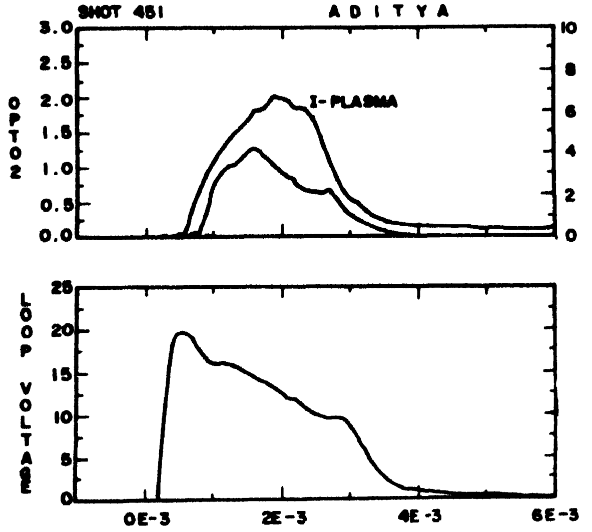

Figure 1. Typical time profiles of different parameter measured during a shot; (a) plasma current (I-Plasma) and optical signal; (b) loop voltage.

Results of a typical discharge is shown in Figure 1. The arrow mark shows the onset of the breakdown, as indicated by the change of slope of the loop voltage. Plasma current and the optical signal start appearing at the same instant. The domain of successful discharges is determined by varying the pressure and the loop voltage. The results are given in Figure 2a, where "X" indicates unsuccessful discharges and 'Y' indicates the successful ones. For gas pressure below 2.4 x 10^{-5} torr no breakdown is observed for loop voltages ≤ 24 volts. The behaviour is similar to the pattern observed by Papoular [1]. The minimum in breakdown voltage for a successful discharge is around 7.0 x 10^{-5} torr. Above 1.0 x 10^{-4} torr the loop voltage required for breakdown increases steeply.

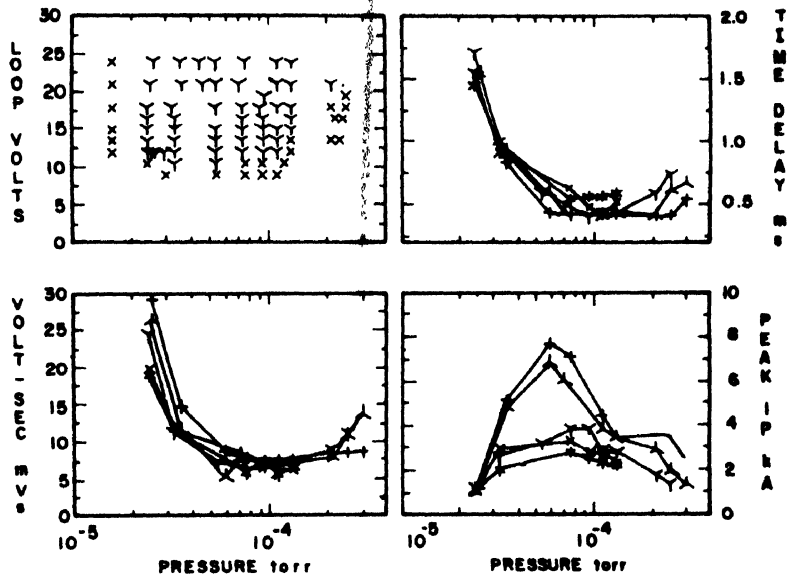

Figure 2. Plots of (a) breakdown voltage, (b) time delay, (c) volt-seconds, (d) peak plasma current, *versus* the neutral gas pressure.

The time delay between the application of the ohmic field and the onset of the breakdown is plotted in Figure 2b as a function of the pressure for various loop voltages. It shows a broad minimum around 7.0 x 10^{-5} torr. The delay increases steeply for lower pressures. For a given pressures the time delay decreases with increasing loop voltage. The volt-seconds consumed during the breakdown, defined as $\int_0^{t_{bd}} V_L dt$ where t_{bd} is the delay time, is shown in Figure 2c as a function of pressure for different applied loop voltage. This also show a broad minimum around 7.0 x10^{-5} torr. Further it is observed that the maximum plasma current is obtained at a fill pressure of 7.0 x 10^{-5} torr for different charging voltages. The peak current increases with increasing charging voltage as shown in Figure 2d. These results indicate that the optimum neutral pressure in around 7.0 x 10^{-5} torr.

The above results are consistent with the following scenario of gas breakdown. The buildup of the discharge is decided by the production of electrons through electron-neutral collisions and loss due to various mechanisms [1]. At the optimum pressure an avlanche is favoured. At lower pressures, the electron-neutral collision frequency decreases resulting in increase in the parallel velocity of the electrons and consequent increase in electron loss due to toroidal drift and error fields. The breakdown is, therefore, inhibited. At higher pressures the electron mean free path becomes smaller and collisions prevent electrons from gaining sufficient energy for ionisation which is detrimental to avalanche.

As per Papoular's model [1] the delay in breakdown time is given by

$$t_{bd} = \frac{1}{(\nu - \beta)} \ln\left[\frac{n_m}{10 n_{e0}}\right] \tag{1}$$

where n_m is the molecular fill density and n_{e0} is the electron density present at time $t = 0$, ν is the production rate given by

$$\nu = \alpha v_{\parallel} \tag{2}$$

where $v_{\parallel}$ is the drift velocity given by

$$v_{\parallel} \approx 3.5 \times 10^5 \frac{E}{P} \text{ cm/s} \tag{3}$$

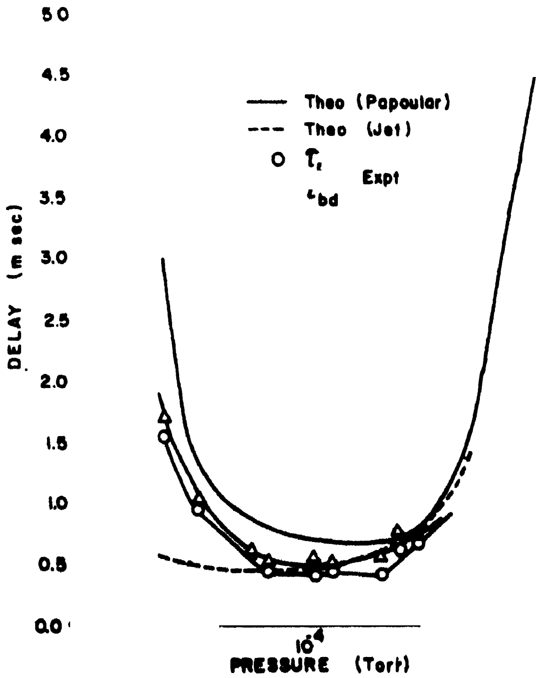

Figure 3. Model calculations of delay time compared with the experimental measurement.

E is the electric fields in volts/cm and pressure P is in torr. The Townsend coefficient is given by [5].

$$\alpha = 2.5 \quad 1 - \exp \left| -7.34 \times 10^{-5} \right. E^2 \tag{4}$$

The loss rate, β is dominated by the error field (B_z) and is given by

$$\beta = \frac{v_{\parallel}}{a}\left[\frac{B_z}{B_T}\right] \tag{5}$$

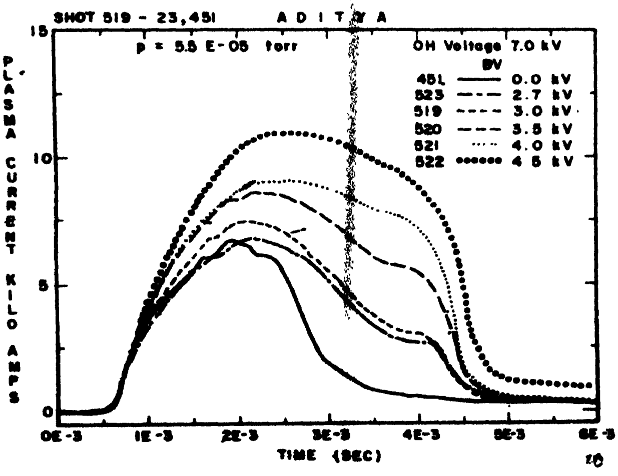

Figure 4. Plasma current evolution for different applied vertical fields.

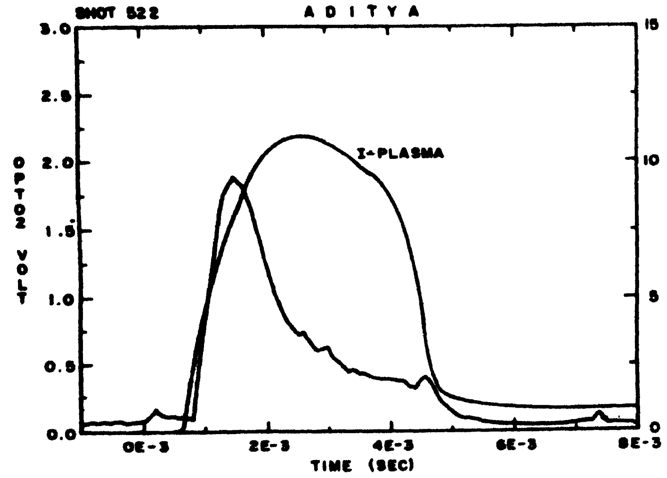

Figure 5. Time profiles of plasma current and optical signal in presence of externally applied vertical magnetic field.

where 'a' is the minor radius, and B_T is the toroidal field. Taking the ratio of $\frac{B_z}{B_T} \approx 10^{-3}$ [6] and 10% ionization the delay time has been estimated and shown in Figure 3. The agreement between the observed and estimated delay times is suprisingly good even though the calculations are for 10% ionisation while the ionisation at the breakdown time is rather poor (≈ 3%).

3.2. *Effect of applied vertical magnetic field :*

For the discharges described above, no attempt was made to obtain equilibrium through vertical magnetic field. In order to study the effects of the vertical field, a capacitor bank was discharged through the vertical field coils simultaneously with the ohmic field. It was found that this did not make any difference to the delay time for the onset of the breakdown. Plasma current and the discharge duration, however, increased significantly. While the rate of rise of the current was ≈ 3 MA/s in absence of the vertical field, it increased to about 5.5 MA/s with a vertical field rising at a rate of 23 kG/s. The results are shown in Figures 4 and 5.

In the absence of the vertical field the ionisation is poor (independent measurement give an estimate of 3%) as indicated by the optical signal which follows the plasma current (Figure 1). As the vertical field is increased optical signal increases initially with plasma current but falls off much faster than plasma current indicating improved degree of ionisation (Figure 5). These observations can be understood as follows :

The estimated error field (B_z), in ADITYA is about 5–10 Gauss and the vertical electric field measured using Langmuire probes show that rotational transform gets established when the plasma current I_p exceed 1-2 kA [6]. The equivalent magnetic field for hoop force, B_{hoop}, is ≈ 4 Gauss per kA of plasma current. Both B_z and B_{hoop} lead to loss in radial outward direction. The applied vertical magnetic field (B_v) must compensate for these fields. The delay in the application of the vertical field and the appearance of this field inside the vacuum vessel is typically 2.5 ms as measured by a magnetic pick-up probe. At the onset of the breakdown, B_v is very low and hence does not effect the time delay. But the improved equilibrium later reduces the losses and hance leads to better ionisation.

4. Conclusions

The breakdown studies in ADITYA indicate that the optimum pressure is ≈ 7.0×10^{-5} torr at which discharge takes place with minimum loop voltage and minimum consumption of volt-second. It is essential to have vertical field to achieve better equilibrium, faster ionisation and faster current rise.

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