PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 55, Nos 5 & 6
Nov. & Dec. 2000
pp. 719–725

Runaway electrons in the SINP tokamak

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Abstract. The experimental determination of the dependance of confinement time of runaways on various discharge parameters has been presented along with the angular distribution of hard X-rays (HXrays) emitted from the torus in presence and absence of Langmuir probes.

Keywords. SINP tokamak; runaway; confinement time; hard X-rays.

PACS Nos 41.75.H; 52.55.F

1. Introduction

The highly energised runaway electrons ($W > 100$ keV) is practically inevitable in the presence of an electric field. In tokamak discharges, these, on one hand, are a source of concern causing damages to the limiter and torus walls [1] whereas, on the other hand, it can be used as a diagnostic tool to determine the properties of a non-collisional plasma [2]. The analysis of the effect of various tokamak discharge parameters on the runaways, thus, becomes important.

In the past, theories have been put forward regarding the generation and acceleration of runaway electrons [3]. Efforts have also been made to calculate the production rate of runaways. In lieu of this fact, various forms of the velocity distribution were considered and the flux expression was obtained upto a certain multiplicative constant [4–7]. Kulsrud *et al* [7] in fact solved the Fokker–Planck equation numerically and compared it with the previous results.

The presence of runaways can be detected by measurement of the synchrotron radiation [2,8], cyclotron radiation [9] and hard X-ray measurement [10–12].

The runaway electrons have been studied in the start-up phase [12–14], as well as in the steady phase [15–17]. We have confined ourselves here to the initial rise phase of the discharge mainly because the runaway electrons find the initial low density (n_e) and large applied toroidal electric field ($E_T = V_{\rm loop}/2\pi R$), where R is the major radius, favourable for their production, and the runaway dynamics in the initial start up phase also influences the bulk discharge behaviour [13].

In this paper we report some of the investigations that have been carried out to determine the parametric dependence, viz., toroidal magnetic field ($\mathbf{B_T}$), toroidal electric field ($\mathbf{E_T}$), vertical magnetic field (B_v) and minor radius (a) on the evolution of 'RUNAWAY ELECTRONS' in the SINP tokamak.

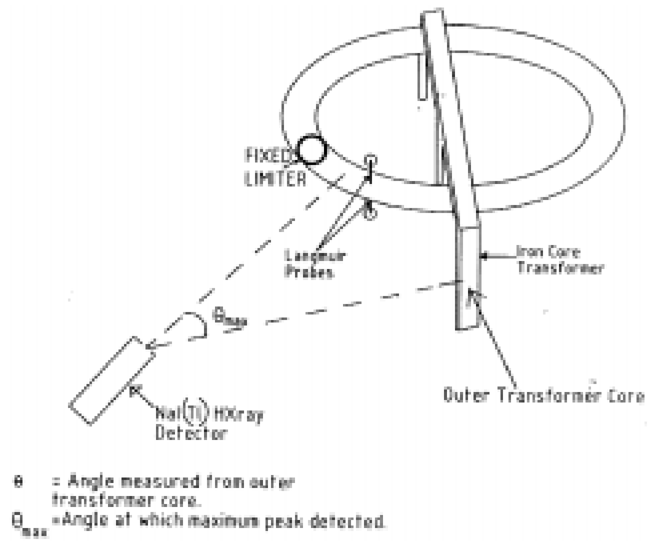

Figure 1. Detector setup for angular distribution measurement of HXrays.

We then give a plausible explanation of the results in comparison with theoretical predictions and finally give our conclusions.

2. Experimental setup

The experiments were carried out in the SINP tokamak [18] by varying the toroidal electric field (E_T) between 10.2 V/m to 45.9 V/m, the toroidal magnetic field (B_T) from 0.264 Tesla to 0.62 Tesla. The minor radius has been varied from 4.5 cms to 7.5 cms by moving the two vertically placed movable limiters 180° away from the fixed limiter in the toroidal direction. The vertical magnetic field (B_v) is varied from 0 Tesla to 0.027 Tesla. The filling pressure has been kept at 2×10^{-4} Torr and 3.5×10^{-4} Torr.

It is a well known fact that when high energy electrons hit a metal target HXrays are emitted. These emitted HXrays gives one a knowledge of the energy of the impinging electrons. Scintillation detector is commonly used to monitor these HXrays. We have mainly performed an analysis of the runaways present in a discharge with the help of the HXray detector unit. The detector system of the SINP tokamak [19] consists of a NaI(Tl) scintillator placed at the front end of a lead shielded photo-multiplier tube. The detector was calibrated with standard sources such as ^{57}Co and ^{133}Ba, as well as X-ray tube, and was found to register X-ray with energies in the range 3 to 150 keV.

Figure 1 shows the exact position of the NaI(Tl) scintillator detector of the SINP tokamak, used for detecting the hard Xrays emitted. This setup also shows the angular base considered for locating the position of maximum detection. The fixed limiter in the SINP tokamak and the Langmuir probes were placed 11 cms apart in the toroidal direction. As seen from figure 3, the maximum in the angular distribution of the hard X-rays is seen within a cone of 5° of the fixed limiter with respect to the detector, i.e., 15 cms in

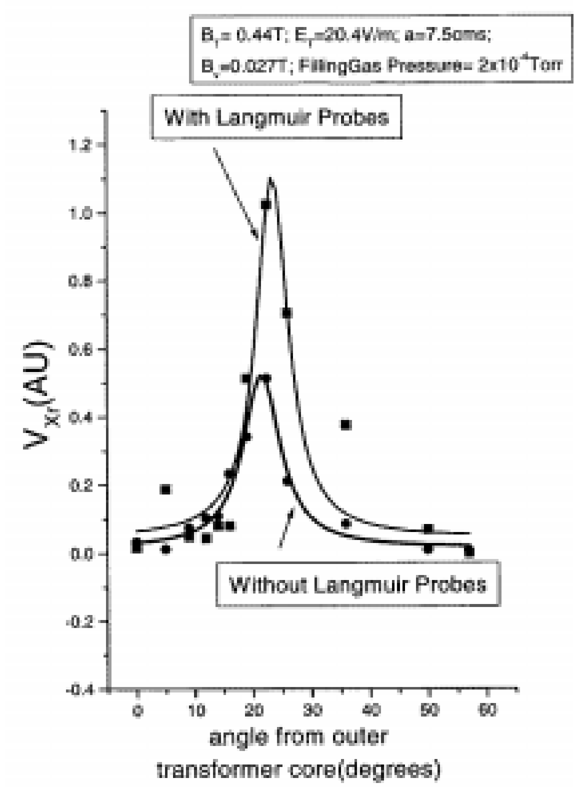

Figure 2. Angular distribution of the HXray detected.

the toroidal direction on either side of the fixed limiter. We felt that the Langmuir probes could also have acted as a target for the runaway electrons. Hence we performed the angular scan once more in the absence of the probes. The decrease in HXray detected intensity by approximately a factor of two (figure 2) confirmed the fact that the probes did act as a target.

In addition to this we have used the loop voltage coil and Rogowskii coil to measure E_T and the total plasma current respectively. We had also placed two sets of three Langmuir probes each at minor radius = 6.5, 7.0 and 7.5 cms respectively which measured the edge electron density and floating potential.

3. Observations and discussions

Figure 3 shows a typical plasma discharge of the SINP tokamak during the rise phase. In this figure,the loop voltage $(V_{\rm loop})$, the total plasma current (I_p) and the HXray intensity (V_{Xr}) detected is depicted. In this figure, I_p has been shown till the point it has reached the maximum current value. The HXray signal is seen to rise to a maximum value in about

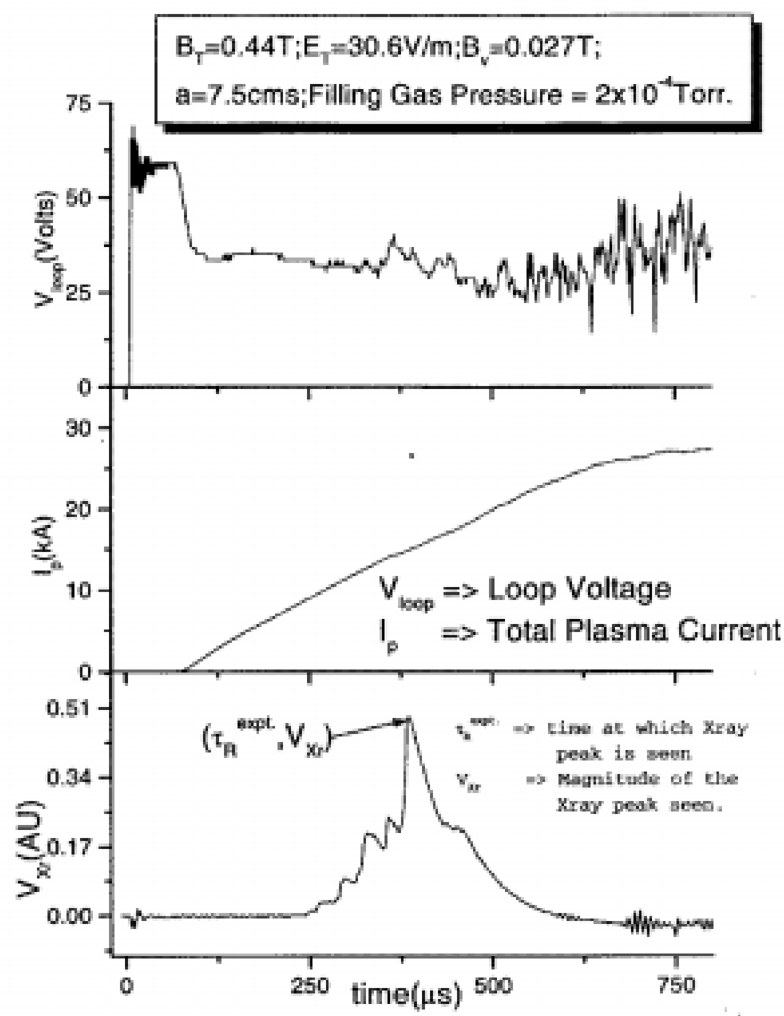

Figure 3. Typical plasma discharge in the SINP tokamak.

125 μsecs. The signal is seen to decrease thereafter. No X-ray signal are detected in the later phases. The experimental confinement time ($\tau_R^{\text{expt.}}$) has been considered as the time where the HXray signal has reached its peak from the start of the discharge.

In figure 4a the experimental confinement time is seen to have a peak when the minor radius is 5.5 cms. In figure 4b, we see that $\tau_R^{\text{expt.}}$ is seen to increase with B_T and tends to saturate at higher values of B_T. Figure 4c gives the variation of $\tau_R^{\text{expt.}}$ with B_v wherein it is seen that the experimental confinement time is linearly increasing with time. Figure 4d gives an inverse variation of τ_R with E_T.

The theoretical confinement time of runaways is given as [14,20]:

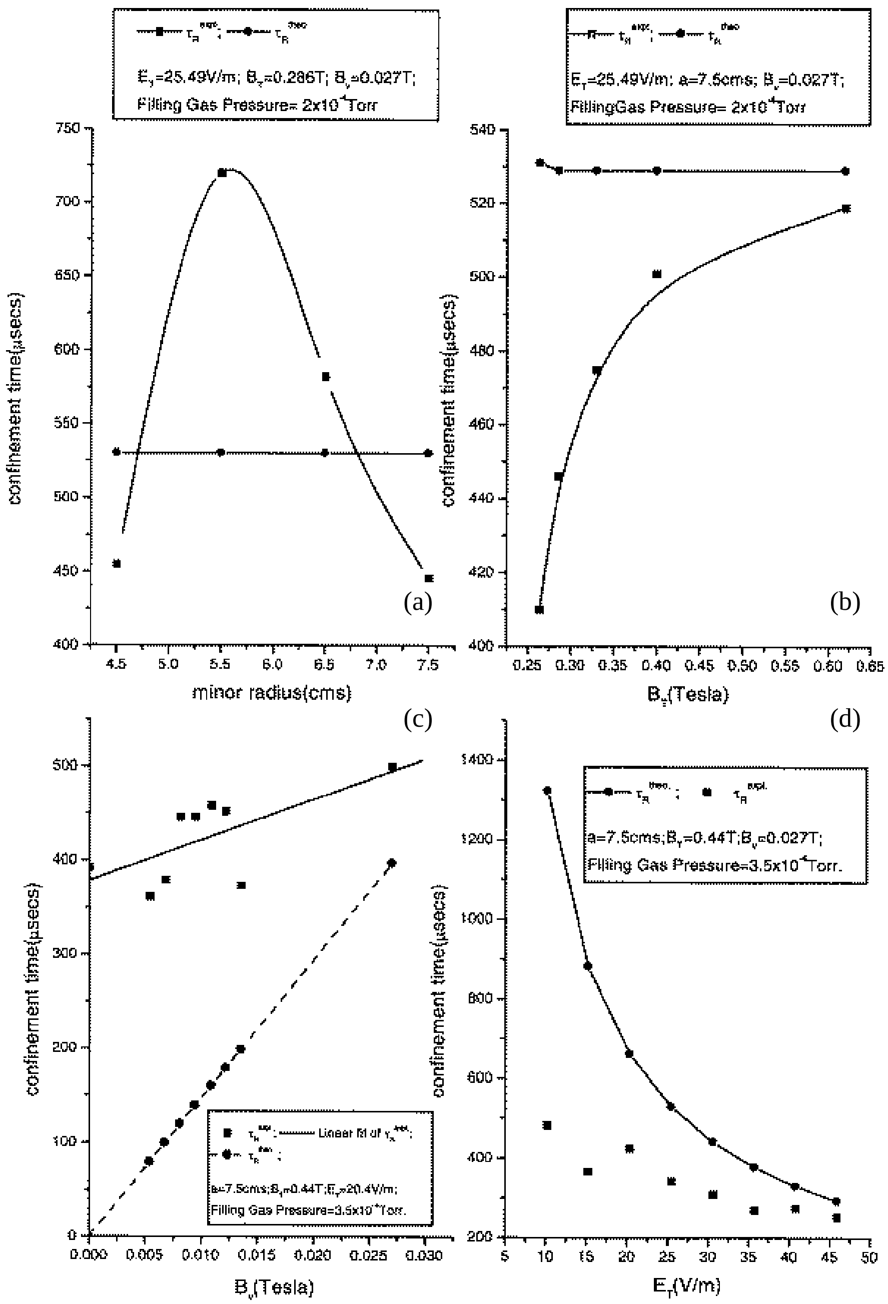

Figure 4. Comparison of theoretical and experimental results: (**a**) on variation of minor radius; (**b**) on variation of toroidal magnetic field; (**c**) on variation of vertical magnetic field and (**d**) on variation of applied electric field.

$$\tau_R^{\text{theo}} = \frac{B_v R}{E_T}. \tag{3.1}$$

This expression indicates no dependence of minor radius or B_T on the confinement time which is quite contrary to what is seen in figures 4a and 4b respectively. The theoretical value with varying B_v does not seem to follow the experimental results exactly even though there is a general tendency to rise. The theoretical and experimental confinement times with varying E_T is seen to match within the experimental errors, though the functional behaviour seems to follow eq. (3.1).

The discrepancies seen in the theoretical and experimental values of the confinement time is probably due to the various assumptions made in the derivation of the expression (3.1). The dependance on minor radius and B_T could be present if one does take into account the large variations in E_T during the rise phase, as is seen in figure 1.

4. Conclusions

The angular measurement of hard X-ray emission shows that most of the runaway electrons hit the fixed limiter but the Langmuir probes can also act as a target for the runaways. It is seen that τ_R increases with B_T whereas a decrease is seen with increasing E_T. The confinement time is seen to have a hump at minor radius, $a = 5.5$ cms. The tendency to increase linearly is seen in B_v but the slope rate of increase is not the same. As a part of our future plans, we intend carrying out a more detailed modelling of the confinement time taking into account its dependence on other parameters such as B_T, minor radius etc.

Acknowledgements

We wish to express our deep sense of gratitude and indebtedness to all the members of the Plasma Physics Group of SINP for their co-operation during the course of our experiments and analysis.

References

[1] H Bolt and A Miyahara, *Runaway-electron-materials interaction studies* Research Report NIFS-Tech Series, NIFS-TECH-1, March 1990, National Institute for Fusion Research, Nagoya, Japan
[2] R Jaspers, *Relativistic runaway electrons in tokamak plasmas* thesis work submitted in Feb. 1995 at FOM Institute, Netherlands
[3] D A Spong, J F Clarke, J A Rome and T Kammash, *Nucl. Fusion* **14**, 397 (1974)
[4] H Dreicer, *Phys. Rev.* **115**, 238 (1959); *Phys. Rev.* **117**, 329 (1960)
[5] A V Gurevich, *Sov. Phys.–JETP* **12**, 904 (1961)
[6] A N Lebedev, *Sov. Phys.–JETP* **21**, 931 (1965)
[7] R M Kulsrud, Y C Sun, N K Windsor and H A Fallon, *Phys. Rev. Lett.* **31**, 690 (1973)
[8] K H Finken, J G Watkins, D Rusbülott, J W Corbett, K H Dippel, D Goebel and R A Moyer, *Nucl. Fusion* **30**, 859 (1990)
[9] I Fidone and G Giruzzi, *Nucl. Fusion* **30**, 803 (1990)

[10] D W Swain and S J Zweben, *Nucl. Fusion* **20**, 711 (1980)
[11] C W Barnes and J D Strachand, *Nucl. Fusion* **22**, 1090 (1982)
[12] A D Cheetam and J A How *et al*, *Nucl. Fusion* **23**, 1694 (1983)
[13] A S Sharma and R Jayakumar, *Nucl. Fusion* **28**, 491 (1988)
[14] H Knoepfel and D A Spong, *Nucl. Fusion* **19**, 785 (1979)
[15] S Von Coeler and W Stodiek, *Controlled fusion and plasma physics research* **1**, 2 (1972)
[16] D Grove and V Arunasalam *et al*, *Plasma physics and controlled nuclear fusion research IAEA, Vienna* **1**, 21 (1977)
[17] A B Berlizov and G A Bobrovskii *et al*, *Plasma physics and controlled nuclear fusion research IAEA, Vienna* **1**, 3 (1977)
[18] J Basu, *Science Reporter* (July, 1998) 366
[19] A N S Iyengar, R Pal, S Lahiri and S Mukhopadhyay, *Nucl. Fusion* **38**, 1177 (1998)
[20] I H Hutchinson and J D Strachan, *Nucl. Fusion* **14**, 649 (1974)