

Some Aspects of Disruptive Instabilities  
in Alcator A

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# Some Aspects of Disruptive Instabilities in Alcator A

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The tokamak Alcator A experiences, from time to time, a variety of 'disruptions' i.e., violent alterations of the current profile on a time scale faster than that of normal resistive current diffusion. The character of these events may be categorized according to both the stage of the discharge at which they occur and also their immediate effect on the plasma parameters. Here we discuss disruptive instabilities under three headings. First we discuss those that are associated with rising current. These have a different signature from the more familiar instabilities and we present evidence to show that they are related to the formation of hollow current profiles. Secondly, some observations are made concerning what may be considered the 'classic disruptive instability', characterized by a large negative voltage spike related to rapid current-channel expansion and occurring typically close to the time of maximum current. Finally, we consider those disruptions which lead directly to total termination of the plasma current.

## Current-Rise Disruptions<sup>1</sup>

Sequences of perturbations of the loop voltage during the rise of plasma current have been observed on many tokamaks and have been correlated with MHD activity of decreasing poloidal periodicity ( $m$ ).

On Alcator A such series of disruptions are often observed. Statistically, the disruptions are found to occur predominantly not at limiter safety factor ( $q_\ell$ ) values that are integral but at  $q_\ell \approx 1.6 m$ , where  $m$  is integral, equal to the poloidal periodicity of the related helical magnetic perturbation. These facts indicate that the site of the disruptions' initiation is not near the plasma edge but well inside the column. Observations of second-harmonic electron cyclotron emission show an abrupt decrease in electron temperature throughout the plasma at the time of each disruption. This decrease is sometimes as much as 50% in the most severe disruptions, particularly at the lower  $m$  numbers (2-4). More typically, however, it is less than about 20%.

The cyclotron radiation measurements show also that the electron temperature profile remains peaked at the centre throughout the current rise phase. However, an analysis of the current diffusion equation indicates that for the experimental  $T_e$  profiles and the timescales in Alcator A, a hollow current profile should form due to the skin effect. Moreover the ratio of  $q_\ell$  to the minimum  $q$  value inside the plasma is typically found to be  $\sim 1.6$  for the calculated current profiles. Thus, it seems, it is the minimum  $q$  value in the plasma which determines the MHD mode instability not the limiter  $q$ . This is quite consistent with the theoretical model of the double tearing mode.

We find that these disruptions appear to have a regulating effect on the electron temperature during the current rise such that the plasma never evolves far from a state of marginally hollow current. However their overall effect is strongly deleterious to the plasma parameters throughout the ensuing discharge. Severe disruptions in the early phases greatly increase the tendency to disrupt later in the discharge. This effect appears to be related to impurities.

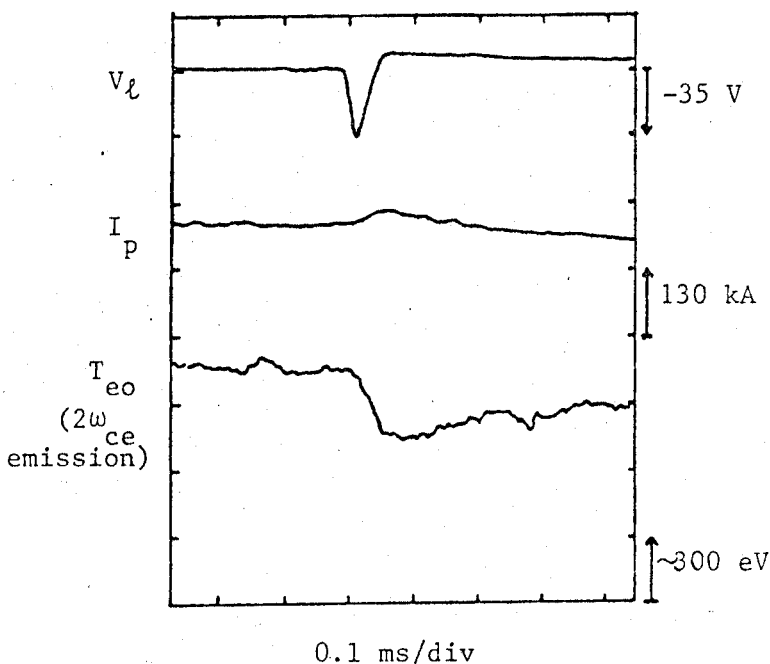
These early disruptions can be avoided or at least reduced in intensity by two means: increasing the electron density and reducing the rate of current rise. These measures reduce the ratio of ohmic power to the rate of plasma energy increase and thus reduce the temperature, the conductivity, and hence the tendency to form hollow current profiles.

### Classic Disruptive Instabilities

Disruptions which occur at times when the current is no longer rapidly changing can have severity widely varying, from those which perturb the plasma temperature by as little as 10% to those which lead to total termination of the discharge. This latter extreme is discussed later.

The timescales in which the rapid evolution, characteristic of the disruptions, occurs in Alcator are such that the penetration (L/R) time for poloidal flux through the vacuum chamber ( $\sim 80 \mu\text{s}$ ) must be considered. This time sets the timescale over which the loop voltage and total measured current (plasma plus bellows current) can vary in response to plasma perturbations. The typical duration of the observed negative voltage spike is generally of this order; though, somewhat surprisingly, as Fig. 1 illustrates

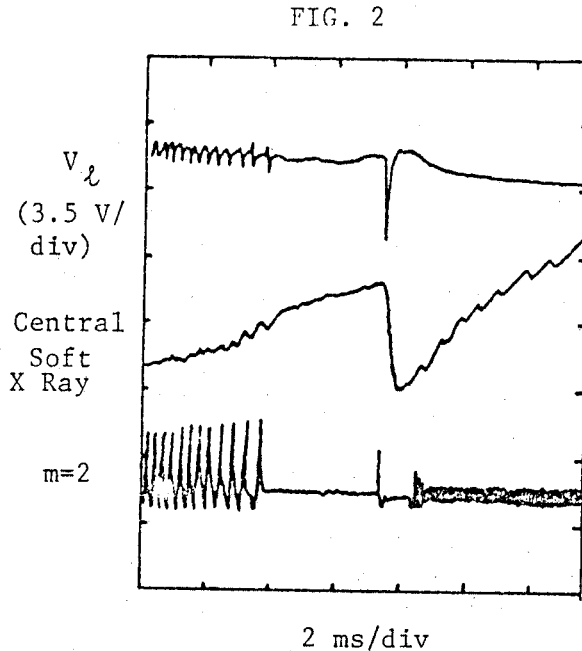
FIG. 1



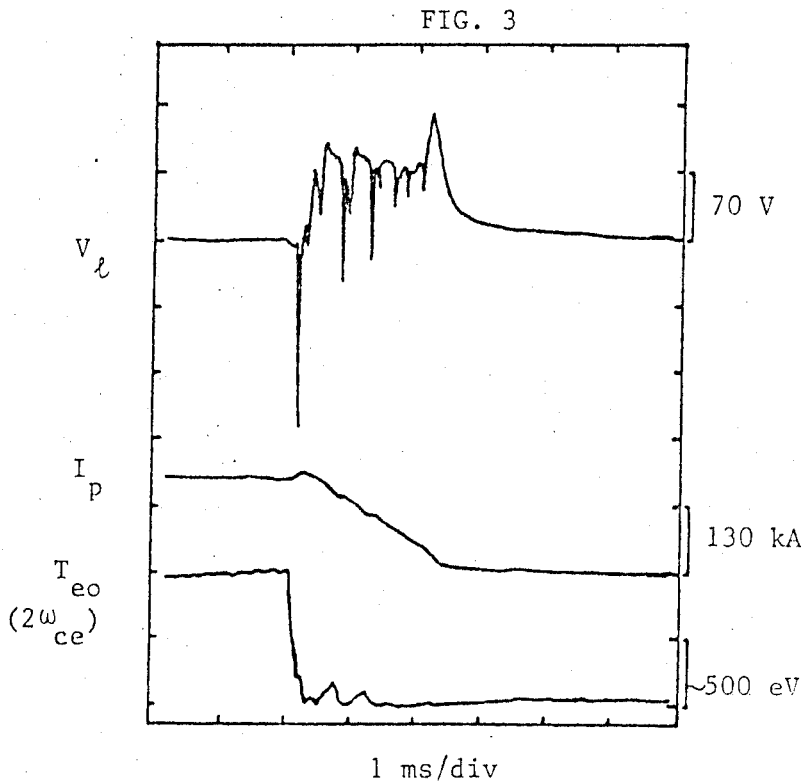
it often appears rather shorter than this. In any case, a measurement of the central temperature from cyclotron radiation (confirmed by soft x-ray diodes) which has  $\sim 10$  kHz bandwidth ( $\sim 15 \mu\text{s}$ ) shows the fall in temperature to take  $\sim 60$ - $100 \mu\text{s}$ . Moreover the fall begins, to within our resolution, simultaneously with the leading edge of the voltage spike.

A notable feature of the  $m=2, n=1$  mode, which is generally closely related to disruptions, has been observed. This consists in a 'locking' effect whereby the rotation of the mode is stopped. Fig. 2 illustrates the effect. The  $m=2$  mode

grows in amplitude until gradually a distortion appears and the  $\cos 2\theta$  magnetic coil eventually shows a non-sinusoidal signal with increasing period. Such a distortion is indicative of nonuniform rotation of the mode presumably due to incipient mode locking occurring periodically as the mode passes the locking point. Eventually the mode locks completely and all oscillation on the coil signal ceases. In Fig. 2, four milliseconds later a disruption occurs and then  $\sim 1$  ms afterwards the  $m=2$  signal reappears but at much higher frequency, characteristic of more benign modes. Thereafter more normal plasma behaviour ensues and sawteeth (absent before) appear in the plasma centre.

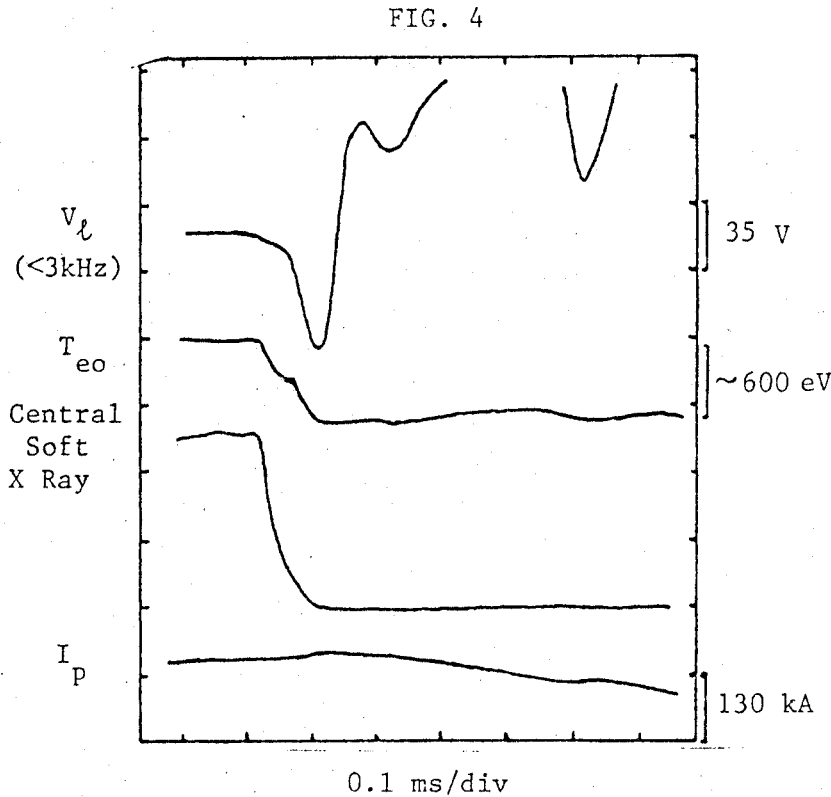


It is not unusual for the  $m=2$  mode to be locked for perhaps 100 ms which may constitute most of the discharge, before a disruption occurs. Sometimes, towards the end of the discharge, the mode simply begins to rotate again without a disruption. In the presence of this large saturated mode, no sawteeth are observed and the plasma density generally is significantly depressed relative to discharges with comparable parameters and no such MHD problems. We find that strong gas puffing helps to avoid these large  $m=2$  modes.



Current Termination

Sometimes a severe disruption will lead to a complete termination of the plasma current. An example is shown in Fig. 3. As can be seen the time taken for the current to reach zero is typically 2 ms. During this period a number of negative voltage spikes occur (6 in this case), indicating that the current terminates through several distinct disruptions. The time-scale for each of these is typically  $\sim 100 \mu\text{s}$ , as before. The central



temperature during the current decay remains very low. After the first disruption, which typically lowers the temperature to perhaps 10% of its previous value in  $\sim 100 \mu\text{s}$ , it often recovers somewhat until the next disruption in the series occurs, causing it to fall again, typically to  $< 50 \text{ eV}$  at each disruption. Soft x-ray measurements indicate that throughout the current decay the plasma is shifted inwards. A detector viewing at 4 cm inside sometimes shows significant signal during the recovery while that at 4 cm outside shows no signal. However the position loop would indicate a shift of only  $\leq 2 \text{ cm}$  consistent with the equilibrium expectations for a tokamak with copper shell when virtually all plasma energy is lost.

Figure 4 shows the first disruption in a current termination sequence. It should be noted that the main drop in voltage occurs about  $40 \mu\text{s}$  after the temperature begins to fall. This is similar to an effect noticed on Pulsator<sup>2</sup>. However, close inspection reveals that there is a preliminary fall in voltage simultaneous with the temperature fall. Moreover, the cyclotron emission reveals that the temperature actually drops in two stages, one associated with the preliminary voltage drop and a second associated with the major spike. This two-stage process is apparent in many of the more severe disruptions including some which do not lead to total current termination.

#### Acknowledgements

We are greatly indebted to all the Alcator group for their support and encouragement.

#### References

1. A detailed account of this work is submitted to Nuclear Fusion.
2. F. Karger et al. in Plasma Physics and Controlled Nuclear Fusion Research (Proc. 6th Int. Conf., Berchtesgaden) 1, IAEA, Vienna (1977) 267. See also S.V. Mirnov and I.B. Semenov, *ibid* 291.