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1980

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ABSTRACT

The major disruption has been studied in detail on the TOSCA tokamak with the use of approximate helical coils. The m=3, n=2 mode has been clearly observed for the first time before a major disruption. The amplitude of the m=2, n=1 mode at the rational surface is about 4% and the m=3, n=2 mode amplitude $\sim$ 4.5% before a major disruption. When the m=2, n=1 and m=3, n=2 approximate helical coils are energised with large coil currents, a major disruption occurs.

(Submitted for publication in Physical Review Letters)

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December 1979
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Further improvements of plasma parameters in present day tokamak devices are limited by the major disruption[1]. In the next generation of tokamaks, the major disruption can be a severe problem because large forces and voltages are generated by the sudden decrease in plasma current following the disruption. An understanding and a means of controlling this dangerous instability is therefore very important for the future of the tokamak device.

TOSCA is a small air-core tokamak, which can produce non-circular plasmas[2]. The major radius of the vacuum vessel is 30 cm and the minor radius 10 cm. Central electron temperatures of 300 eV and central electron densities of 3×10^{13} cm^{-3} are routinely obtained, with a plasma current of 12 kA and loop voltage of 2.5 volts.

A large saddle coil, when rotated about the minor axis so as to form an integral number of helices produces a 'k' coil[3]. If the periodic structure of the coil matches that of the plasma generated radial field perturbation then a signal is observed and all other pertubations eliminated. An approximation to these 'k' coils was used on the TOSCA device.

The coils were used in two ways, first as passive coils to detect particular mode structures and second, as active coils to produce a helical radial field which would result in the formation of magnetic islands with the same toroidal structure as the coil.

In the active mode, coil systems which could produce a dipole, quadrupole and a hexapole field were used. In the case of the quadrupole and hexapole systems, a computer code was used to determine the position of the 4 and 6 coils, carrying equal currents. This was necessary because TOSCA is a tight torus with an aspect ratio R/a = 3. The coils were made from flexible cable and positioned at a radius of 19 cm. For convenience the coils were wound, so that they had no net helicity. The nA value of these approximate 'k' coils is 1.125 m^2.

The winding performance was checked by measuring the azimuthal variation of the poloidal field generated by the coils and comparing this with 3-D magnetic field computations: the agreement was good. The question of the penetration of the helical fields through the vacuum vessel and into the plasma was considered. For a uniform conductivity profile the penetration time for the m=1 mode is calculated to be a few 100 μs (and faster for the m=2 and 3 modes) for the plasma parameters in this experiment. Since the vacuum vessel time constant is about 7 μs for radial and poloidal fields, it can be assumed that the fields from the external coils penetrate to the centre of the plasma in less than 500 μs.

Using the approximate m=3, n=2 and m=2, n=1 'k' coils, the major disruption was studied in detail. A high frequency mode was detected on the 3/2 'k' coil[4] with large amplitude just before the major disruption. This mode is shown in Fig.1 along with the 2/1 mode. The amplitude of the 2/1 mode reaches a value with $\tilde{B}r/B_\theta \approx 4\%$ before the disruption, (assuming q=2 at 6 cm, and $\tilde{B}r$ is the perturbed radial field). During the last 40 μs the 3/2 mode grows rapidly in amplitude and reaches a level with $\tilde{B}r/B_\theta \approx 4.5\%$ (assuming q=3/2 at 4 cm). The H_α light emission is shown, and it is clear that the level does not change before the disruption provided the plasma is well centred. The central channel of a soft x-ray array is also shown in the figure. The x-ray emissivity starts to fall when the m=2 amplitude reaches 2% ($\tilde{B}r/B_\theta \sim 2\%$), and the m=2 mode is clearly observed. This soft x-ray signal is filtered to give frequencies between 10-100 kHz only. (Detailed investigation of the soft x-ray signals also reveals the presence of the 3/2 mode).

The general characteristics of the 3/2 mode are demonstrated in Fig.1. The frequency of the 3/2 mode is about twice the frequency of the 2/1(this has a frequency of about 50 kHz which is close to the electron diamagnetic drift frequency). The growth rate of the 3/2 mode is approximately three times faster than the 2/1 mode. It is interesting to note that the amplitude of the 3/2 mode decreases about 10μs before the disruption which could indicate the presence of another mode. Indeed further investigations have shown that a mode with m=5 and n=3 is also present before the major disruption.

Figure 2 indicates the size of the 3/2 and 2/1 radial field perturbations associated with a major disruption. This figure can be used to calculate the size of the magnetic islands present at disruption but care must be exercised because different discharges may possess different current profiles. It is clear from the experiments that when the 2/1 mode exceeds a certain amplitude, a 3/2 mode is generated and this may lead to a major disruption. For a major disruption, the critical amplitude of the 2/1 mode is $\tilde{B}r/B_\theta \approx 4\%$ and of the 3/2 mode is $\tilde{B}r/B_\theta \approx 4.5\%$. For any reasonable current profile these values of $\tilde{B}r/B_\theta$ imply that the resultant magnetic islands have overlapped.

The 2/1 and 3/2 modes are always observed before a soft or major disruption for circular, triangular and elliptical plasmas. For triangular and elliptical plasmas the amplitude of the 2/1 and 3/2 modes are somewhat different from those shown in Fig.2, but the general pattern of the 2/1 and 3/2 mode production and interaction is the same as for circular plasmas.

Recent theories[5] suggest that the 2/1 and 3/2 mode may play an important part in the disruptive process. The disruptive instability is thought to be produced by a large 2/1 magnetic island, which may interact with the 3/2 island or with the limiter (or cold gas)[6,7]

Because of the possible importance of the 3/2 mode in the disruptive process on the TOSCA device, it was considered essential to test whether a major disruption could be produced by activating the external helical coils. When both the 2/1 and 3/2 coils are activated with large coil currents, ($I_{m=2} = 3$ kA, $I_{m=3} = 4$ kA, $I_p = 12$ kA), a major disruption[4] occurs depending on the position of the plasma. The quadrupole and hexapole fields are only accurate if the plasma is well centred in the vacuum vessel, so the resultant island sizes are sensitive to plasma position. A feature of these artificially produced disruptions is that they occur very rapidly and the faster the growth rate of the modes the more severe the disruption. Growth rates down to 25μs for the 2/1 mode have been measured.

When the 3/2 coil is activated with a coil current of approximately 4 kA a disruption occurs but only at low density ($\bar{n}_e < 1\text{x}10^{13}\text{cm}^{-3}$). This result is somewhat similar to that obtained by the Pulsator group, when they used an m=1 helical coil[8]. This low density effect may be associated with a relatively flat current profile, which permits a large stationary 3/2 island to be generated.

From the attempts to produce a major disruption, a stabilisation of the 2/1 mode was observed when the 2/1 coil alone was activated with low coil current[4]. The major disruption can also be delayed by activation of this 2/1 coil[9]. Production of major disruptions with these helical coils shows that it is easier to obtain a major disruption with both the 2/1 and 3/2 coils activated together. Field line tracing calculations for the actual equilibria with the appropriate helical windings show large distorted magnetic islands with large ergodic regions.

A study of disruptions caused by interaction of the plasma with the vacuum vessel wall either associated with incorrect vertical field control or positional instabilities[2] has been made. It was observed that the effect of the plasma touching the walls, was to increase the 2/1 and 3/2 mode activity. The H_α and 3845 Å impurity light did not increase dramatically until after the negative voltage spike occurred. A double Langmuir probe was also used to detect activity at the plasma boundary. The probe did not detect any significant change until after the disruption. From these experiments, it appears that the major disruption is due to some form of internal interaction in the plasma in this device.

The principal result from these experiments is the observation of a growing m=2, n=1 mode which at a critical amplitude leads to the rapid growth of an m=3, n=2 mode just before the major disruption. The production of a rapid major disruption is possible by the creation of magnetic islands with mode numbers 2/1 and 3/2. These results indicate that the major disruption is due to an internal interaction in the plasma in which several modes of different helicity are involved. Control of the 2/1 and/or 3/2 mode should prevent the major disruption.

REFERENCES

[1] B B Kadomtsev, Sov.J.Plasma Physics., 1 389 (1975)

[2] K M McGuire, D C Robinson and A J Wootton in Plasma Physics and Controlled Fusion Research (Proc. 7th Int. Conf. Innsbruck 1978), IAEA Vienna 1 339 (1979).

[3] E P Butt, P Ginot, W M Jones, H Kuus and P Plinate, Journal de Physique Colloque C3, 173 (1968).

[4] K M McGuire and D C Robinson, Proc. 9th Euro. Conf. on Controlled Fusion and Plasma Physics, Oxford 1 93 (1979).

[5] B V Waddell, B Carreras, H R Hicks and J A Holmes, Phys. Fluids 22, 896 (1979).

[6] R B White, D A Monticello, M N Rosenbluth and B V Waddell, Phys. Fluids 20, 800 (1977).

[7] R Pollard, M Turner, A Sykes, and J A Wesson, Paper presented at Symposium on Current Disruptions in Toroidal Devices, Garching, IPP, D1, February 1979.

[8] G Fussman et al in Plasma Physics and Controlled Nuclear Fusion Research (Proc. 7th Int. Conf. Innsbruck, 1978), IAEA Vienna, Vol 1, 401, (1979).

[9] F Karger et al, Proc. 8th Euro. Conf. on Controlled Fusion and Plasma Physics, Prague 1 3, (1977), also

K Bol et al, in Plasma Physics and Controlled Nuclear Fusion Research (Proc. 5th Int. Conf. Tokyo 1974), IAEA Vienna, Vol 1, 83 (1975).

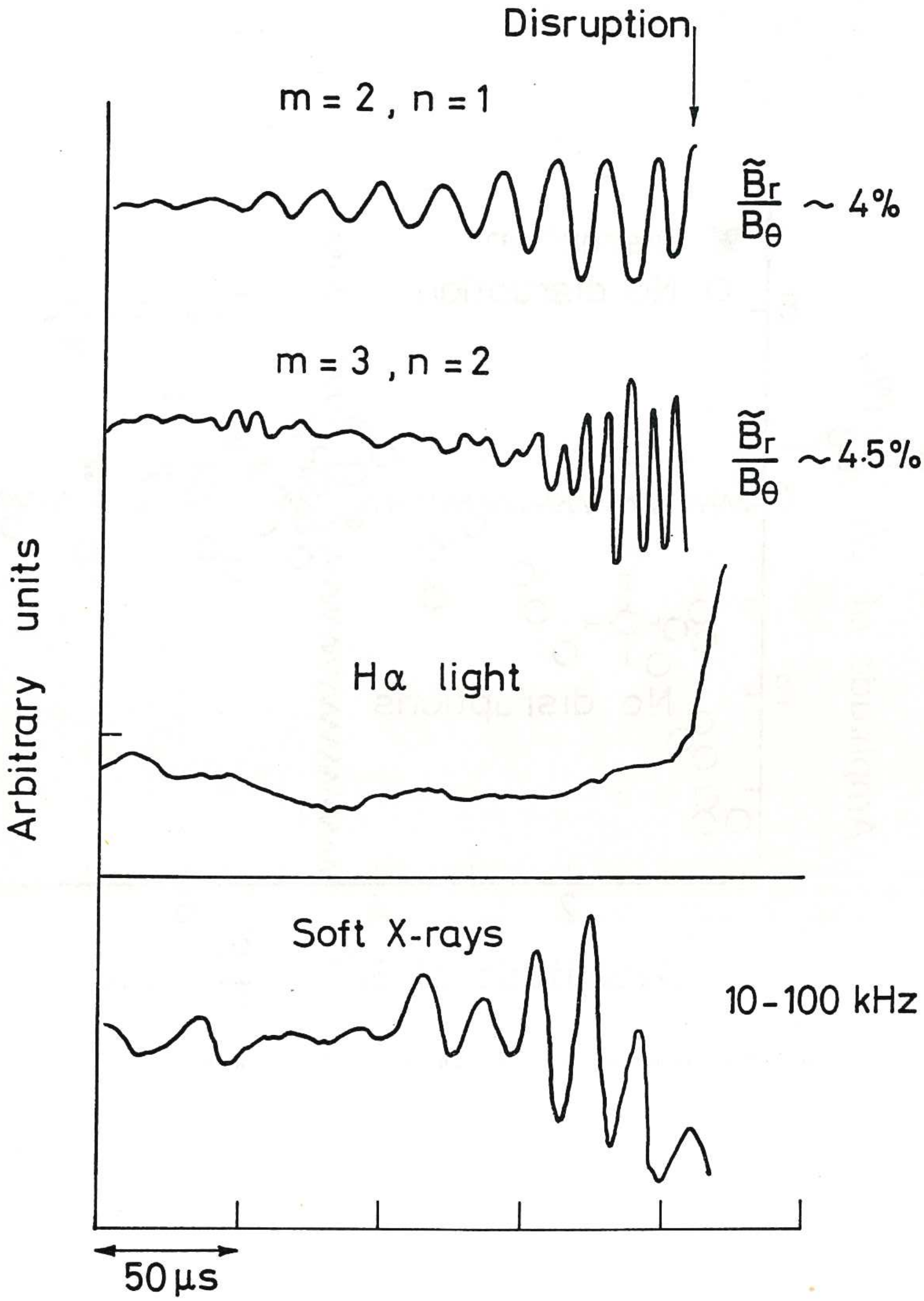

Fig. 1 Evolution of the m=2, n=1 and m=3, n=2 modes at a major disruption, together with the H_α light, and the soft x-ray central channel emission, the arrow indicates the time of disruption.

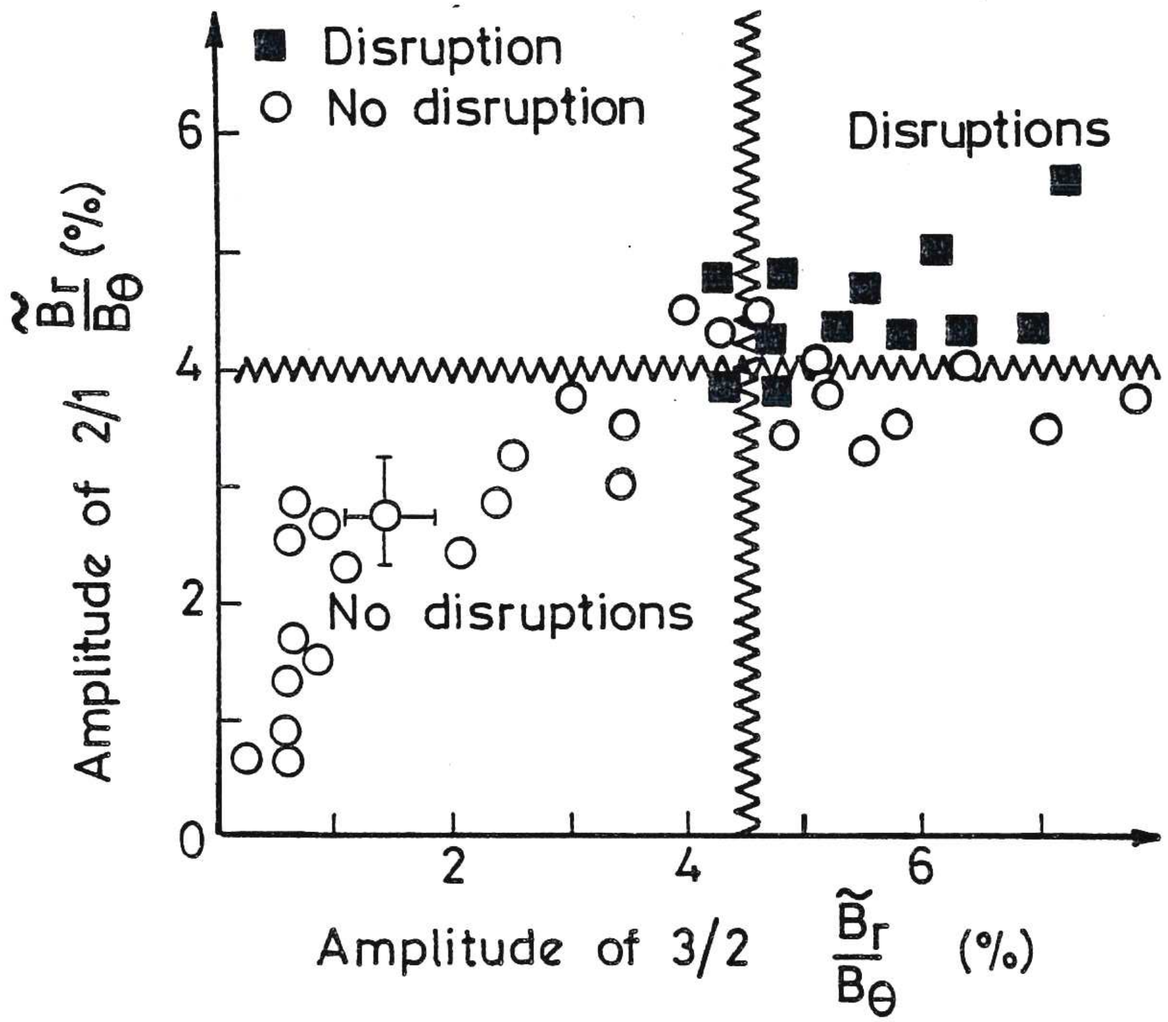

Fig. 2 The amplitudes of the 2/1 and 3/2 modes necessary for a major disruption.