

## Variation of MHD stability in JET Optimised Shear Discharges

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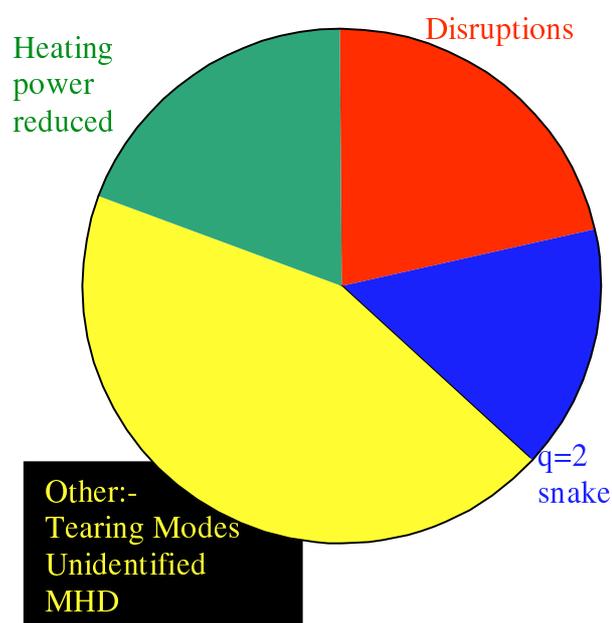
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### Introduction

In the JET Optimised Shear (OS) regime a combination of Lower Hybrid current drive, Ion Cyclotron Resonance Heating (ICRH) and Neutral Beam Injection (NBI) heating is used during the current rise phase to control the plasma current profile. Typically the high power heating phase is timed such that  $q_0 \leq 2.0$ , and if a power threshold is exceeded then an Internal Transport Barrier (ITB) forms [1]. This combination of relatively low core magnetic shear and high pressure gradients represents the conditions in which MHD instabilities such as the infernal mode [2] would be expected to be destabilised.

Experimentally the main MHD types observed to limit performance are shown in Fig 1. Disruptions were extensively studied in the previous MKIIa divertor (1996-7), where it was shown that they have a  $n=1$  pre-cursor [3]. These  $n=1$  pre-cursors were quantitatively identified as being due to a pressure driven kink mode. The  $q=2$  snakes, which are discussed in [4], are causal in limiting performance. In the large 'Other' category in Fig1, a rollover of  $R_{nt}$  does occur but no MHD can definitely be associated with this event. Many of the discharges in the 'Other' category have moderate- $n$  (typically  $n \sim 4$ ) tearing modes present which seem to reduce the energy confinement [5] but do not cause a prompt rollover. The variation of MHD stability shown in Fig 1 is achieved primarily by adjusting the heating timing and by puffing impurities (notably Ar) to control ELMs (which are a feature of the OS regime in the MKII GB divertor).



*Fig 1 MHD at peak  $R_{nt}$  for MKIIGB pulses with  $R_{nt} > 3 \times 10^{16} s^{-1}$ . Pulses where the rollover in  $R_{nt}$  is due to step-down of heating power are also*

### Variation of MHD stability

Disruptions, which represent a fundamental limit to performance, occur in discharges with the strongest pressure peaking (Fig 2). By delaying the high power NBI heating phase, slightly

less peaked pressure profiles result and the disruption is avoided but a  $q=2$  snake may occur. Delaying the heating still further avoids both disruptions and snakes, allowing a long high performance phase (Fig 3) in which the only significant MHD is an  $n=5$  tearing mode. A key ingredient in achieving this long high performance phase is the Argon puffing which inhibits large ELMs. The cause of rollover in performance in these long pulse discharges (such as 47413) is unclear. It can be seen from Fig 3b that an ELM free phase occurs at 8.84s, followed by a period of large ELMs which lead to an irreversible loss of the ITB. There is no fast magnetic data during the rollover in 47413, so the presence of some MHD activity causing an energy loss which triggers the ELM-free period can not be excluded. However, examination of similar discharges, which have fast magnetic data at the time of the prompt rollover, shows no evidence of MHD which is causal; it is possible that a bifurcation in transport properties is occurring in these discharges, resulting in the prompt rollover.

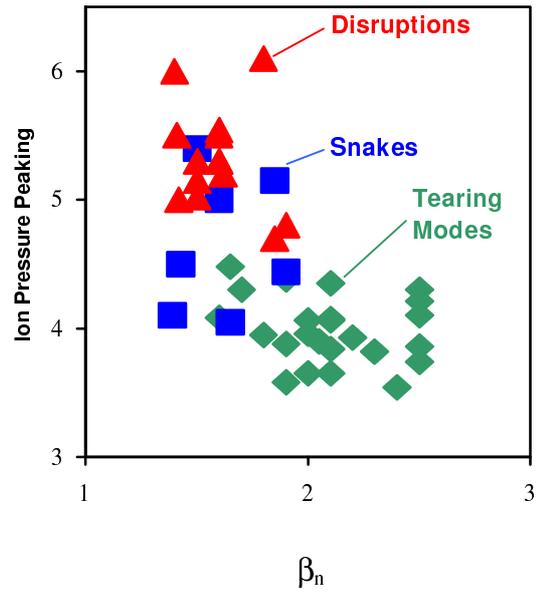


Fig 2 Type of MHD at  $R_{nt}(max)$  as a function of pressure peaking and  $\beta_n$ . It can be seen that disruptions occur for the most peaked pressure profiles, snakes for intermediate peaking and tearing modes for the lowest peaking.

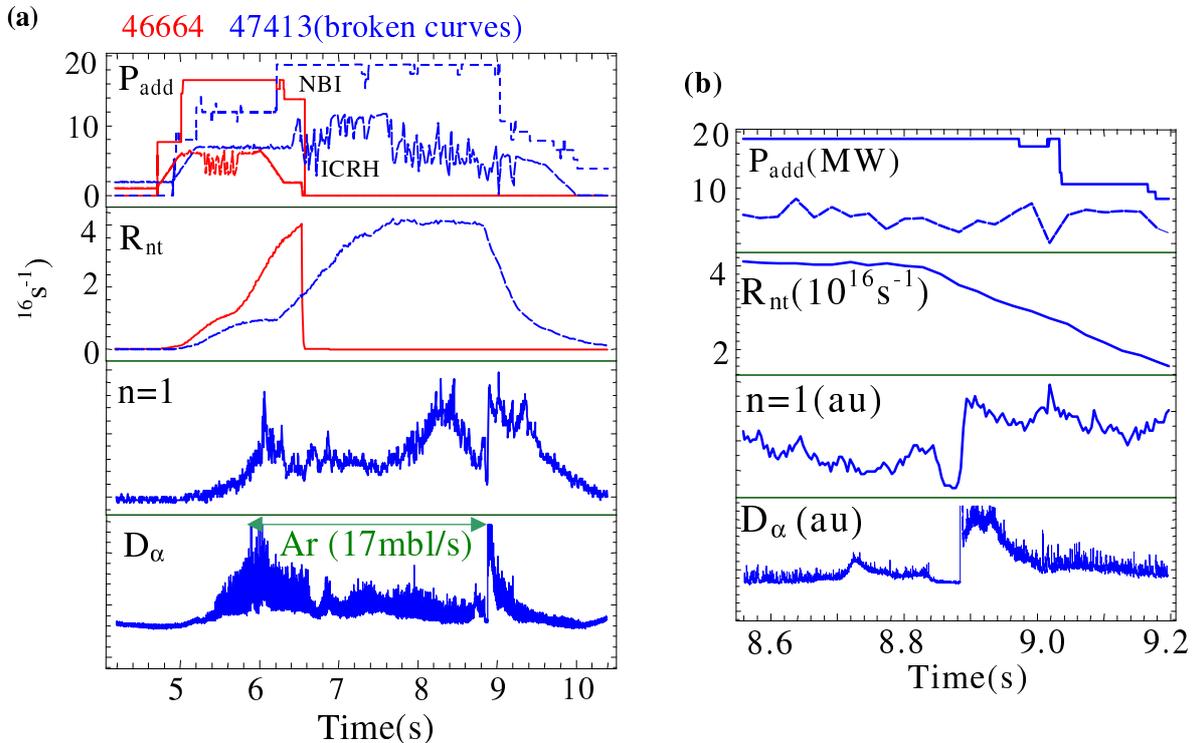


Fig 3(a) Record duration high performance OS pulse (47413, broken curves in top 2 sets of traces). The top 2 traces show a comparison with a typical high performance disruption (46664). (b) Expanded time history near the rollover in 47413, there is no evident  $n=2$  activity during this time and the  $n=1$  is at very low level ( $dB/B \sim 2 \times 10^{-5}$ ).

The variation of MHD stability by adjusting the heating timing lowers the pressure peaking, allowing higher  $\beta_n$  to be achieved while just avoiding the  $n=1$  disruptive limits in the highest performance discharges, as shown in Fig 4

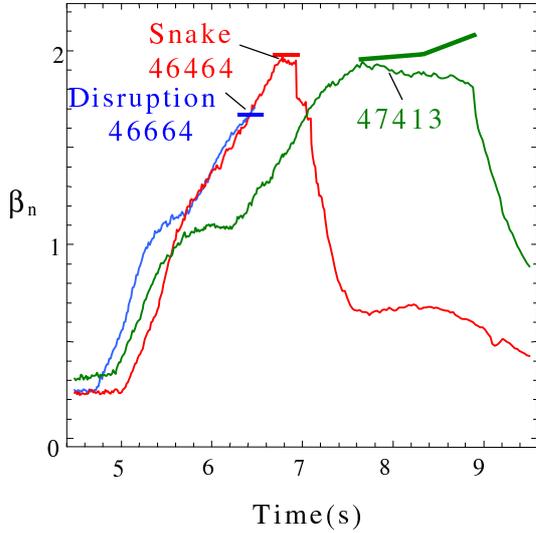


Fig 4  $b_n$  versus time for high performing disruptive (46664), snake-limited (46464) and long duration (47413) discharges. The thick lines show the calculated  $n=1$  stability limit with an ideal wall at the JET location. The pressure peaking for the disruptive discharge is 0.5 to 0.8 higher than in the longer duration discharges, accounting for their ability to reach higher  $b_n$

### Variation of target $q$ -profile

The discharges discussed in the previous section have  $I_p \sim B_t$ , and  $q_0 \lesssim 2.0$  at the start of the high power heating phase. By using relatively higher toroidal fields it has also been possible to form good confinement barriers for plasmas with  $q_0 \lesssim 3.0$ ; an example of such a discharge is shown in Fig 5a.

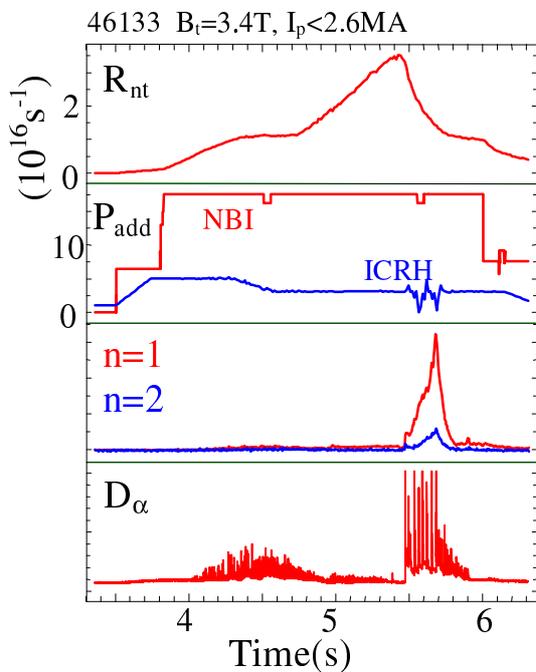


Fig 5a Discharge in which a transport barrier is formed with  $q_0 \lesssim 3.0$ . Note the absence of MHD ( $n=1,2$ ) until the large ELMs at 5.5 s.

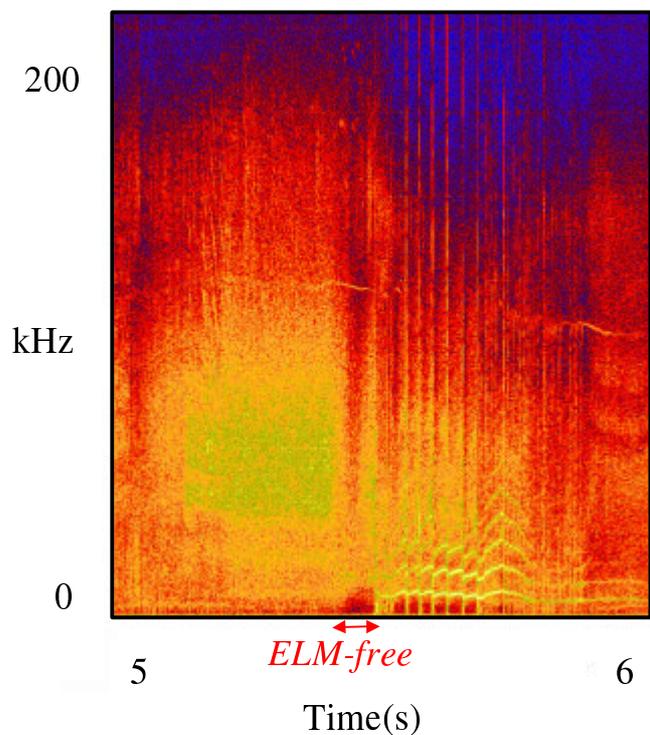


Fig 5b Spectrogram of MHD activity in 46133 (lighter colours indicate higher dB). No precursor causing an energy loss and triggering the ELM-free phase is evident.

In common with the long duration discharges (eg 47413) the high performance phase of this discharge is terminated by an ELM-free period, followed by large ELMs. As can be seen from Fig 5b there is no coherent MHD activity preceding the ELM-free H-mode phase; the broad-band turbulence extending up to about 100kHz is characteristic of a good ITB. This result is in accord with stability calculations which show that the n=1 ideal kink mode would be expected to be stable for these discharges (with ITBs formed at  $q_0 \leq 3.0$ , and  $\beta_n \sim 2$ ).

## Discussion

A good understanding of the disruptions in Optimised Shear, as being due to pressure driven kink modes, has allowed discharge optimisation through varying the peaking of the pressure profile. The primary means of broadening the pressure profile, in ELMy H-mode operation is by timing the high power NBI heating phase to be later. It is also important to use impurity puffing to avoid large ELMs which are incompatible with a good ITB. If the pressure profile is slightly broadened then a limit due to a q=2 snake occurs a little before the calculated disruptive limit. Broadening the pressure profile still further (by later heating) avoids both disruptions and snakes and in general the only coherent MHD activity is moderate-n tearing modes; these types of discharge nearly always suffer a rapid rollover in performance but no coherent MHD has been identified as causing this rollover, and it may be that some kind of abrupt change in transport properties occurs.

Looking to the future the new JET MSE system [6] coupled with real-time EFIT and/or the possibility of directly measuring the margin of n=1 stability with internal saddle coils gives great promise for further systematic optimisation against disruptions.

## References

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