Influence of Edge Currents and Pressure Gradients on the MHD Stability of Low-n External Kink Modes

G.T.A. Huysmans, C.D. Challis, M. Erba, W. Kerner and V.V. Parail
JET Joint Undertaking, Abingdon, OX14 3EA, UK.

Introduction

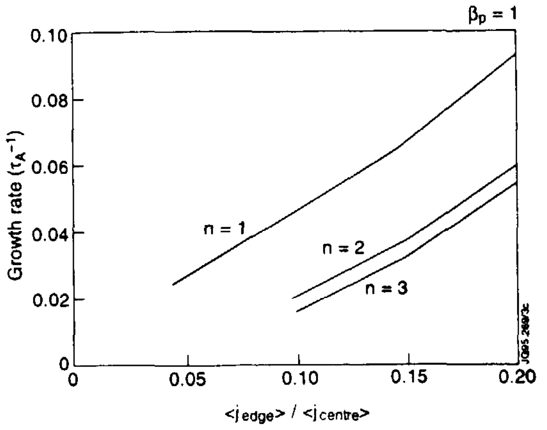
In JET hot-ion H-mode discharges, a large pressure gradient and the associated bootstrap current develops at the edge of the plasma. The good confinement properties of these discharges is often lost due to an instability localised at the edge, i.e. a giant ELM or a so-called 'slow roll-over mode' [1]. The slow roll-over mode is a small amplitude mode which can exist for about a hundred milliseconds with a constant amplitude. Low-n external kink modes (also called peeling modes) are a possible cause for these edge localised modes

In this paper, the stability of the low-n external kink mode is studied as a function of the edge pressure gradient and the edge current. First, the general behaviour in a circular plasma is discussed. Then the kink stability is discussed for two types of JET discharges, a high performance hot ion H-mode discharge and a high beta poloidal discharge. Also discussed is the access to the region of second stability for ballooning modes. Access to this regime requires a finite edge current for typical JET plasma shapes. The edge current required for access to second stability depends strongly on the plasma shaping and the value of β_{pol}. If this current is too large, the external kink can become unstable before the plasma becomes second stable and stable route into the second stable regime exists.

The MHD stability calculations are performed with the CASTOR code [2] in the JET geometry. The HELENA code [3], linked to the JETTO [4] and TRANSP [5] transport code provides the equilibrium and metric as input for the CASTOR code.

Circular plasmas

The growth rate of the low-n external kink mode mainly depends on the value of the edge current (see Fig.1). However, the edge pressure gradient in the region of the localisation of the mode has a strong influence (see Fig.2). For small pressure gradients, well below the ballooning limit, a finite pressure gradient is stabilising the external kink mode. This effect is most pronounced for the lowest toroidal mode numbers. For edge pressure gradients close to the ballooning limit, the pressure gradient becomes destabilising for the n>1 modes. This is because the higher-n modes can be more localised on the outside in the bad curvature region.



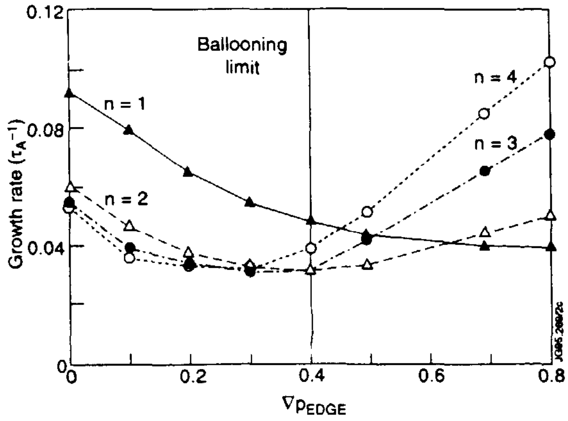


Fig.1 The growth rate of the n=1,2 and 3 external kink mode in a circular plasma as a function of the edge current density. (a/R=0.3, β_{pol} *= 1)*

Fig. 2 The growth rate of the external kink for toroidal mode numbers n=1, 2, 3 and 4 as a function of the edge pressure gradient. The ballooning limit is also indicated.

JET hot ion H-mode discharges

The JET hot-ion H-mode discharge #30591(see Fig. 3a) is analysed with respect to kink and ballooning modes. The good performance phase is terminated by a giant ELM at t = 52.2s. (I = 2.5 MA, $\beta_N = 2.5$). The evolution of the current density profile of this discharge is modelled with the JETTO transport code using measured pressure profiles. The total bootstrap current is increasing linearly in time up to the point of the giant ELM. The stability diagram for this low triangularity discharge ($\delta_{lower} = 0.29$, $\delta_{upper} = 0.13$) is shown below (Fig. 3b). The figure is calculated by changing the pressure gradient and the current density in the region $\psi = 0.95$ - 1.0, keeping the total poloidal β ($\beta_{pol} = 0.98$) fixed. The value of the pressure gradient and the edge bootstrap current as obtained from the JETTO simulation is indicated in Fig. 3b, showing that the values of the bootstrap current are potentially large enough to drive an external kink unstable.

It is clear from Fig.3b that for this discharge with a low triangularity there is no access to the second stable region for ballooning modes. A low-n kink mode would become unstable well before the plasma edge becomes reaches the second stability region.

JET high β_{pol} discharges

Transiently improved confinement has been observed in some JET high β_{pol} discharges [6]. This has been correlated with oscillations in the total current. Discharge #32344 is an example of this (see Fig. 4a). Repeating the discharge with pre-programmed current ramps yields a similar phase of improved confinement. The edge pressure gradient show a marked increase during this phase.

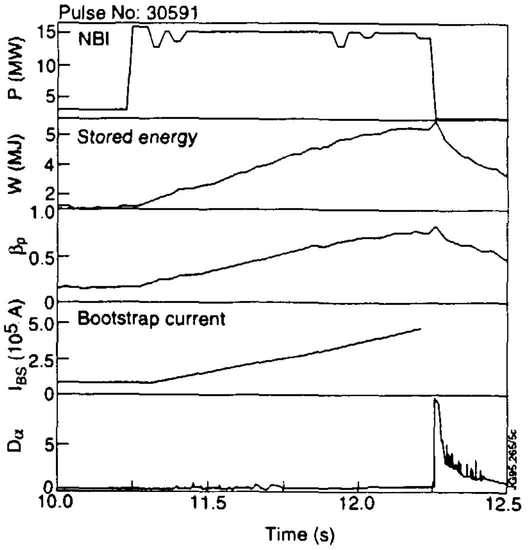


Fig 3a Traces of the NBI heating power, stored energy, poloidal beta, the total bootstrap current and D_α. *for the hot ion H-mode discharge #30591.*

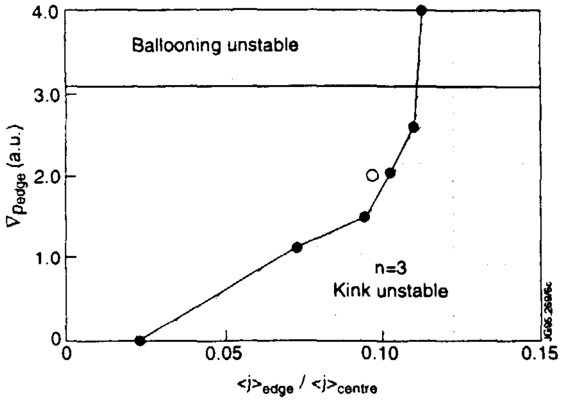


***Fig.3b** Stability diagram for discharge #30591, t=52.2s. The ballooning mode stability is evaluated at* ψ*=0.95. The external kink has a toroidal mode number n=3. The open circle indicates the pressure gradient and the edge current from the JETTO simulation.*

The current profile evolution of this discharge was analysed with the TRANSP code. Due to the high value of β_{pol} (>2.5) and the inherent high value of the triangularity only a small edge current is required to bring the plasma edge from $\psi = 0.95$ to 1.0 into the second stable region with respect to ballooning modes (see Fig. 4b). The time at which the experimental edge current exceeds this value correlates well with the observed improved confinement and increasing edge gradients.

Results of the n = 1 external kink stability calculation as a function of the edge pressure and edge current density are shown in Fig.4a together with the ballooning stability curve. The n = 1 and n = 2 kinks are very stable in this configuration. An open gap does exist between the ballooning and the kink stability curves giving access to a region where large pressure gradients and the associated edge currents are stable.

The experimental path the discharge follows in the grad(P)- J_{edge} plane is indicated in Fig.4b. Before the ramp of the current the pressure gradients at the edge are calculated to be marginally stable to ballooning modes. But even the small ramp of the oscillation of the total current is sufficient to raise the edge current and to allow access the second stable regime.

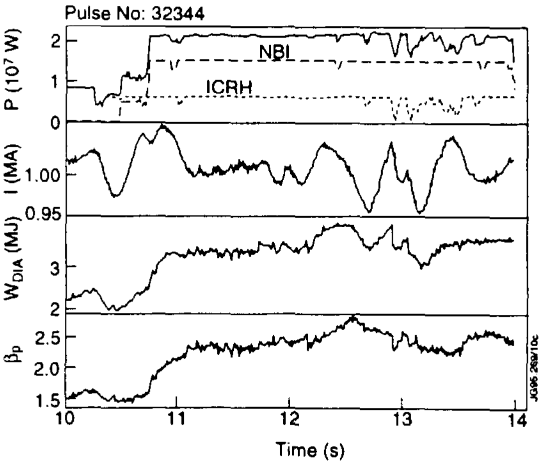


Fig. 4a Traces of the heating power, total current and the stored energy and poloidal β *for discharge #32344.*

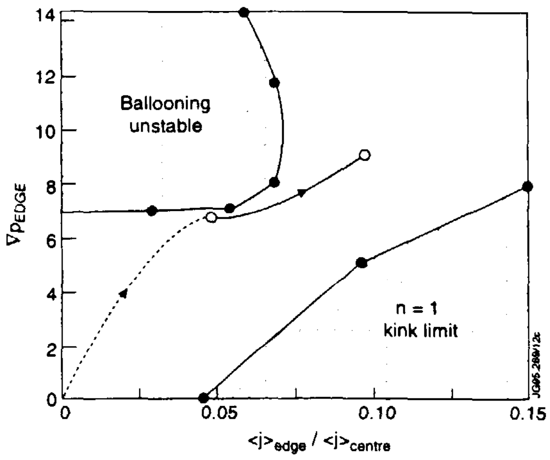


Fig. 4b Stability diagram for high β_{pol} *discharge #32344 at* $t = 52.25$ *s. Ballooning stability is evaluated at* $\psi = 0.95$.

Conclusion

Localised external kink modes are destabilised by a finite value of the edge current. Low values of the edge pressure gradient (well below the ballooning limit) have a stabilising effect on the external kink mode especially on the n=1 mode. With increasing pressure gradient (of the order of the ballooning limit) the external kink mode is destabilised by the pressure, at first for the higher-n kink modes.

The value of the edge bootstrap current obtained from transport simulations of hot-ion H-modes can be large enough to drive an external kink unstable. The external kink is a possible cause for the edge instabilities that limit the performance in the JET hot-ion H-mode discharges.

At the low values of β_{pol} and triangularity there is no access to the second stability region, external kink modes become unstable well before the edge becomes second stable to ballooning modes. However, at high β_{pol} and triangularity the access to the second stable regime occurs at much lower edge currents. The observed improved confinement phases in the JET high poloidal beta discharges due to current ramps agree well with the stability calculations of ballooning and kink modes and the predicted access to the second stable regime.

References

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