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J. L. Dunlap, R. D. Burris, J. H. Harris,
A. P. Navarro, and V. K. Paré

Oak Ridge National Laboratory
Oak Ridge, TN 37830 USA

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SURVEY OF MHD MODES AND THEIR EFFECTS IN
ORMAK, ISX-A, AND ISX-B*

J. L. Dunlap, R. D. Burris, J. H. Harris,† A. P. Navarro,‡ and V. K. Paré
Oak Ridge National Laboratory, Oak Ridge, TN 37830, U. S. A.

Introduction: A comparison of some features of the three tokamaks is given as Table 1. The ORMAK and ISX-A have ceased operation. The ISX-B has completed a checkout phase with studies of circular, ohmically heated plasmas in which it performed much like ISX-A. Shaped and injection heated plasmas are being studied, but the data base for these is not sufficient to include details in this report.

Diagnostics for mode structures were the usual Mirnov loops for $\tilde{B}_\theta$ and collimated soft x-ray detectors for the internal fluctuations $\tilde{X}$. The $\tilde{X}$ measurements on ISX-A, and thus far on ISX-B, used only a single x-ray channel which viewed vertically across the center of a minor cross section. Multiple channels were used on ORMAK in a fashion which permitted m number determinations at several plasma radii. For detailed studies, analog signals were stored on magnetic tape and later digitized for fast Fourier transform analysis.

More complete descriptions of most of the observations are available elsewhere.[1]

Typical Mode Patterns: The "steady state" portion of the discharges usually shows one of two types of general mode behavior.[2] One, Type A, is characterized by strong $m = 2$ $\tilde{B}_\theta$ and $\tilde{X}$ and weak internal disruptions with short sawtoothing periods. The other, Type B, has weak $\tilde{B}_\theta$ but more pronounced internal disruptions with longer periods. Type A was favored by operation at high density and at low q_ℓ. Type B extended farther into those regions when neutral beam heating was added in ORMAK. In ISX-A, weak Type A early in the discharge could be converted into Type B by a programmed gas puff.[3]

Loop signals with Type B in ORMAK were $m = 3$ or 4; in ISX-A, the present evidence indicates simultaneous 2 and 3. We have only loop definitions of toroidal mode number, always $n = 1$.

Effects of Impurities: For most of its lifetime, ORMAK was characterized by $5 \leq Z_{eff} \leq 10$. The ISX plasmas have had $Z_{eff} \leq 2$. The lower impurity levels produced broader profiles and a significant extension of the operating regime stable against disruption, as illustrated in Figure 1. Most of ORMAK's operation was with $q_\ell \approx 5$, and that of ISX-A with $q_\ell \approx 3.5$. Practical low q limits of operation for ORMAK were $q_\ell \approx 3.5$ (OH) and 2.6 (NBI). ISX-A operated well at 2.7; we did not attempt a thorough study at lower q. High density and low q limits of operation usually took the form of a series of soft disruptions with dominant $m = 2$ rather than hard disruptions. The enhanced stability of ISX-A against large $m = 2$ and the gas puff control resulted in its operation almost exclusively with Type B discharges. By way of contrast, much of the parameter space explored by ORMAK was marked by Type A behavior or by only marginal stability to large $m = 2$.

Mode Coupling: Studies of the Type A discharges in ORMAK showed $m = 1$ and 2 structures in $\tilde{X}$ while the $\tilde{B}_\theta$ showed $m = 4$, then 3, and finally 2 as the discharge developed. At any given time, the modes present had the same frequency and coincided in phase along an outward directed minor radius. Most of the Type B behavior in ORMAK was characterized by identical $\tilde{X}$ ($m = 1$) and $\tilde{B}_\theta$ frequencies. An interesting exception was that in some discharges with neutral beam injection, the frequency of $\tilde{X}$ just prior to internal disruption was significantly lower than that of $\tilde{B}_\theta$. This behavior is illustrated in Figure 2. A definite frequency relation between the two signals may not exist, but a ratio of approximately 2/3 was most often observed.

In ISX-A we noted the dominant frequency of the $m = 1$ $\tilde{X}$ changing from a value lower than that of the loop signal to synchronization with the loop as the plasma recovered from an internal disruption, as has been reported[4] for TFR. We have no evidence of this from ORMAK.

Disruptions that develop out of relatively quiet discharges, after a brief interval of growing $m = 2$ with the last few cycles showing distinctive distortion patterns associated with coupled $m = 2$ and $m = 1$ modes, have been reported in a number of tokamaks. The soft disruptions which terminate our Type B discharges develop out of briefly growing $m = 2$, and the last cycles usually show these characteristic distortions. In this connection it is interesting that ORMAK Type A discharges near the low q and high density limits could display these characteristic patterns, grossly distorted and with $\tilde{B}_2/B_\theta \approx 1\%$, for tens of milliseconds without disrupting.

Modes and Confinement: We found a correlation of gross energy confinement time, τ_E, and mode activity in ORMAK in the case of large $m = 2$ at low q. τ_E declined and the level of the $m = 2$ increased as q_ℓ was progressively lowered. Degradation of τ_E by large m = 2 was also observed in ISX-A, but not systematically mapped. In both devices the m = 2 was accompanied by degradation of particle confinement as well.

Disruptions During Current Rundown: Plasmas that are well behaved with regulated I_p often disrupt during current rundown. A gradual approach of the singular surfaces may be involved, since in ORMAK we observed that r_1 remains relatively fixed but r_2 moves inward as I_p is reduced.

Arcing and Disruptions: An experiment in ISX-B by Mioduszewski, Clausing, and Heatherly[5] has revealed a relationship between unipolar arcs and soft disruptions. The arrangement monitored current flow from the wall of the vacuum vessel to a metal sample mounted near the edge of the plasma. In well behaved discharges, arcing was detected only at the initial breakdown and in the quenching phase during I_p rundown. In discharges with soft disruptions, the arcing sample showed current pulses up to 20 A coincident with the disruptions.

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†Present address, University of Wisconsin, Madison, WI 53706.

‡Visitor from J. E. N., Madrid, Spain.

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Table 1. Comparisons of the Tokamaks

DEVICE	PLASMA SHAPE	SHELL	R(cm)	a_ℓ(cm)	I_p, B_T(kA,kG)
ORMAK	Circular	Yes	80	23	170,26
ISX-A	Circular	No	92	26	120,13
ISX-B	Circular	No	93	27	150,12
	Elliptical and D			27/50	

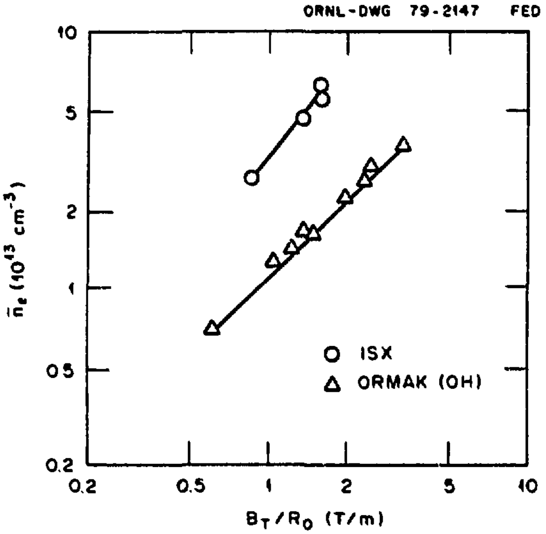

Figure 1. Comparison of stability against disruption (hydrogen plasma).

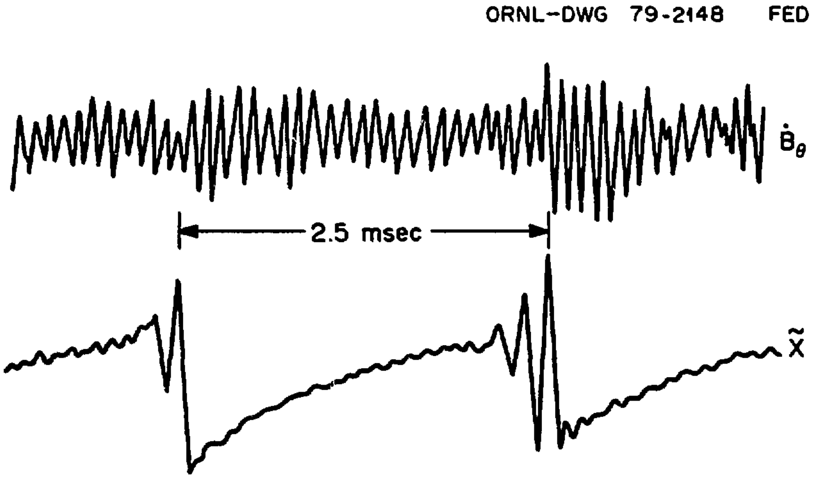

Figure 2. Internal disruptions in ORMAK with neutral beam heating. The $\tilde{X}$ channel includes a 100 Hz high pass filter.