q_{95}<2 Operation Via Control of MHD Stability in the DIII-D Tokamak

P. Piovesan[1], A.W. Hyatt[2], G.L. Jackson[2], R.J. La Haye[2], M.J. Lanctot[2], C. Paz-Soldan[2], E.J. Strait[2], A.D. Turnbull[2], J. Bialek[3], J.M. Hanson[3], G.A. Navratil[3], D. Shiraki[3], F. Turco[3], M. Baruzzo[4], T. Bolzonella[1], L. Marrelli[1], P. Martin[1], L. Piron[1], P. Zanca[1], and M. Okabayashi[4]

[1]*Consorzio RFX, EURATOM/ENEA Association, Padova 35127, Italy*
[2]*General Atomics, PO Box 85608, San Diego, CA 92186-5608, USA*
[3]*Columbia University, New York, NY 10027, USA*
[4]*Princton Plasma Physics Laboratory, Princeton, NJ 08543-0451, USA*

MHD stability sets an upper limit on the plasma current achievable in a tokamak for a given toroidal field. The limit is set by the ideal MHD m=2/n=1 external kink, which is unstable when the edge safety factor q_a is less than 2. Several experiments have confirmed this limit with $q_{95,}$ the safety factor at the 95% flux surface, being the relevant empirical parameter in diverted tokamaks. Recently this limit was overcome in RFX-mod, run as a low-current, circular tokamak, using real-time magnetic feedback control of non-axisymmetric coils to suppress the 2/1 mode. These results motivated further experiments in a larger, shaped tokamak, which were performed in DIII-D in 2012 and confirmed that the apparently general result that the q_{95}=2 limit can be overcome by MHD stability control.

In DIII-D, the q_{95}=2 limit was reached by slowly ramping I_p up at fixed toroidal field B_T in D-shaped, single-null divertor, L-mode discharges. Pre-programmed error field correction with coils external to the wall (C-coils) was optimized to avoid n=1 resonant error-field mode penetration, which approved passively stable operation at q_{95}=2.2. At q_{95}=2, an instability compatible with the expected 2/1 mode, in terms of helicity and growth rate, manifests and disrupts the plasma. Subsequent experiments used magnetic feedback control of internal coils (I-coils) driven by fast audio-amplifiers to access the q_{95}<2 regime. The 2/1 mode was suppressed at q_{95}=1.9 for up to 0.45 s (i.e. about 150 resistive wall times and four energy confinement times). These discharges eventually disrupt due to voltage saturation in the I-coil power supplies, and not due to an intrinsic physics limit. Simulations of the MHD stability under the action of feedback using a cylindrical model indicate that residual error fields may excite the 2/1 mode, which suggests improved error field correction may help to avoid the present limits.

The paper will also report on confinement, MHD dynamics, and plasma rotation in the q_{95}<2 regime, and will assess the potential of this scenario for fusion.

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