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Experimental Simulation of Burn Control Using DIII-D In-Vessel Coils

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A new approach has been developed to control the fusion power by applying a non-axisymmetric magnetic field (n=3) using the DIII-D in-vessel coils to modify the energy confinement time. This is significant because it provides an alternative approach to controlling fusion power in a burning plasma. In future burning plasma experiments as well as magnetic fusion energy power plants, various actuators (e.g. auxiliary heating, fuel injection, impurity injection) have been proposed to control the fusion power. The fusion power in a tokamak burning plasma experiment or power plant operating at high Q_{DT} is a strong function of the energy confinement time and hence the H-factor relative to the scaling relationship, $H_{IPB98(y,2)}$. For a discharge in which alpha heating is negligible compared with auxiliary heating, the thermal fusion power, which scales as W^2, scales as $P_{aux}^{0.62}\ H_{IPB98(y,2)}^{2}$. In a power plant operating near ignition, the auxiliary power is very small compared with the alpha heating power. Thus for constant machine parameters including density, the fusion power would scale approximately as $H_{IPB98(y,2)}^{5.3}$ if the auxiliary heating power is negligible. Thus, an actuator that modifies the confinement time can be used to adjust the fusion power. This has potential advantages for a power plant due to the reduced power requirements relative to auxiliary heating and that it may enable the control of the plasma response more rapidly than with fueling or impurity influxes due to recycling of the fuel gas and impurities.

In the relatively low collisionality DIII-D discharges, the application of non-axisymmetric magnetic fields results in a decrease in confinement time and density pump-out. The stored energy, which is used as a surrogate for fusion power, was controlled by the application of non-axisymmetric fields as shown in Fig. 1. The regulation of the stored energy by means of I-coil feedback yields comparable to or more stationary conditions than by the conventional approach of varying the neutral beam power. The standard deviation in the stored energy fluctuations in the case shown was reduced by 0.7. Furthermore, the temperature and density profiles are found to have less variability as a function of time. This may be, in part, because the

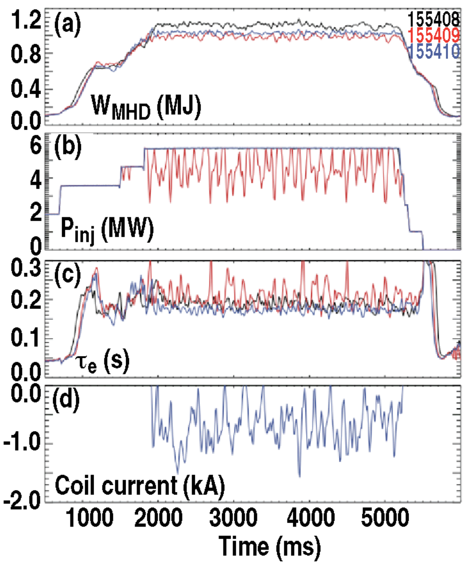

Fig. 1. The stored energy was controlled by applying a non-axisymmetric field (n=3) using the I-coils in a closed feedback loop (155410) and compared with a shot without feedback control (155408) and with a shot with neutral beam power feedback (155409).

application of the non-axisymmetric n=3 magnetic fields using the I-coils results in higher frequency and reduced amplitudes edge localized modes (ELMs). In these experiments, the conditions were chosen to avoid fully suppressing ELMs by operating outside of known resonances in the edge safety factor.

Transient increases in neutral beam power were used to simulate alpha-heating excursions. The feedback loop largely compensated the increased heating power by increasing the I-coil current, which reduced the energy confinement time as shown in Fig. 2. The accompanying increased particle transport in the pedestal was compensated by means of feedback control of the density at the top of the pedestal using the Thomson scattering system and fueling by means of the gas system. As noted above, controlling both the stored energy and the pedestal density is important to control the divertor edge conditions.

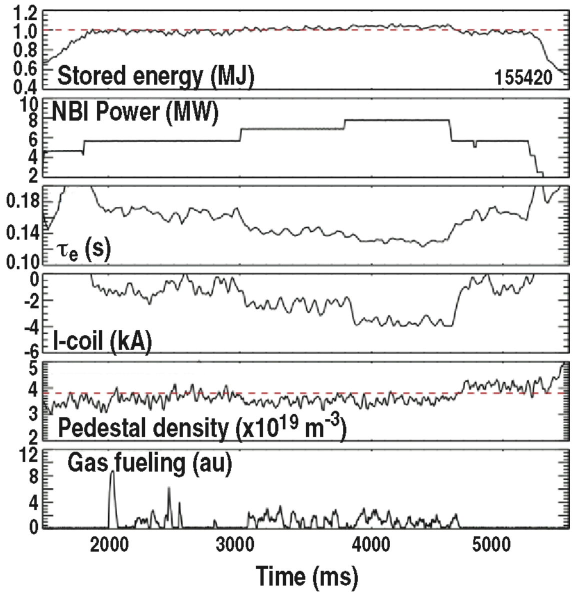

Fig. 2. The I-coil feedback loop compensated for the increased neutral beam power to control the stored energy.

This technique was also demonstrated at reduced levels of input torque. In one set of experiments, one co-source was replaced with a counter source varying the applied torque between 6.7 to 3.7 N-m at constant beam power and control of the confinement time and stored energy by using the I-coil currents was demonstrated despite a significant change in rotation. Limited experiments were performed to assess the impact on beta limits and no significant changes were observed.

While plasma stored energy is a reasonable proxy for fusion power in a power plant, fast ion and profile effects could, in principle, affect these experiments. TRANSP was used to examine these issues. TRANSP analysis (without anomalous fast ion diffusion) shows that the ratio of computed stored energy (including fast ions) to total stored energy from magnetics does not change with the application of non-axisymmetric fields indicating that loss of fast ions is not appreciable. Preliminary TRANSP analysis indicates that the reduction in thermal plasma pressure is across the plasma profile and not only in the pedestal region. The ion pressure in the core decreases in response to the application of current in the I-coils on an energy confinement timescale.

These experiments demonstrated that it is possible to control the stored energy, which is a proxy for fusion power, by means of applying non-axisymmetric magnetic fields. Control of the energy confinement time is potentially advantageous since the power requirements are modest and in these experiments it was possible to compensate for density pump-out. Burn control experiments with simulations of fusion power based on real-time measurements of the fuel density and ion temperature would further extend these results. These experimental results have interesting theoretical interpretations. Various gyrokinetic turbulence models have predicted that the core plasma parameters should be sensitive to the pedestal parameters and have motivated these experiments. The evolution of core parameters is potentially a test of the stiffness of the transport models as well as an important consideration for the feedback system.

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