SELF-ORGANIZED IGNITION OF A TOKAMAK PLASMA

Klaus Schoepf
Institute for Theoretical Physics, University of Innsbruck, Austria
E-mail: *klaus.schoepf@uibk.ac.at*

ABSTRACT

The continuous progress in the attainment of plasma parameters required for establishing nuclear fusion in magnetically confined plasmas as well as the prospect of feasible steady-state operation has instigated the interest in the physics of burning plasmas [1]. Aside from the required plasma current drive, fusion energy production with tokamaks demands particular attention to confinement and fuelling regimes in order to maintain the plasma density n and temperature T at favourable values matching with specific requirements such as the triple product $n\tau_E T$, where τ_E represents the plasma energy confinement time. The identification of state and parameter space regions capable of ignited fusion plasma operation is evidently crucial if significant energy gains are to be realized over longer periods. Examining the time-evolving state of tokamak fusion plasma in a parameter space spanned by the densities of plasma constituents and their temperatures has led to the formation of an ignition criterion [2] fundamentally different from the commonly used static patterns. The incorporation of non-stationary particle and energy balances into the analysis here, the application of a 'soft' Troyon beta limit [3], the consideration of actual fusion power deposition [4,5] and its effect of reducing τ_E are seen to significantly influence the fusion burn dynamics and to shape the ignition conditions. The presented investigation refers to a somewhat upgraded (to achieve ignition) ITER-like tokamak plasma and uses volume averages of locally varying quantities and processes. The resulting ignition criterion accounts for the dynamic evolution of a reacting plasma controlled by heating and fuel feeding. Interestingly, also self-organized ignition can be observed: a fusion plasma possessing a density and temperature above a distinct separatrix in the considered parameter phase space is seen to evolve – without external heating and hence practically by itself – towards an ignited stable equilibrium state, even if the initial state is outside the positive power balance region. Since fuel is assumed to be constantly supplied for that, cold fuelling is the sole required injection to the system during the ignition dynamics. The known parameter discrepancy between stable and unstable ignited operation is found to be controllable by the fuelling rate, and thus may be reduced for a D-T fusion plasma to only a very few keV difference in the plasma temperature T. Further, the minimum heating path toward stable ignition was inspected; however, it was identified as an impracticable operational scenario due to substantial oscillations of the plasma density and temperature. Avoiding the latter, a heating regime with optimized low energy expense is proposed that leads conveniently to the stable ignition point at reasonable plasma temperatures in the 20 keV range. To minimize the energy required to heat the plasma beyond a state, from where it evolves by itself to ignited stable equilibrium, a relatively high power neutral beam applied for a short duration is found to be more efficient than a less powerful beam over a longer time period.

References

[1] IAEA Workshop on Burning Plasma Physics and Simulation, Tarragona, Spain, July 4-5, 2005; Workshop Summary in Fusion Sci. Techn. **49**, 79 (2006)
[2] K. Schoepf, T. Hladschik, Ann. Nucl. Energy **23**, 59 (1996)
[3] D. Anderson et al., Fusion Technology **23**, 5 (1993)
[4] K. Schoepf et al., Kerntechnik **67**, 285 (2002)
[5] K. Schoepf et al., TH/P6-3 at 21st IAEA Fusion Energy Conf., Chengdu, China, Oct. 2006