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NUMERICAL STUDY AND OPTIMIZATION OF NON-INDUCTIVE CURRENT DRIVE EFFICIENCY IN FNS TOKAMAK PLASMAS

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Tokamak-based fusion neutron sources (FNS) can effectively address the fuel problems of nuclear energy and future fusion power plants operation [1]. FNS primary mission is testing technological systems being exposed to intense neutron flux and evaluation of relevant effects in materials and structural components designed for future nuclear reactors, fusion-fission and pure thermonuclear devices. Hybrid facilities based on FNS can provide invaluable experimental data on nuclear waste management, nuclear fuel production and other technologies for future hybrid reactors. Ultimately, a steady state tokamak-based neutron source with intensity level $10^{18} - 10^{19}$ neutrons per second can become a cost effective solution when compared to other neutron generators.

At present, two major design options of FNS are considered and still a subject for comparison: a conventionally shaped tokamak DEMO-FNS with a moderate aspect ratio ($R_0 = 3.2m, a = 1m, k = 2.1, B_0 = 5T, P_f = 400MW, Q = 1$), and a strongly shaped spherical device FNS-ST ($R_0 = 0.5m, a = 0.3m, k = 2.75, B_0 = 1.5T, P_f = 2MW, Q = 0.2$). Both tokamak designs assume steady state operation sustained by bootstrap and auxiliary current drive (CD). Neutral beam injection (NBI) is chosen as a main source of energetic particles for plasma fuelling, heating, torque, and as the most efficient current driver (NBCD), with high efficiency confirmed theoretically [2] and experimentally [3].
In theory, NBCD efficiency ($= I_{CD} n_e R / P_{NB} / 10^{20}$) is much higher when compared to other auxiliary CD sources [4, 5]. Our numerical analysis predicts **η = 0.2-0.5** can be achieved in optimized scenarios for both FNS devices. In reality, NBCD values strongly depend on the magnetic field shape, NB size and injection geometry, on plasma target density and temperature. The target values of non-inductive current drive are: **~5 MA** (DEMO-FNS, P_{NB} = 30 MW), and **~1.5-2 MA** (FNS-ST, P_{NB} = 6-10 MW). NBI parameters are optimized either to maximize NBCD efficiency in a given plasma or, alternatively, to obtain a hollow current profile favourable for steady-state operation. NBCD and bootstrap profiles for expected range of DEMO-FNS and FNS-ST scenarios are presented in this contribution.

A simple numerical model [6] is used for beam-driven effects analysis in tokamak plasmas. It incorporates the beam detailed structure with account of NB producing technology and the ions tracking in the equilibrium magnetic field. MHD equilibria are reconstructed by the analytic solution of Grad-Shafranov equation [7]; the approach allows the study of plasma shaping effects through configurations of interest - from conventional to spherical tokamaks. NB fast ion distributions and resulting NBCD profiles are obtained by fast ion tracking in magnetic field. For both FNS devices, non-inductive CD is expected to reach the target values. The results prove NBI is a plausible solution for accessing the long pulse plasma operation and control in FNS, if NBI parameters and injection geometry are chosen appropriately.

[1] Shpansky Y.S. and DEMO-FNS Project Team, 2019 Nucl. Fusion 59 076014

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