Plasma Parameters of Compact Fusion Reactors using Similarity Scaling Laws of Spherical Tokamak Fusion Plasmas

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Abstract

Spherical tokamaks (ST) represent an attractive alternative to large aspect ratio tokamaks as they may provide a faster, more economical and compact solution on the path to a fusion reactor. Plasma studies carried out so far on compact, low aspect ratio tokamaks have been limited to small, low/ medium magnetic field and low plasma current therefore the information available for extrapolating to large scale ST plasmas are limited. The scaling law recently obtained [1] links the major radius (R_{ST}) to the fusion gain factor (Q_0) , the magnetic field on axis (B) , the aspect ratio (A), the isotopic mass (M) and the cylindrical safety factor (q) (where C_{ST} is a dimensional constant and H_{ST} is the confinement improvement factor with reference to the ST confinement scaling law): $R_{ST} = C_{ST}\ H_{ST}^{-1/2.23}\ Q_0^{0.464}\ B^{-1.13}\ A^{1.59}\ M^{0.22}\ q^{0.4}$, and allows for the plasma design of compact spherical neutron sources with higher magnetic field compatible with the use of high temperature superconductors. In fact, a feature of the scaling for fusion-reactor plasmas is a stronger dependence on the magnetic field and aspect ratio than the one for ordinary sub-ignited plasmas. The parameters of a spherical tokamak producing the same fusion gain Q (=10) of ITER under different confinement assumptions and for different aspect ratios are presented and discussed. An example of parameters of a ST device deduced using the previous scaling and the ITER confinement time scaling is : R=1.58m, A=1.8, B=3.7T, plasma current Ip=7.8MA, fusion power P_{fus}=118MW, auxiliary heating power P_{AUX}=11.8MW, confinement improvement factor with respect to the ITER IPBy2 confinement time scaling H_{IPBy2} =3.5, q=1.99. In addition, scaling laws for spherical tokamaks related to TFTR supershots and JET hot-ion scenarios are derived and discussed in the context of the operation of compact neutron fusion sources.

1.Michele Romanelli and Francesco Paolo Orsitto, On Similarity Scaling of Tokamak Fusion Plasmas with different Aspect-Ratio , Plasma Phys. Control. Fusion 63 (2021) 125004