Goals and Initial Progress of EXL-50 Experimental Plasma Physics Research

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EXL-50 is a spherical tokamak (ST) designed to produce, test, explore and understand collisionless high-performance plasmas (aiming at temperatures and densities towards ~1keV and ~$10^{19}m^{-3}$, respectively) without relying on a central solenoid coils. Its design and parameter goals are provided in Figure 1 and Table 1. Its vacuum vessel permits a closed-flux-surface region for thermal plasma with aspect ratio (A) ~1.5, overlapped by a larger region of low-density current-carrying energetic electrons with A ~1.3, which in turn also exist in a substantial volume of open field lines (Figure 2). [1,2] A long-term goal of this research is to determine if this confinement configuration has a potential to produce, test and realize high-density ~100-keV plasmas required for p-^{11}B fusion.

EXL-50 commenced its full-field experimental research in April 2020. Substantial progress has since been made in the plasma parameters produced and the underlying physics principles discovered and studied, as follows:

1) Using ECRH (water dump) powers up to 170kW from a gyrotron at 28GHz, plasma currents of up to 150kA have been produced and maintained for beyond 1s in duration. [3] Measured HXR intensity and energy spectrum indicated average electron energies as high as 250keV with maximum energies above MeV's. [3] Lower currents around 76kA were also maintained for line-densities of ~$10^{19}m^{-2}$, exceeding the cut-off densities. [4]
2) As a first approximation, a multi-fluid equilibrium model was developed together with a computational method and applied to reproduce available plasma and magnetic data, [2] verifying the reality of the EXL-50 plasma confinement configuration (Figure 2).
3) Following the turn-off of the ECRH power, the EXL-50 plasma configuration and current (up to 130kA) can be maintained via the energetic electrons beyond 1s until the magnetic coil currents are ramped down. The turnoff is also accompanied by a strong reduction in H_a signal at the top limiters and a factor of 2-4 rise in line density. These suggest the possibility of a prompt improvement in thermal plasma ion and electron confinement, which is under investigation.
4) With ECRH alone, total plasma stored energy up to 8kJ has been measured via diamagnetic loops. High-resolution multi-chord visible spectroscopy of helium lines was utilized and data analyzed, showing ion temperatures in the 20-40eV range for line densities of ~$2x10^{18}/m^{-2}$. First Thomson Scattering data indicated electron temperatures up to ~100eV. [5] It is estimated that in this case, the stored energy is carried predominantly by the energetic electrons.

As ICRH, LHW, NBI heating systems, additional diagnostic capabilities [6] (e.g., multi-chord interferometers, AXUV), and physics analysis tools are brought forth, up-to-date progress of the EXL-50 experimental research will be reported.

References

[1] H. Idei et al, 27th IAEA-FEC (2018), EX/P4-50.
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[3] Y. Shi et al, arXiv:2104.14844 (2021).
[4] H. Tanaka et al, 26th IAEA-FEC (2016) EXW/P4-45.
[5] H. Li et al, invited paper at 7th Conf. on Fusion Plasma Diagnostics, Shanghai, China (2021, July 22-25).
[6] B. Deng et al, invited paper at 7th Conf. on Fusion Plasma Diagnostics, Shanghai, China (2021, July 22-25).

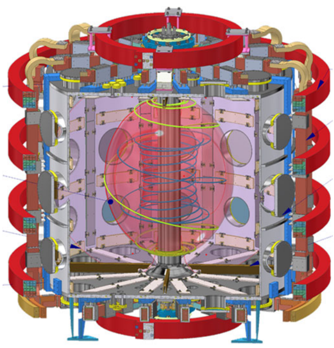

Figure 1. EXL-50 device design fitted with an artist's rendition of a multi-fluid plasma

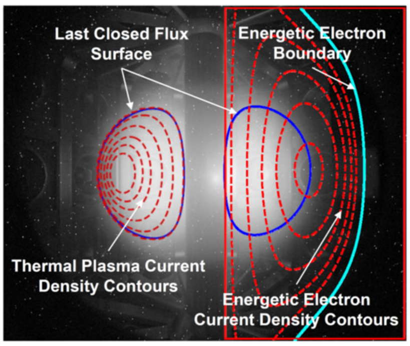

Figure 2. An EXL-50 plasma image and the concurrent current density distribution of a multi-fluid equilibrium reconstruction [2]

Design Parameter Goals	
Plasma current (kA)	500
Major radius R_0 (m)	0.6
Minor radius a (m)	0.4
Toroidal field (T)	0.46
Plasma elongation	1.8 – 2.2
Plasma triangularity	0.1 – 0.4
Plasma duration (s)	5

Table. EXL-50 device parameter design goals