PROGRESS OF THE EHL-2 SPHERICAL TORUS ENGINEERING DESIGN

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After nearly 40 years of development, the spherical torus has become an important research direction for fusion energy. The UKAEA, PPPL, Japan, and the ENN in China are each beginning to design future spherical torus fusion devices known as STEP[1], STAR[2], ST2035[3], and EHL-3[4]. In recent years, to extend the plasma parameters of the spherical torus to a magnetic field $B_0 > 1.5$T, and plasma current $I_p > 2$MA, a number devices are being upgraded or newly designed, such as the ST-40[5], EHL-2[6], GLOBUS-3[7]. Among these the ENN EHL-2 is an experimental platform for hydrogen-boron fusion (Fig. 1).

The physics design of EHL-2 is focused on addressing three main operating scenarios, i.e., (1) high ion temperature scenario, (2) high-performance steady-state scenario and (3) high triple product scenario.

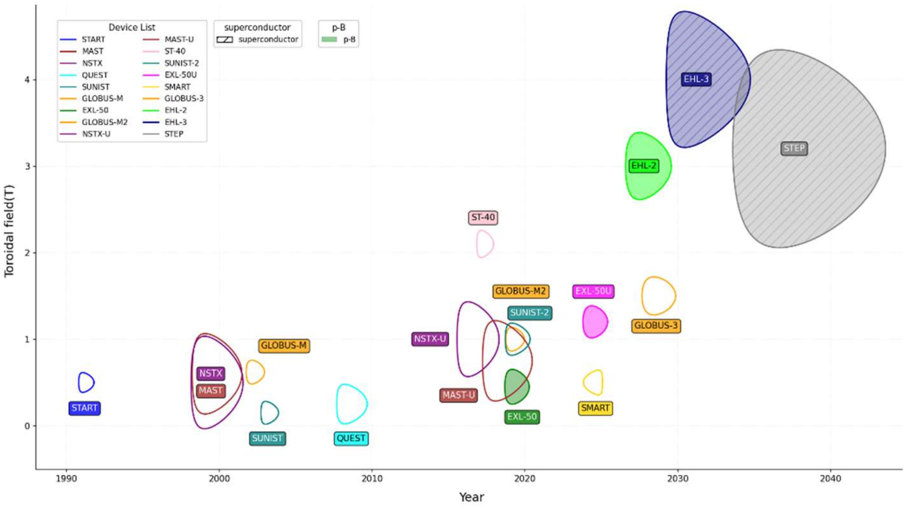

Fig.1 Spherical torus fusion power DEMO 2035-2040

Target parameter

The EHL-2's key parameter are set: a plasma radius (R_0) of 1.05 m, aspect ratio (A) of 1.85, max central magnetic field (B_0) of 3T, and plasma current (I_p) of 3 MA. The toroidal field holds for 2.3s at 3T, with the central solenoid able to drive plasma current at 5 V•s.

Engineering Challenges

For a toroidal field (B_0) of 3 T, the current density needs to be increased to 88 A/mm². This requires experimental validation of the conductor materials and redesign of the magnet joint methods. The low aspect ratio requirement restricts the space on the high-field side. Particularly when $B_0 \geq 3$T and the flat-top time exceeds 2s, it is necessary to seek the optimal configuration among the maximum magnetic field, flat-top time, central solenoid volt-second, shot interval, and safety reliability.

The TF magnets require a power supply capability of 200 kA and 600 MVA, for which a mature design validation has not yet been achieved. To achieve a plasma current of 3 MA, higher current ramp-up rates and multiple plasma drive methods are needed.

The high magnetic field and the high ion temperature required for p-B fusion heating necessitate 100 GHz electron cyclotron resonance heating system and a 200keV negative ion sources neutral beam system. This imposes more specific requirements on the existing wave source suppliers, power supplies, and system integration, and necessitates early design and single-system testing.

Verification of Key Technologies

To ensure the reliability of the designed structure under various operating conditions, in addition to conducting design analysis and calculations, experimental verifications have been carried out on components such as the flexible joint, the TF centre bundle, and the CS coils. These include tests like the 200kA current test for the TF flexible joint, development of materials and structures compatible with both room temperature and cryogenic conditions, and testing of the liquid nitrogen cooling circulation systems for TF and CS. Maintenance analysis in case of magnet component damage. Experiment on the plasma current start-up mode with the central solenoid coil and electron cyclotron heating system working in coordination. Coupling tests of the 80keV positive ion source neutral beam, 200keV negative ion source neutral beam, and ion cyclotron heating system.

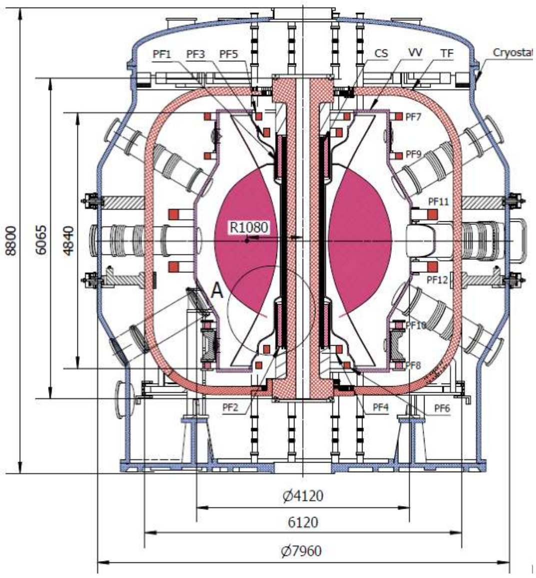

Fig.2 EHL-2 spherical torus layout

Structure and design features

The toroidal field (TF) magnets need to provide a magnetic field over 3T and a flat-top discharge duration exceeding 2.3s, calculations have shown that the temperature rise of the copper conductors operating at room temperature would exceed 160°C. This temperature is beyond the limit of existing insulating materials, making it unfeasible. Therefore, using copper conductors operating at liquid nitrogen temperature range as TF magnets has emerged as a potentially viable option.

According to the design, the main components of the torus include the toroidal field (TF) magnets, poloidal field (PF) magnets, vacuum vessel, magnet supports, and the outer cryostat. Among these, the TF magnets consist of the TF center bundle and the TF C-shaped components, with the center bundle and the C-shaped segments connected by a flexible joint. The central solenoid (CS) is located around the TF center bundle, and operates within the liquid nitrogen temperature range. After being integrally manufactured and assembled with the central tube of the vacuum vessel, it forms a complete component, which is then assembled with the vacuum vessel at the site. The poloidal field coils (PF1-PF12) are arranged outside the vacuum vessel, using water cooling and operating at room temperature.

Design verification is progressing alongside our construction schedule: We completed the engineering concept and preliminary design between June 2023 and June 2024. Detailed engineering and key technology verification will take place from January 2024 through December 2025, followed by the procurement of long-lead items from June 2025 to December 2026.

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