Technology Offer

Compact Stellarator-Tokamak Hybrid: Enhanced Plasma Stability and Efficient Fusion Reactor Design

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Abstract

This invention introduces a novel hybrid fusion reactor concept that combines the advantages of tokamaks and stellarators. In tokamaks the magnetic confinement field is generated by toroidal coils and the plasma current driven by a central solenoid coil, while in stellarators the magnetic confinement field is created by a complex magnetic coil system. The proposed design integrates a single type of simple quasi-axisymmetric (QA) coil to introduce 3D shaping effects while maintaining a compact tokamak-like structure. This hybrid approach enhances plasma stability, enables steady-state operation, and eliminates the need for a central solenoid for startup. The resulting fusion device optimizes confinement performance and simplifies reactor construction, making it a viable candidate for next-generation fusion power plants.

Background

Tokamaks and stellarators are the most researched fusion reactor designs, but each has limitations. Tokamaks require induced plasma currents, potentially leading to disruptions. Stellarators, while inherently more stable, rely on intricate three-dimensional magnetic coils, which complicate manufacturing and limit the achievable plasma volume. Previous attempts at hybrid devices failed due to the complexity of coil configurations and the drastic reduction of the useful plasma volume. This invention presents an optimized quasi-axisymmetric stellarator-tokamak hybrid, where a small number of specially designed coils enhance magnetic field control without compromising compactness.

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The hybrid system replaces the central solenoid with four identical quasi-axisymmetric coils (Fig. 1A) placed on the inboard side of the reactor. The quasi-axisymmetric (QA) coils modify the magnetic field to form self-sustaining flux surfaces. The QA shaping introduces external rotational transform and improves plasma stability while maintaining a large plasma volume comparable to conventional tokamaks (Figs. 1B and 1C). The hybrid device operates in a continuous spectrum between pure tokamak and quasi-axisymmetric stellarator configurations, offering flexibility in plasma shaping and operational modes. Advanced coil optimization algorithms ensure efficient design and manufacturability.

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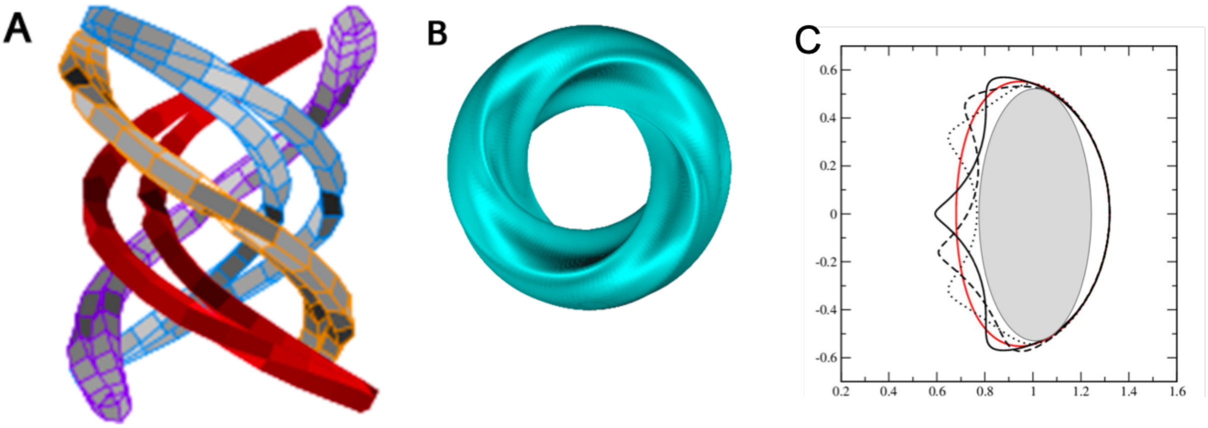

Figure 1: Hybrid Stellarator-Tokamak Design and Magnetic Field Configurations. **(A)** Four identical quasi-axisymmetric (QA) coils control the 3D shape of the magnetic field while maintaining a compact design. **(B)** The shape of the plasma boundary confined by the magnetic field configuration. **(C)** Poloidal cross sections of the plasma boundary produced by the magnetic field configuration.

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Advantages

- **Enhanced Plasma Stability:** Reduces disruptions by incorporating 3D shaping while preserving neoclassical transport properties.
- **No Central Solenoid Required:** Enables alternative startup methods, reducing cost and complexity.
- **Compact and Efficient Design:** Retains tokamak-like geometry while leveraging stellarator benefits.
- **Scalability and Retrofitting Potential:** Can be integrated into existing tokamak designs with minimal modifications.
- **Simplified Coil System:** Uses a single type of modular QA coil, reduces manufacturing costs compared to traditional stellarators.

Potential applications

- **Fusion Power Plants:** Enables next-generation fusion reactors with improved efficiency and reliability.
- **Plasma Stability Research:** Provides a testbed for studying 3D shaping effects on plasma confinement.
- **Tokamak Upgrades:** Offers a cost-effective alternative to existing fusion reactors.
- **Nuclear Research Facilities:** Supports experimental and theoretical studies for advanced fusion configurations.

Patent Applications

PCT (not yet disclosed)

Publications

Henneberg, S. A., & Plunk, G. G. (2024). Compact stellarator-tokamak hybrid. *Physical Review Research*, *6*(2), L022052.

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