of conservation of canonical angular momentum. A novel solution to provide stability control without enhancing diffusion of any particles is, thus, important to take advantage of the higher performance potential of these never-before explored advanced FRC concepts. In light of the foregoing, it is, therefore, desirable to improve the confinement and stability of FRCs in order to use steady state FRCs as a pathway to a whole variety of applications including compact neutron sources (for medical isotope production, nuclear waste remediation, materials research, neutron radiography and tomography), compact photon sources (for chemical production and processing), mass separation and enrichment systems, and reactor cores for fusion of light nuclei for the future generation of energy.

SUMMARY

[009] The present embodiments provided herein are directed to systems and methods that facilitate the formation and maintenance of new High Performance Field Reversed Configurations (FRCs). In accordance with this new High Performance FRC paradigm, the present system combines a host of novel ideas and means to dramatically improve FRC confinement of particles, energy and flux as well as provide stability control without negative side-effects. According to a first aspect of the invention, a method for generating and maintaining a magnetic field with a field reversed configuration (FRC) within a confinement chamber is described, the method comprising the steps of forming an FRC about a plasma in a confinement chamber wherein the FRC plasma is in spaced relation with the wall of the confinement chamber, and

maintaining the FRC at or about a constant value without decay by injecting beams of fast neutral atoms from neutral beam injectors into the FRC plasma at an angle towards the mid-plane of the confinement chamber of about 15° to 25° less than normal to the longitudinal axis of the confinement chamber and towards the mid-plane of the confinement chamber, wherein the neutral atom beam injectors are coupled to the confinement chamber adjacent a midplane of the confinement chamber and oriented to inject neutral atom beams toward the mid-plane at an angle of about 15° to 25° less than normal to the longitudinal axis of the confinement chamber.

[009a] According to a second aspect of the invention, a system for generating and maintaining a magnetic field with a field reversed configuration (FRC) is described, the system comprising a confinement chamber, first and second diametrically opposed FRC formation sections coupled to the confinement chamber, the formation section comprising modularized formation systems for generating an FRC and translating the FRC toward a midplane of the confinement chamber, first and second divertors coupled to the first and second formation sections, first and second axial plasma guns operably coupled to the first and second divertors, the first and second formation sections and the confinement chamber, a plurality of neutral atom beam injectors coupled to the confinement chamber and oriented to inject neutral atom beams toward a mid-plane of the confinement chamber at an angle of about 15° to 25° less than normal to a longitudinal axis of the confinement chamber, a magnetic system comprising a plurality of quasi-dc coils positioned around the confinement chamber, the first and second formation sections, and the first and second divertors, first and second set of quasi-dc mirror coils positioned between the confinement chamber and the first and second formation sections, and first and second mirror plugs position between the first and second formation sections and the first and second divertors, a gettering system coupled to the confinement chamber and the first and second divertors, one or more biasing electrodes for electrically biasing open flux surface of a generated FRC, the one or more biasing electrodes being positioned within one or more of the confinement chamber, the first and second formation sections, and the first and second divertors, two or more saddle coils coupled to the confinement chamber, and an ion pellet injector coupled to the confinement chamber.

[009b] According to a third aspect of the invention, a system for generating and maintaining a magnetic field with a field reversed configuration (FRC) is described, the system comprising a confinement chamber, first and second diametrically opposed FRC formation sections coupled to the confinement chamber, first and second divertors coupled to the first and second formation sections, one or more of a plurality of plasma guns, one or more biasing electrodes and first and second mirror plugs, wherein the plurality of plasma guns includes first and second axial plasma guns operably coupled to the first and second divertors, the first and second formation sections and the confinement chamber, wherein the one or more biasing electrodes being positioned within one or more of the confinement

chamber, the first and second formation sections, and the first and second divertors, and wherein the first and second mirror plugs being position between the first and second formation sections and the first and second divertors, a gettering system coupled to the confinement chamber and the first and second divertors, a plurality of neutral atom beam injectors coupled to the confinement chamber and oriented to inject neutral atom beams toward a mid-plane of the confinement chamber at an angle of about 15° to 25° less than normal to a longitudinal axis of the confinement chamber, and a magnetic system comprising a plurality of quasi-dc coils positioned around the confinement chamber, the first and second formation sections, and the first and second divertors, first and second set of quasi-dc mirror coils positioned between the confinement chamber and the first and second formation sections, wherein the system is configured to generate an FRC and maintain the FRC ~~without decay while the neutral beams are injected into the plasma~~ within the confinement chamber of the system, the FRC being maintainable by the system in spaced relation to the wall of the confinement chamber at or about a constant value without decay while the neutral beams are injected from the plurality of neutral atom beam injectors into the FRC at an angle of about 15° to 25° less than normal to the longitudinal axis of the confinement chamber and towards the mid-plane of the confinement chamber.

[010] An FRC system provided herein includes a central confinement vessel surrounded by two diametrically opposed reversed-field-theta-pinch formation sections and, beyond the formation sections, two divertor chambers to control neutral density and impurity contamination. A magnetic system includes a series of quasi-dc coils that are situated at axial positions along the components of the FRC system, quasi-dc mirror coils between either end of the confinement chamber and the adjacent formation sections, and mirror plugs comprising compact quasi-dc mirror coils between each of the formation sections and divertors that produce additional guide fields to focus the magnetic flux surfaces towards the divertor. The formation sections include modular pulsed power formation systems that

CLAIMS

What is claimed is:

1. A method for generating and maintaining a magnetic field with a field reversed configuration (FRC) within a confinement chamber, the method comprising the steps of:

forming an FRC about a plasma in ~~a~~ the confinement chamber, wherein the FRC plasma is *in spaced relation with the wall of the confinement chamber, and*

maintaining the FRC at or about a constant value without decay by injecting beams of fast neutral atoms from neutral beam injectors into the FRC plasma at an angle towards the mid-plane of the confinement chamber of about 15° to 25° less than normal to the longitudinal axis of the confinement chamber and towards the mid-plane of the confinement chamber, wherein the neutral atom beam injectors are coupled to the confinement chamber adjacent a midplane of the confinement chamber and oriented to inject neutral atom beams toward the mid-plane at an angle of about 15° to 25° less than normal to the longitudinal axis of the confinement chamber.

2. The method of claim 1 further comprising the step of generating a magnetic field within the chamber with quasi-dc coils extending about the chamber.

3. The method of claims 1 and 2 further comprising the step of generating a mirror magnetic field within opposing ends of the chamber with quasi-dc mirror coils extending about the opposing ends of the chamber.

4. The method of claims 1 through 3 wherein the step of ~~the~~ forming the FRC includes forming a formation FRC in a formation section coupled to an end of the confinement chamber and accelerating the formation FRC towards the mid-plane of the chamber to form the FRC.

5. The method of claim 4 wherein the step of ~~the~~ forming the FRC includes forming a second formation FRC in a second formation section coupled to a second end of the confinement chamber and accelerating the second formation FRC towards the mid-plane of the chamber where the two formation FRCs merge to form the FRC.

6. The method of claims 4 and 5 wherein the step of forming the FRC includes one of forming a formation FRC while accelerating the formation FRC towards the mid-plane of the chamber and forming a formation FRC then accelerating the formation FRC towards the mid-plane of the chamber.

7. The method of claim 5 further comprising the step of guiding magnetic flux surfaces of the FRC into diverters coupled to the ends of the formation sections.

8. The method of claim 4 further comprising the step of guiding magnetic flux surfaces of the FRC into a diverter coupled to the end of the formation section.

9. The method of claim 8 further comprising the step of guiding magnetic flux surfaces of the FRC into a second diverter coupled to the end of the chamber opposite the formation section.

10. The methods of claims 7 through 9 further comprising the step of generating a magnetic field within the formation sections and diverters with quasi-dc coils extending about the formation sections and diverters.

11. The method of claims 7 and 10 further comprising the step of generating a mirror magnetic field between the formation sections and the diverters with quasi-dc mirror coils.

12. The method of claim 11 further comprising step of generating a mirror plug magnetic field within a constriction between the formation sections and the diverters with quasi-dc mirror plug coils extending about the constriction between the formation sections and the diverters.

13. The method of claims 1 through 12 wherein the step of maintaining the FRC further comprising the step of injecting pellets of neutral atoms from a pellet injector coupled to the confinement chamber into the FRC.

14. The method of claims 1 through 13 further comprising the step of generating one of a magnetic dipole field and a magnetic quadrupole field within the chamber with saddle coils coupled to the chamber.

15. The method of claims 1 through 14 further comprising the step of conditioning the internal surfaces of the chamber, formation sections, and diverters with a gettering system.

16. The method of claim 15 wherein the gettering system includes one of a Titanium deposition system and a Lithium deposition system.

17. The method of claims 1 through 16 further comprising the step of axially injecting plasma into the FRC from axially mounted plasma guns.

18. The method of claims 1 through 17 further comprising the step of controlling the radial electric field profile in an edge layer of the FRC.

19. The method of claim 18 wherein the step of controlling the radial electric field profile in an edge layer of the FRC includes applying a distribution of electric potential to a group of open flux surfaces of the FRC with biasing electrodes.

20. A system for generating and maintaining a magnetic field with a field reversed configuration (FRC) comprising

a confinement chamber,

first and second diametrically opposed FRC formation sections coupled to the confinement chamber, the formation section comprising modularized formation systems for generating an FRC and translating the FRC toward a midplane of the confinement chamber,

first and second divertors coupled to the first and second formation sections,

first and second axial plasma guns operably coupled to the first and second divertors, the first and second formation sections and the confinement chamber,

a plurality of neutral atom beam injectors coupled to the confinement chamber and oriented to inject neutral atom beams toward a mid-plane of the confinement chamber at an angle of about 15° to 25° less than normal to a longitudinal axis of the confinement chamber,

a magnetic system comprising a plurality of quasi-dc coils positioned around the confinement chamber, the first and second formation sections, and the first and second divertors, first and second set of quasi-dc mirror coils positioned between the confinement

chamber and the first and second formation sections, and first and second mirror plugs position between the first and second formation sections and the first and second divertors,

a gettering system coupled to the confinement chamber and the first and second divertors,

one or more biasing electrodes for electrically biasing open flux surface of a generated FRC, the one or more biasing electrodes being positioned within one or more of the confinement chamber, the first and second formation sections, and the first and second divertors,

two or more saddle coils coupled to the confinement chamber, and

an ion pellet injector coupled to the confinement chamber.

21. The system of claim 20 wherein the system is configured to generate an FRC and maintain the FRC within the confinement chamber of the system, the FRC being maintainable by the system in spaced relation to the wall of the confinement chamber at or about a constant value without decay while the neutral atom beams are injected into the FRC at an angle of about 15° to 25° less than normal to the longitudinal axis of the confinement chamber and towards the mid-plane of the confinement chamber.

22. The system of claim 20 wherein the mirror plug comprises third and fourth set of mirror coils between each of the first and second formation sections and the first and second divertors.

23. The system of claims 20 and 21 wherein the mirror plug further comprises a set of mirror plug coils wrapped around a constriction in the passageway between each of the first and second formation sections and the first and second divertors.

24. The system of claims 20-23 wherein the elongate tube is a quartz tube with a quartz liner.

25. The system of claims 20-24 wherein the formation systems are pulsed power formation systems.

26. The system of claims 20-25 wherein the formation systems comprise a plurality of power and control units coupled to individual ones of a plurality of strap

assemblies to energize a set of coils of the individual ones of the plurality of strap assemblies wrapped around the elongate tube of the first and second formation sections.

27. The system of claim 26 wherein individual ones of the plurality of power and control units comprising a trigger and control system.

28. The system of claim 27 wherein the trigger and control systems of the individual ones of the plurality of power and control units being synchronizable to enable static FRC formation wherein the FRC is formed and then injected or dynamic FRC formation wherein the FRC is formed and translated simultaneously.

29. The system of claims 20-28 wherein the plurality of neutral atom beam injectors comprises one or more RF plasma source neutral atom beam injectors and one or more arc source neutral atom beam injectors.

30. The system of claims 20-29 wherein the plurality of neutral atom beam injectors are oriented with an injection path tangential to the FRC with a target trapping zone within separatrix of the FRC.

31. The system of claims 20-30 wherein the gettering system comprises one or more of a Titanium deposition system and a Lithium deposition system that coat the plasma facing surfaces of the confine chamber and the first and second divertors.

32. The system of claims 20-31 wherein biasing electrodes includes one or more of one or more point electrodes positioned within the containment chamber to contact open field lines, a set of annular electrodes between the confinement chamber and the first and second formation sections to charge far-edge flux layers in an azimuthally symmetric fashion, a plurality of concentric stacked electrodes positioned in the first and second divertors to charge multiple concentric flux layers, and anodes of the plasma guns to intercept open flux.

33. A system for generating and maintaining a magnetic field with a field reversed configuration (FRC) comprising

a confinement chamber,

first and second diametrically opposed FRC formation sections coupled to the confinement chamber,

first and second divertors coupled to the first and second formation sections,

one or more of a plurality of plasma guns, one or more biasing electrodes and first and second mirror plugs, wherein the plurality of plasma guns includes first and second axial plasma guns operably coupled to the first and second divertors, the first and second formation sections and the confinement chamber, wherein the one or more biasing electrodes being positioned within one or more of the confinement chamber, the first and second formation sections, and the first and second divertors, and wherein the first and second mirror plugs being position between the first and second formation sections and the first and second divertors,

a gettering system coupled to the confinement chamber and the first and second divertors,

a plurality of neutral atom beam injectors coupled to the confinement chamber and oriented to inject neutral atom beams toward a mid-plane of the confinement chamber at an angle of about 15° to 25° less than normal to a longitudinal axis of the confinement chamber ~~normal to the axis of the confinement chamber~~, and

a magnetic system comprising a plurality of quasi-dc coils positioned around the confinement chamber, the first and second formation sections, and the first and second divertors, *first and second set of quasi-dc mirror coils positioned between the confinement chamber and the* first and second formation sections,

wherein the system is configured to generate an FRC and maintain the FRC within the confinement chamber of the system, the FRC being maintainable by the system in spaced relation to the wall of the confinement chamber at or about a constant value without decay while the neutral beams are injected from the plurality of neutral atom beam injectors into the FRC at an angle of about 15° to 25° less than normal to the longitudinal axis of the confinement chamber and towards the mid-plane of the confinement chamber~~plasma~~.

~~34. The system of claim 33 wherein the system is configured to generate an FRC and maintain the FRC at or about a constant value without decay while neutral atom beams are injected into the FRC.~~

3435. The system of claims 33 ~~and 34~~ wherein the mirror plug comprises third and fourth sets of mirror coils between each of the first and second formation sections and the first and second divertors.

3536. The system of claims 33-3435 wherein the mirror plug further comprises a set of *mirror plug coils wrapped around a constriction in the passageway between each of the first and* second formation sections and the first and second divertors.

3637. The system of claims 33-3536 further comprising first and second axial plasma guns operably coupled to the first and second divertors, the first and second formation sections and the confinement chamber.

3738. The system of claims 33-3637 further comprising two or more saddle coils coupled to the confinement chamber.

3839. The system of claims 33-3738 further comprising an ion pellet injector coupled to the confinement chamber.

3940. The system of claims 33-3839 wherein the formation section comprises modularized formation systems for generating an FRC and translating it toward a midplane of the confinement chamber.

4041. The system of claims 33-3940 wherein biasing electrodes includes one or more of one or more point electrodes positioned within the containment chamber to contact open field lines, a set of annular electrodes between the confinement chamber and the first and second formation sections to charge far-edge flux layers in an azimuthally symmetric fashion, a plurality of concentric stacked electrodes positioned in the first and second divertors to charge multiple concentric flux layers, and anodes of the plasma guns to intercept open flux .