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# (54) PLASMA FLOW INTERACTION SIMULATOR

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**Related U.S. Application Data**

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(51) **Int. Cl.**

| | |
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| ***H05H 1/22*** | (2006.01) |
| ***H05H 1/12*** | (2006.01) |
| ***H05H 1/02*** | (2006.01) |
| ***G06F 17/50*** | (2006.01) |
| ***G09B 23/06*** | (2006.01) |
| ***H02K 44/06*** | (2006.01) |
| ***H02K 44/08*** | (2006.01) |
| ***H05H 1/03*** | (2006.01) |
| ***H05H 1/04*** | (2006.01) |
| ***G09B 23/12*** | (2006.01) |

(52) **U.S. Cl.**

CPC ............ ***G06F 17/5009*** (2013.01); ***G09B 23/06*** (2013.01); ***H02K 44/06*** (2013.01); ***H02K 44/085*** (2013.01); ***H05H 1/03*** (2013.01); ***H05H 1/04*** (2013.01); ***G09B 23/12*** (2013.01); *G06F 2217/16* (2013.01)

USPC .................. **310/11**; 156/345.48; 315/111.21; 315/111.41

(58) **Field of Classification Search**

CPC .... H01J 37/321; H01J 37/32082; H05H 1/54; H05H 1/04; H05H 1/03; G06F 17/5009; G09B 23/06; G09B 23/12; H02K 44/085; H02K 44/06

USPC .................. 156/345.48, 345.49; 315/111.21, 315/111.41, 111.81

See application file for complete search history.

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| 4,274,919 | A | * | 6/1981 | Jensen et al. | 376/133 |
| 4,330,864 | A | | 5/1982 | Ohyabu | |
| 4,654,561 | A | * | 3/1987 | Shelton | 315/111.71 |
| 5,198,181 | A | | 3/1993 | Jacobson | |
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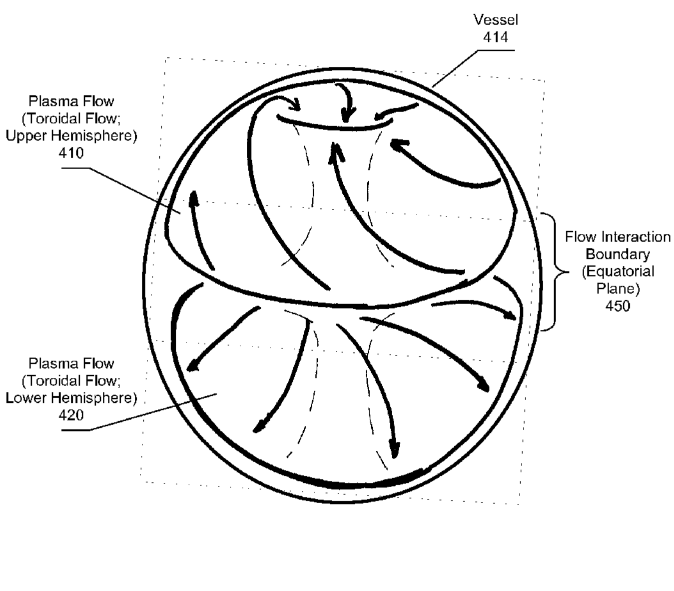
(57) **ABSTRACT**

A plasma interaction simulator is presented. The simulator magnetically induces multiple distinct flows of plasma within a physical plasma vessel. The plasma flows collide with each other at flow interaction boundaries where discontinuities arising due to differences between the flows give rise to interactions. Sensors can be incorporated into the plasma simulator to observe and collect data about the plasma flow interactions.

**16 Claims, 7 Drawing Sheets**



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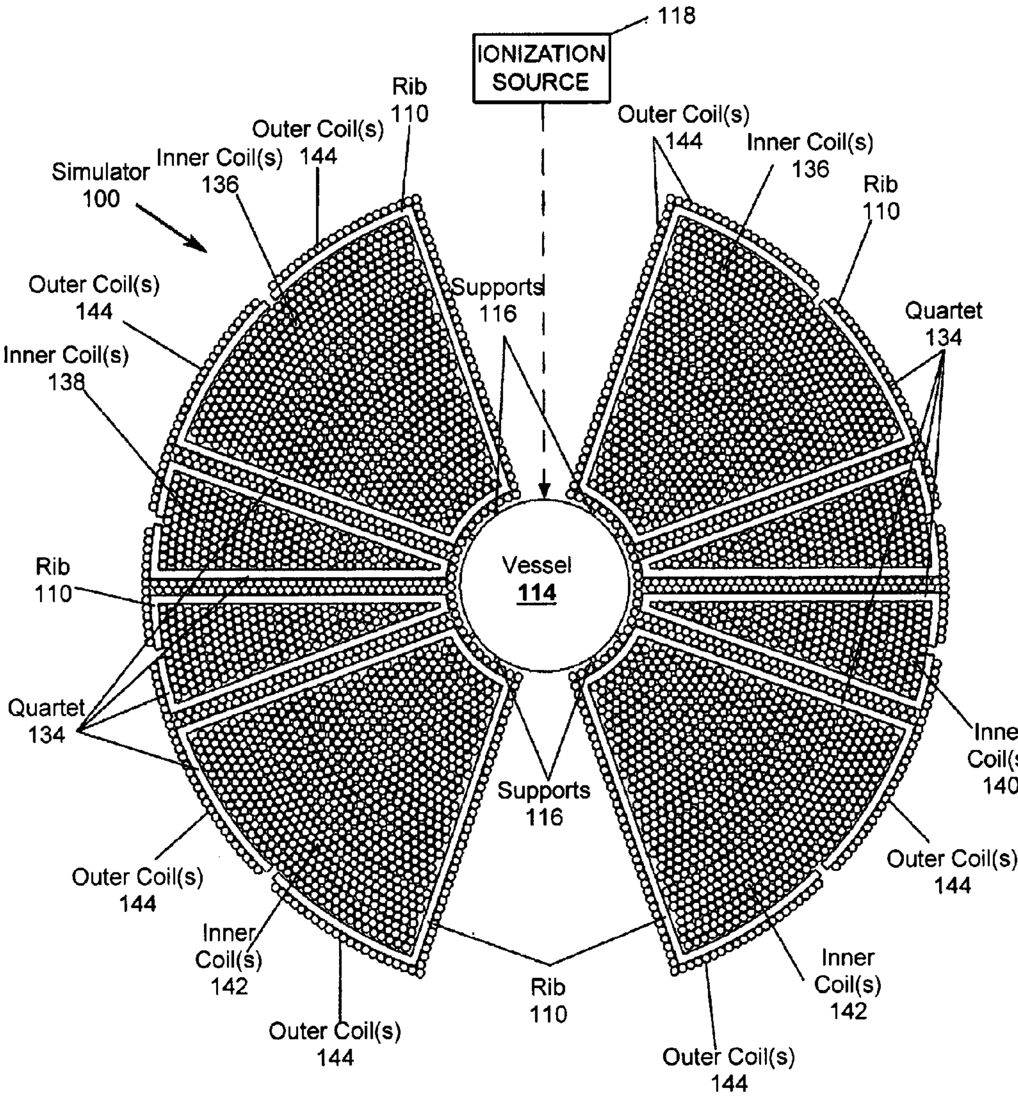

118
IONIZATION SOURCE
Rib 110
Outer Coil(s) 144
Inner Coil(s) 136
Simulator 100
Outer Coil(s) 144
Inner Coil(s) 138
Supports 116
Outer Coil(s) 144
Inner Coil(s) 136
Rib 110
Quartet 134
Rib 110
Vessel 114
Quartet 134
Inner Coil(s) 140
Supports 116
Outer Coil(s) 144
Outer Coil(s) 144
Inner Coil(s) 142
Inner Coil(s) 142
Rib 110
Outer Coil(s) 144
Outer Coil(s) 144


Figure 1

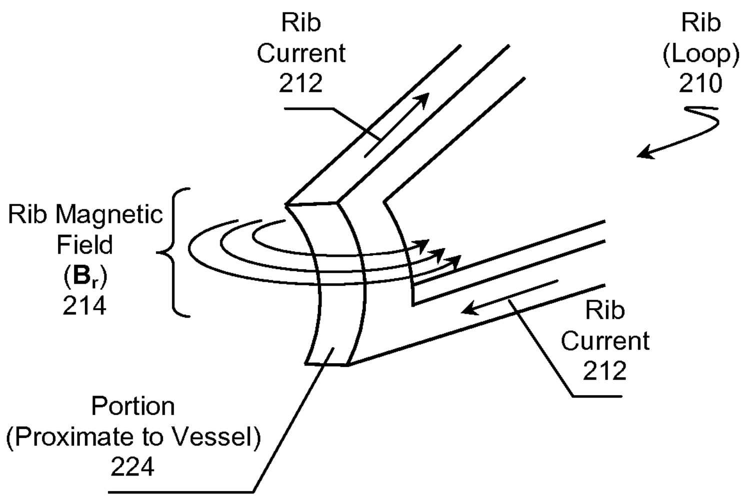
Rib
Current
212
Rib
(Loop)
210
Rib Magnetic
Field
($\mathbf{B}_r$)
214
Rib
Current
212
Portion
(Proximate to Vessel)
224

Figure 2

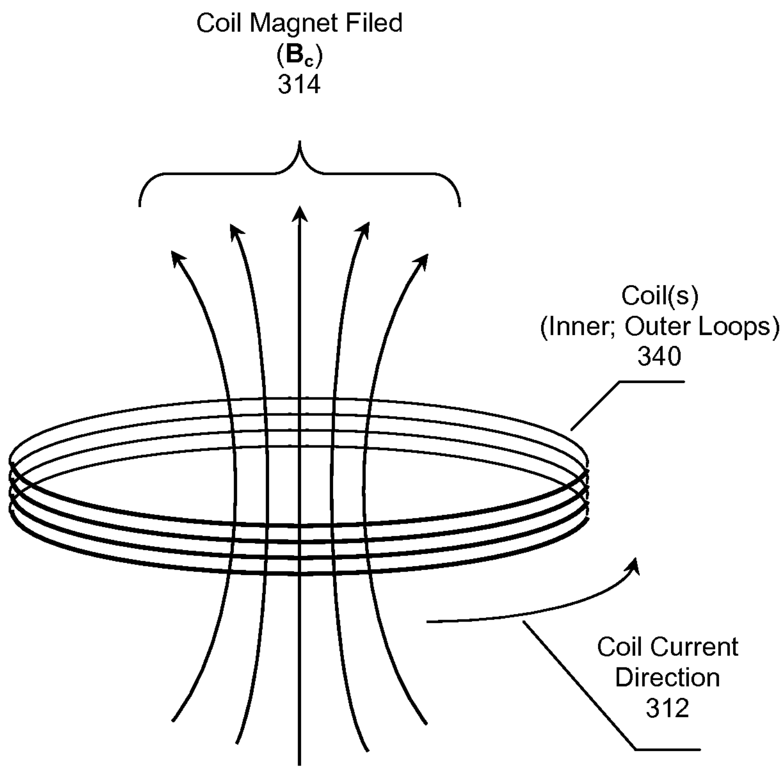
Coil Magnet Filed
($\mathbf{B}_c$)
314
Coil(s)
(Inner; Outer Loops)
340
Coil Current
Direction
312

Figure 3

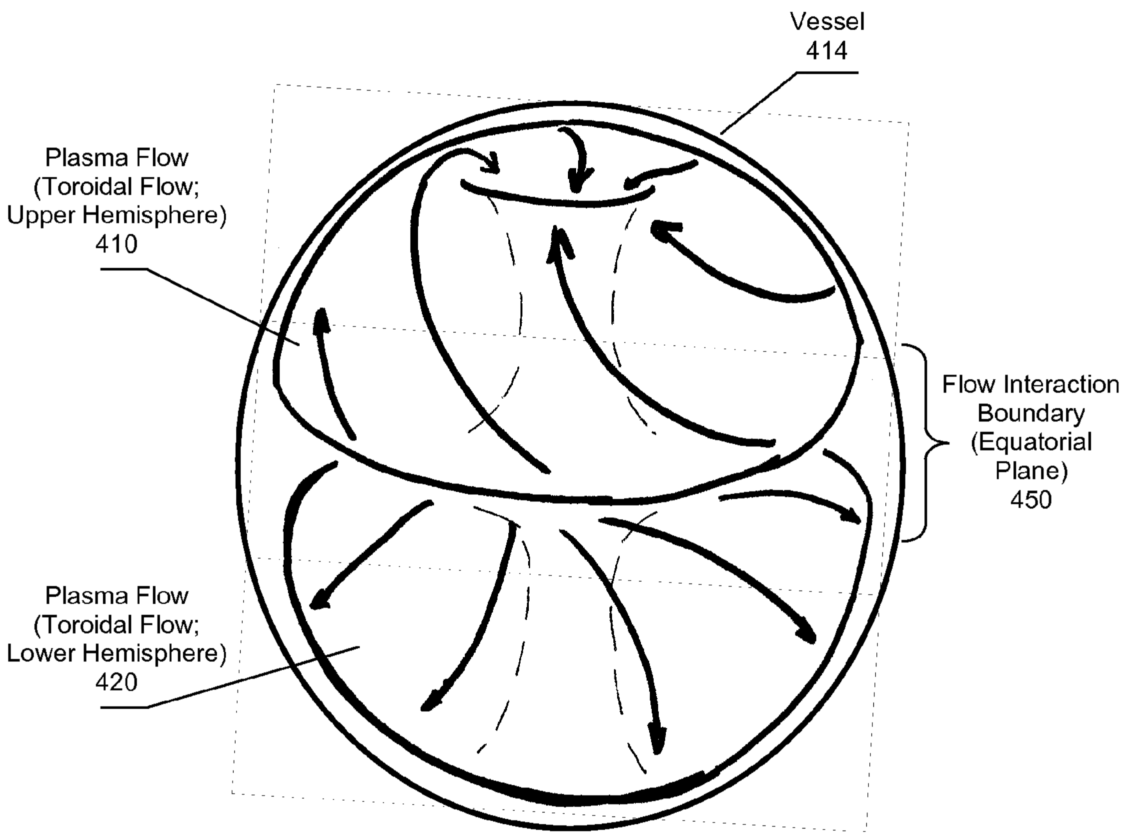
Vessel
414
Plasma Flow
(Toroidal Flow;
Upper Hemisphere)
410
Flow Interaction
Boundary
(Equatorial
Plane)
450
Plasma Flow
(Toroidal Flow;
Lower Hemisphere)
420

Figure 4

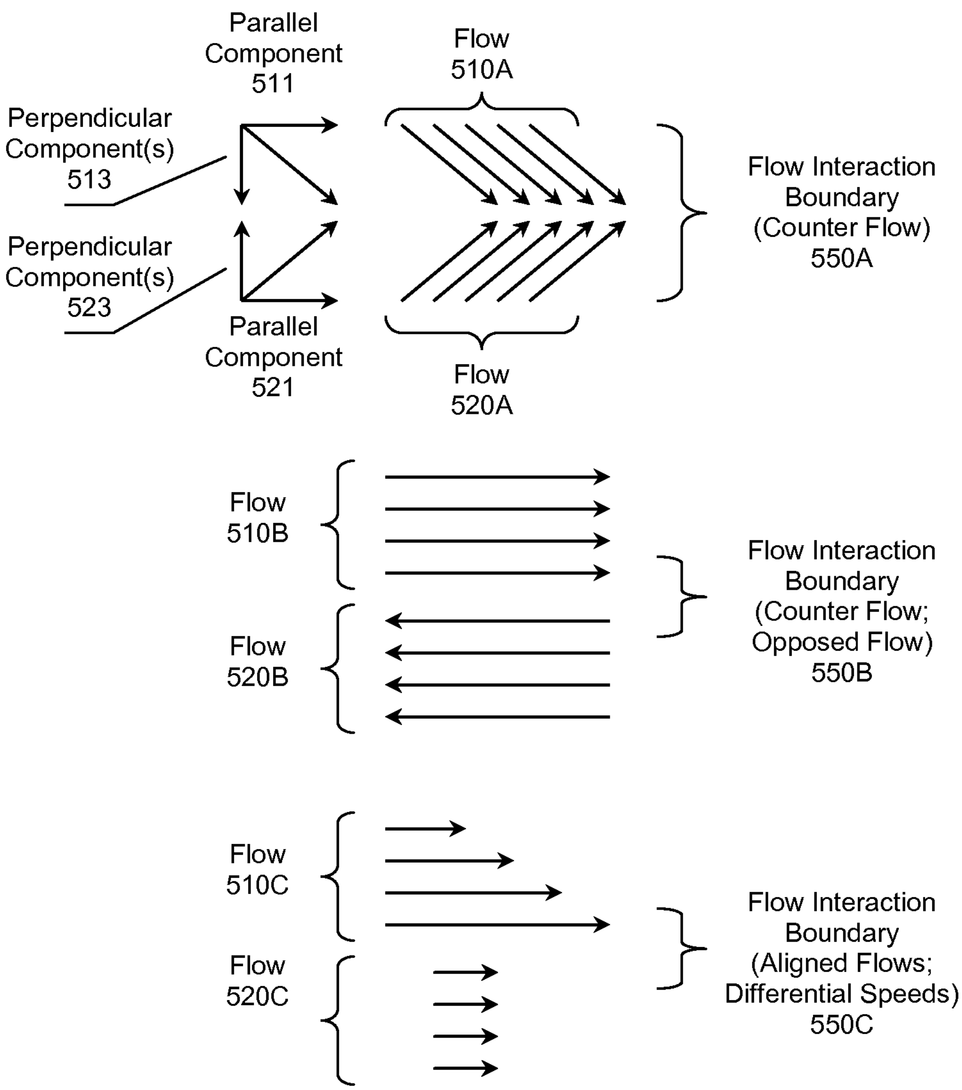
Parallel
Component
511
Flow
510A
Perpendicular
Component(s)
513
Flow Interaction
Boundary
(Counter Flow)
550A
Perpendicular
Component(s)
523
Parallel
Component
521
Flow
520A
Flow
510B
Flow Interaction
Boundary
(Counter Flow;
Opposed Flow)
550B
Flow
520B
Flow
510C
Flow Interaction
Boundary
(Aligned Flows;
Differential Speeds)
550C
Flow
520C

Figure 5

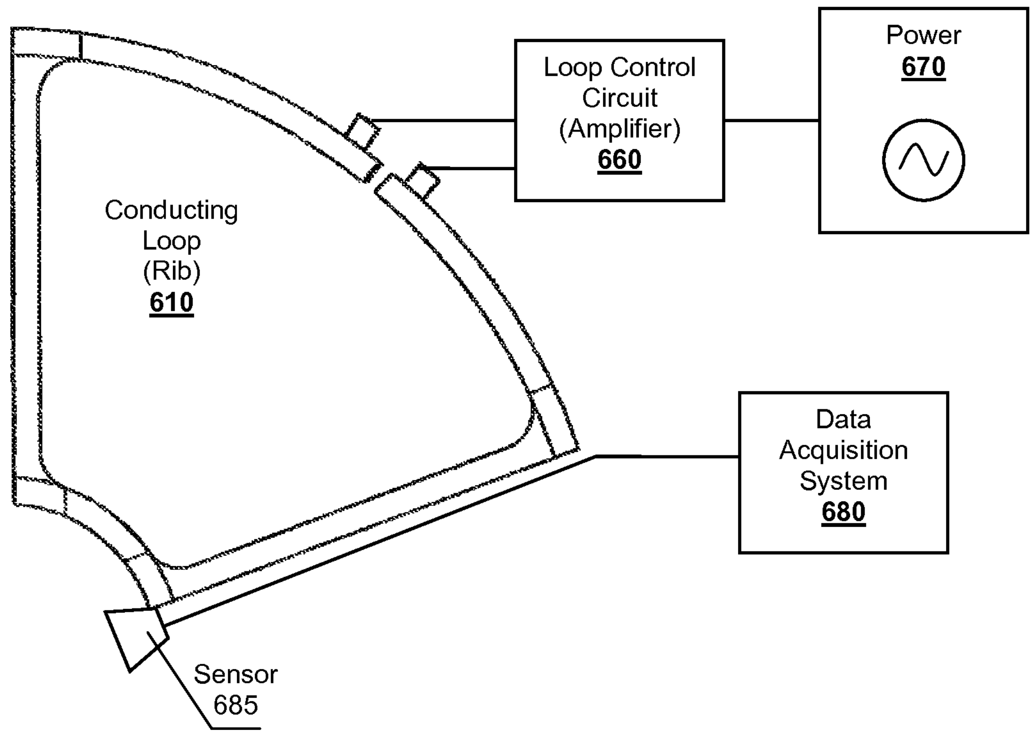
Loop Control
Circuit
(Amplifier)
660
Power
670
Conducting
Loop
(Rib)
610
Data
Acquisition
System
680
Sensor
685

Figure 6

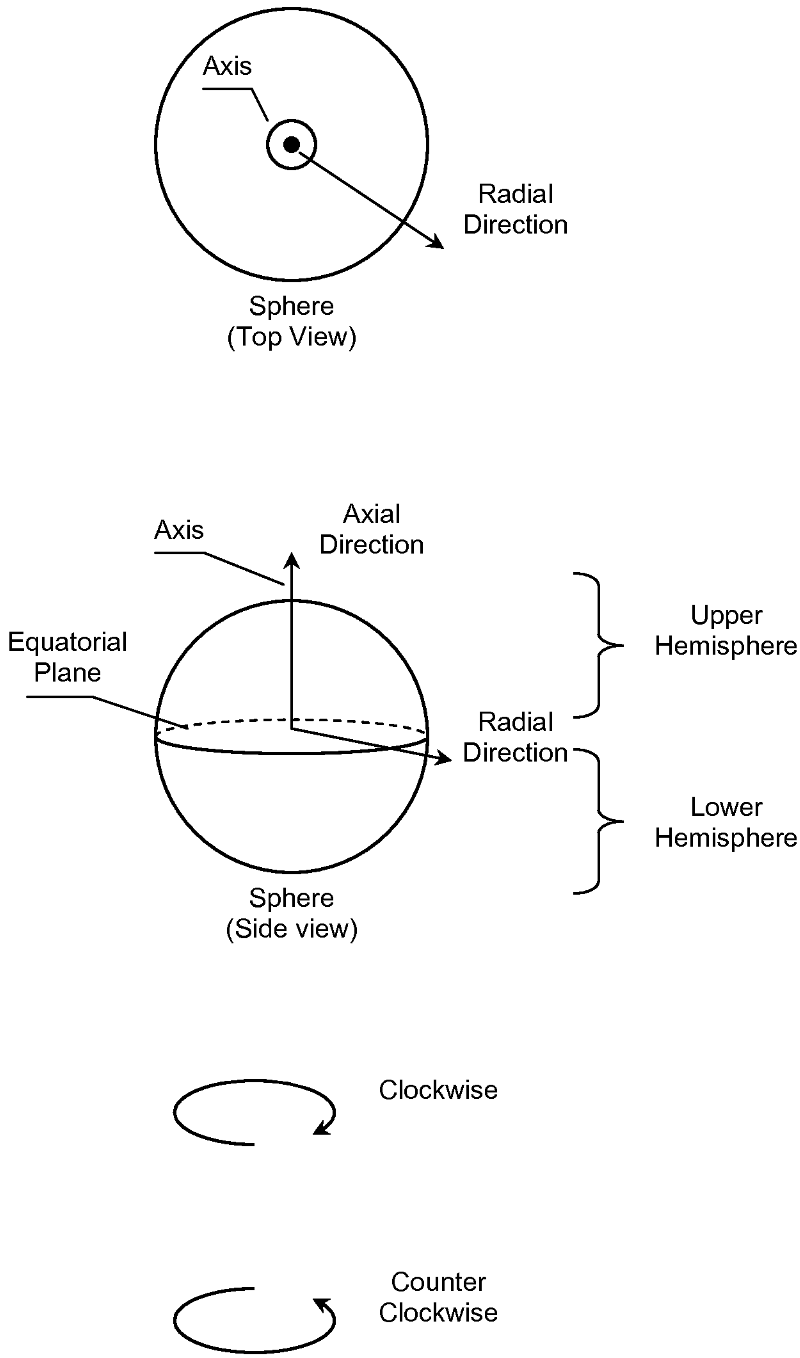
Axis
Radial Direction
Sphere (Top View)
Axis
Axial Direction
Equatorial Plane
Upper Hemisphere
Radial Direction
Lower Hemisphere
Sphere (Side view)
Clockwise
Counter Clockwise

Figure 7

# PLASMA FLOW INTERACTION SIMULATOR

This application is a continuation-in-part of U.S. patent application Ser. No. 12/837,295 filed Jul. 15, 2010, which is a divisional of U.S. patent application Ser. No. 11/976,364 filed on Oct. 24, 2007, which issued as U.S. Pat. No. 8,073,094 Dec. 6, 2011. This and all other extrinsic materials discussed herein are incorporated by reference in their entirety. Where a definition or use of a term in an incorporated reference is inconsistent or contrary to the definition of that term provided herein, the definition of that term provided herein applies and the definition of that term in the reference does not apply.

## FIELD OF THE INVENTION

The field of the invention is plasma control technologies.

## BACKGROUND

Flow dynamics of plasmas and gases continues to be a topic of much interest as scientists study plasma flows relating astronomical phenomenon. For example, much effort has been directed to studying plasma flows in the sun, around black holds, within planetary atmospheres (e.g., Jupiter, Saturn, etc.), or other under other circumstances. In addition, work in fusion requires manipulating, controlling, or confining plasmas in fusion reactors via magnetic fields. Unfortunately, technologies directed toward controlling fusion plasmas for containment are not necessarily practical when studying plasma flow interactions. Example technologies employing magnetic fields to control fusion plasmas, ionized gases, or charged particle beams include the techniques described in the following references.

U.S. Pat. No. 4,236,964 to Bass et al. titled "Confinement of High Temperature Plasmas", filed Oct. 18, 1974, describes confining a plasma in a smooth toroidal configuration by constructing a toroidal magnetic bottle.

U.S. Pat. No. 4,267,488 to Wells titled "Containment of Plasmas at Thermonuclear Temperatures", filed Jan. 5, 1979, discloses using multiple magnetic fields to generate a ringlike toroidal plasma vortex structure.

U.S. Pat. No. 4,330,864 to Ohyabu titled "Double Layer Field Shaping Systems for Toroidal Plasmas", filed Jun. 28, 1978, describes using multiple conducting coils to generate magnetic fields to control plasma generation, confinement, and control.

U.S. Pat. No. 4,654,561 to Shelton titled "Plasma Containment Device", filed Oct. 7, 1985, discusses using electromagnets to sustain a ball of plasma rather than a toroidal configuration as some of the previous references.

U.S. Pat. No. 5,198,181 to Jacobson titled "Stabilizing Plasma in Thermonuclear Fusion Reactions Using Resonant Low Level Electromagnetic Fields", filed Apr. 27, 1992, discusses using strong magnetic fields for confinement and weaker magnetic fields to cause a plasma to resonant.

U.S. Pat. No. 6,027,603 to Holland et al. titled "Inductively Coupled Planar Source for Substantially Uniform Plasma Flux", filed Nov. 28, 1997, describes using planar coils to generate magnetic fields that control generation of a plasma flux on a workpiece surface.

U.S. Pat. No. 6,484,492 to Meholic et al. titled "Magnetohydrodyanmic Flow Control for Pulse Detonation Engines", filed Jan. 9, 2001, discloses using magnetic and electric fields to control a traveling detonation flame front within a pulse detonation engine.

U.S. Pat. No. 6,575,889 to Reiffel titled "Scanning and Flexing Charged Particle Beam Guide", filed Nov. 24, 1999, discusses varying magnetic fields to guide particle beams useful in radiation oncology.

U.S. Pat. No. 7,079,001 to Nordberg titled "Nuclear Fusion Reactor Incorporating Spherical Electromagnetic fields to Contain and Extract Energy", filed Mar. 16, 2005, describes using a spherical magnetic confinement field to contain plasma. Electrical power is obtained inductively from a reactor core.

U.S. patent application publication 2002/0080904 to Rostoker et al. titled "Magnetic and Electrostatic Confinement of Plasma in a Field Reversed Configuration", filed Jul. 25, 2001, and U.S. patent application publication 2003/0007587 to Monkhorst et al. titled "Controlled Fusion in a Field Reversed Configuration and Direct Energy Conversion", filed Feb. 14, 2002, both describe using magnetic fields to confine a plasma during fusion.

These and all other extrinsic materials discussed herein are incorporated by reference in their entirety. Where a definition or use of a term in an incorporated reference is inconsistent or contrary to the definition of that term provided herein, the definition of that term provided herein applies and the definition of that term in the reference does not apply.

Unless the context dictates the contrary, all ranges set forth herein should be interpreted as being inclusive of their endpoints, and open-ended ranges should be interpreted to include commercially practical values. Similarly, all lists of values should be considered as inclusive of intermediate values unless the context indicates the contrary.

Although the above references provide a great deal of insight into using magnetic fields to contain, confine, or control plasmas, the techniques they suggest would not be practical in a small laboratory setting. Nor would the techniques be useful in generating interactions between two or more plasma flows because the interactions between flows would, by their nature, cause instabilities within the plasma flows. Interestingly, known efforts to date have focused on achieving some form of controlled stability of plasma flows. What has yet to be appreciated is that a plasma interaction simulator can be designed and built where magnetic fields can induce multiple plasma flows in a plasma vessel where the flows interact due to discontinuities between the flows. One can then observe how the plasma flows interact at their interaction boundaries. Contemplated simulators can be used to model atmospheric banding on gas giants, plasma flows of the Sun, or other interesting plasma interaction phenomenon.

Thus, there is still a need for plasma interaction simulators.

## SUMMARY OF THE INVENTION

The inventive subject matter provides apparatus, systems and methods in which one can simulate plasma flows within a laboratory environment. One aspect of the inventive subject matter is considered to include a plasma interaction simulator where plasma contained within a vessel can be induced to flow in response to magnetic fields. Loops of conducting material can be disposed about the plasma vessel and can generate various configurations of magnetic fields when current flows through the conducting loops. The magnetic fields can be controlled to induce two or more distinct plasma flows where the flows interact at an interaction boundary between the flows. Interactions occur at the boundaries due to gradients or discontinuities arising from differences between the flows.

Interaction boundaries between plasma flows can be generated by inducing multiple plasma flows via controlling the currents in conducting loop via one or more loop control circuits. Interaction boundaries can include counter-flow interactions, opposed-flow interactions, aligned-flow interactions, or other types of interactions. In some embodiments, the flows include two counter rotating toroidal flows that interact at an equatorial plane of the plasma vessel.

Various objects, features, aspects and advantages of the inventive subject matter will become more apparent from the following detailed description of preferred embodiments, along with the accompanying drawing figures in which like numerals represent like components.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a schematic overview of a possible plasma interaction simulator.

FIG. **2** illustrates a magnetic field generated by a rib conducting loop of a plasma interaction simulator.

FIG. **3** illustrates a magnetic field generated by a coil conducting loop of a plasma interaction simulator.

FIG. **4** is a schematic of two interacting plasma flows having an equatorial interaction boundary.

FIG. **5** illustrates various types of plasma flow interaction boundaries that can be achieved with the contemplated plasma interaction simulator.

FIG. **6** is a schematic of a rib conducting loop under control of a loop control circuit.

FIG. **7** illustrates orientations associated with descriptive terms used with respect to the figures presented.

## DETAILED DESCRIPTION

It should be noted that while the following description comprises disclosure directed to control circuits, various alternative configurations of control circuits are also deemed suitable and may employ various computing devices including servers, interfaces, systems, databases, engines, controllers, or other types of computing devices operating individually or collectively. One should appreciate the computing devices comprise a processor configured to execute software instructions stored on a tangible, non-transitory computer readable storage medium (e.g., hard drive, solid state drive, RAM, flash, ROM, etc.). The software instructions preferably configure the computing device to provide the roles, responsibilities, or other functionality as discussed below with respect to the disclose apparatus. In especially preferred embodiments, the various servers, systems, databases, or interfaces exchange data using standardized protocols or algorithms, possibly based on HTTP, HTTPS, AES, public-private key exchanges, web service APIs, known financial transaction protocols, or other electronic information exchanging methods. Data exchanges preferably are conducted over a packet-switched network, the Internet, LAN, WAN, VPN, or other type of packet switched network.

One should appreciate that the disclosed techniques provide many advantageous technical effects including producing observable plasma flow interactions.

As used herein, and unless the context dictates otherwise, the term "coupled to" is intended to include both direct coupling (in which two elements that are coupled to each other contact each other) and indirect coupling (in which at least one additional element is located between the two elements). Therefore, the terms "coupled to" and "coupled with" are used synonymously.

The reader's attention is directed to FIG. **7** which graphically illustrates how terms reflecting orientations or directions (e.g., radial, axial, clockwise, etc.) are use in reference to the figures.

In FIG. **1** simulator **100** represents a cross sectional view of one possible embodiment of a plasma interaction simulator. Simulator **100** is described more fully in co-pending parent U.S. patent application having Ser. No. 11/976,364 to Haramein titled "Device and Method for Simulation of Magnetohydrodynamics" filed Oct. 24, 2007.

Simulator **100** broadly comprises plasma vessel **114** containing an ionizable gas and surrounded by a plurality of individually controlled conducting loops. The conducting loops comprise conducting coils as represented by inner coils **136**, **138**, **140**, and **142**, and by outer coils **144**. The conducting loops can also include one or more ribs **110** through which inner coils **136**, **138**, **140**, or **142** thread. Each of the conducting coils is configured to generate electromagnetic fields within plasma vessel **114** when a current pass through the coils. The interplay of the fields induces multiple plasma flows within plasma vessel **114** where the plasma flows interact at flow interaction boundaries.

One should appreciate that disclosed techniques are directed to causing plasma flow interactions at an interaction boundary between the flows rather than merely confining or containing plasma. The inventive subject matter is considered to include creation of the plasma flows and allowing the plasma flows to interaction as desired. Plasma flow interactions can arise due to substantial gradients or discontinuities between the flows.

Ribs **110** are disposed in radial directions about plasma vessel **114**. Ribs **110** have a portion closest to vessel **114** where the portion can conform to the shape of plasma vessel **114**. In the example shown, vessel **114** is a sphere and the portions closest to vessel **114** are curved according to the spherical shape of vessel **114**. Ribs **110** can be spaced away from vessel **114** by one or more of support **116**. As current flows through ribs **110**, magnetic fields are generated that penetrate within vessel **114**.

In the example shown ribs **110** are arranged in rib groups extending radially from an axis of simulator **100**, the groups as represented by quartets **134**. The cross sectional view of simulator **100** presents two of quartets **134** while a full version would have more groups. The number ribs **110** in a group vary and depends on many factors including size of vessel **114**, required field strength, material used, desired simulation, or other factors. The number of rib groups can also vary. For example, in a more preferred embodiments having a spherical vessel **114**, twelve of quartets **134** can be around vessel **114** at equally spaced angles (i.e., about every 30 degrees). Other embodiments could have a different number of groups. A cylindrical vessel **114** might only utilize four groups where each group has only one or two ribs **110**.

Ribs **110** preferably comprise a conducting material possibly including aluminum, copper, or other conductors. Typically, ribs **110** can be constructed with struts having a cross sectional area of about 0.25 inches on a side for a small desktop apparatus. Naturally, the size can be scaled as desired. More preferred conductors include those capable of conducting heat so that heat can be dissipated via an outer surface of simulator **100**.

As mentioned briefly above, inner coils **136**, **138**, **140**, and **142** thread through ribs **110**. One should appreciate that each of the inner coils can pass through multiple ribs **110**. For example, inner coil **136** winds around an axis of simulator **100** and winds through all of the upper hemisphere's topmost ribs **110**. In some embodiments, each of the inner coils represents a single winding of a conductor (e.g., aluminum, copper, etc) having multiple turns so the interior regions of ribs **110** are filled. However, in other embodiments, multiple individually controlled inner coils can also be disposed within the interior regions of each rib **110**.

Outer coil **144** represents a single coil winding around the exterior of ribs **110**. Although represented as a single coil **144** having multiple turns around simulator **110**, one could construct multiple, individually controlled outer coils **144**. One should note, as illustrated, outer coil **144** can thread through the space between vessel **114** and the closest portion of ribs **110** near vessel **114**.

Plasma simulator **100** can also include ionization source **118**. Ionization source **118** can be used to ionize gases contained within vessel **114** and can be arranged so that ionizing energy can be directed axially toward vessel **114**. For example, two ultraviolet lasers can be positioned above each pole of simulator **100** and their beams can be directed along the axis of simulator **100**. Suitable ionization sources include lasers, gamma ray sources, or other ionizing energy sources.

Although plasma vessel **114** is illustrated as a sphere, other shapes are also contemplated. For example, plasma vessel **114** can be constructed as a cylinder where the contained plasma can be induced to flow about the axis of the cylinder. Ribs **110** and conduction coils can be configured appropriate to fit the size, shape, or dimensions of vessel **114**. Other shapes can be constructed as well beyond a sphere or cylinder. However, shapes having rounded surfaces interior surfaces (e.g., sphere, cylinders, round disks, etc.) are more preferred as such shapes typically offer better models for physical phenomenon. For example, a sphere can provide for multiple flow interaction boundaries that model atmospheric phenomenon at different latitudes due to the flows following the interior contours of plasma vessel **114**. A cylinder can be used to model flows at different depths in a column of plasma. A disk might be used to model accretion disk interactions.

One should appreciate that the plasma can be considered "cold" and does not necessarily require confinement as plasmas in fusion reactions require. Rather, the interior contours of vessel **114** can be used to confine the plasma. Still, one should further appreciate that the plasma within plasma vessel **114** can achieve high temperatures as the plasma flows circulate at high speeds within vessel **114**. In some embodiments, flows can circulate around vessel **114** at high frequencies greater than $10^6$ cycles per second (i.e., 1 MHz), even as high as 20 MHz. At such frequencies, the temperature of the plasma flows, even at low pressure, can become quite high.

Plasma vessel **114** can be prepared according to a desired simulation. In some embodiments, plasma vessel **114** is prepared by forming two halves of the vessel **114**, two hemispheres for example in the case of a sphere. The two halves can be placed in a gas chamber filled with a desired gas mixture at a desired pressure. The two halves can then be joined and sealed thus enclosing a desired volume of the gas mixture. Drawn crystal has shown to be a useful material for constructing vessel **114** to withstand operational limits of simulator **100**. The gas mixture can be configured to match a desired simulation (e.g., helium, hydrogen, nitrogen, argon, etc.) and have a desired pressure. Pressures of $10^{-3}$ to $10^{-4}$ torr are considered adequate for most modeling purposes. Still, all pressures sustainable by plasma vessel **114** are contemplated.

Once plasma vessel **114** has been prepared, it can be placed within simulator **100** and subjected to magnetic fields resulting from currents flowing through the various conducting loops (e.g., ribs **110**, outer coils **144**, inner coils **136**, **138**, **140**, or **142**). To further understand the operation of simulator **100**, one should understand how the magnetic fields are generated by the various conducting loops.

FIG. **2** illustrates a possible rib magnetic field ($B_r$) **214** generated by rib **210**. As rib current **212** flows around rib **210**, a magnetic field is generated. Rib portion **224** represents the portion of rib **210** proximate or closest to the plasma vessel. Rib portion **224** generates magnetic field **214**, which penetrates into the vessel. The magnitude and direction of rib current **212** can be adjusted to achieve the desired magnetic field **214**. In more preferred embodiments, rib current **212** is pulsed in a manner where the current direction remains constant, while the magnitude of the current cycles from a minimum to a maximum. The initial pulses might cycle from a magnitude of zero up to maximum amount, while during an operational phase of a simulation might pulse the current magnitude from a minimum non-zero value to a maximum value. Thus, the magnitude of the current remains within a time-dependent envelope.

As the flux of rib magnetic field **214** changes within the plasma of the plasma vessel, the flux induces a flow of plasma according to the well known Maxwell's equations. Each rib **210** can be cycled according to its own sequence alone or in conjunction with other ribs to generate simple or highly complex flow patterns. Thus, the operation of the plasma simulator can be controlled with a high level of precision by an operator.

FIG. **3** illustrates a coil magnetic field ($B_c$) **314** generated by one or more coils **340** in response to a coil current **312** in coil **340**. Coils **340** as discussed above are circumferentially disposed about an axis of the plasma simulator so that coil magnetic field **314** runs generally in an axial direction through the plasma vessel based on current **312**. As with the rib conducting loops, each of coils **340** can be individually controlled so that current **312** can be adjusted as desired. By constructing a plasma simulator having multiple coils **340** an operator can create a highly complex set of axial magnetic fields **314** that interact within the contained plasma. Coil magnetic fields **314** originating from different coil conduction loops can be aligned with each other or can be counter to each. From the configuration of conducting loops in FIGS. **1**, **2**, and **3** one can see that rib conducting loops are substantially orthogonal to the coil conduction loops, which in turn yields orthogonal magnetic fields.

In some modeling environment, coil magnetic field **314** can be static or dynamic depending on the desired simulation. An astute reader will appreciate that coil magnetic field **314** can be used to model planetary magnetic fields. Thus, one can construct a model of aurora as the plasma flows travel along polar or axial magnetic field lines.

In an especially preferred embodiment, the rib magnetic fields and coil magnetic fields interact with each other to form one or more toroidal plasma flows as illustrated by FIG. **4**. In view that an operator (e.g., human, computer, etc.) can control each conducting loop individually, which also controls each loop's magnetic field, the operator can create highly complex stable plasma flows. In the example shown, an operator has created toroidal flow **410** in an upper hemisphere of plasma vessel **414** and a separate distinct toroidal flow **420** in a lower hemisphere of plasma vessel **420**.

Toroidal flows **410** and **420** represent plasmas flows were the plasma circulates out from the flows at the equatorial plane of plasma vessel **414**, up following the interior surface walls of plasma vessel **414**, then in toward the poles or along the axis of the toroidal flows. Each flow comprises plasma that flows in a helical manner about the tori. Pulsing rib conducting loop currents causes the plasma to flow while the coil loop currents provide axial field lines that guide plasma down through the axis of the torus.

One should note that each of toroidal flows **410** and **420** can be created by controlling the magnetic fields of conducting loops in the upper hemisphere of the plasma simulator separately from the conducting lops in the lower hemisphere of the plasma simulator. Thus the coil magnetic fields in the upper hemisphere can be in an opposite direction from the coil magnetic fields in the lower hemisphere as desired.

By construction two or more distinct flows, for example toroidal flows **410** and **420**, flow interaction boundary **450** is formed. In the example shown, flow interaction boundary **450** is located in an equatorial plane of plasma vessel **414**. One can then observe interactions between flows **410** and **420** via one or more sensors disposed about plasma vessel **414** or around the plasma simulator. Although FIG. **4** illustrates that interaction boundary **450** is located an equatorial plane, one should keep in mind that through suitable configurations of magnetic fields arising from the conducting loops the interaction boundary **450** can be generated at any latitude, or other locations. For example, one could cause interaction boundary **450** to occur at 22 degrees away from equatorial plane (i.e., latitude of Jupiter's Great Red Spot), or even have multiple interaction boundaries at various latitudes. Especially preferred latitudes include 19.5 degrees, 54.7 degrees, or 70.5 degrees as suggested by key angles derived from a $U_4$ metric contemplated by Haramein and Rauscher (see paper titled "The Origin of Spin: Consideration of Torque and Coriolis Forces in Einstein's Field Equations and Grand Unification Theory" by Haramein et al., Beyond the Standard Model: Searching for Unity in Physics, pages 153-168, The Noetic Press© 2005).

One should appreciate that plasma flows can be created and controlled via the pixilated nature of the rib and coil conducting loops. Thus, one can create many different essentially smooth plasma flows that can interact at one or more interaction boundaries **450**. Interaction boundary **450** represents areas of instability caused by interactions of the plasma flows. The instabilities, or gradients, arising from competing flows provide insight into the physics of interaction plasmas.

FIG. **5** presents various classes of interaction boundaries **550**A, **550**B, or **550**C collectively referred to as boundaries **550**, that could arise from interactions of plasma flows. Keeping in mind that a plasma flow can be represented by a vector field, interaction boundaries **550** are considered to be areas of instability between flows that arise due to discontinuities from one plasma flow's vector field to another. Discontinuities can occur due to differences in directions of the plasma flows at their boundaries, differences in magnitude of their vectors, or both. Interaction boundaries **550** present different types of discontinuities. The examples are presented in two dimensions for clarity. However, one skilled in the art will now appreciate that discontinuities or gradients in a flow's vector field can occur in more than two dimensions.

Flow interaction **550**A comprises a counter-flow interaction where flow **510**A can be represented as a vector field having at least one vector component counter to the vector field of flow **520**A at their interaction point. In the example shown, flow **510**A has parallel component **511** which is parallel to parallel component **521** of flow **520**A, thus these components are aligned, but are not counter to each other. However, perpendicular component **513** of flow **510**A is opposite to, or counters perpendicular component **523** of flow **520**A. In such an arrangement, flow **510**A and **520**A are considered to have a counter flow interaction.

Flow interaction **550**B presents a more severe type of counter-flow. Flow interaction **550**B illustrates an opposed flow where flow **510**A is of an opposite direction (i.e., an opposed direction) to that of flow **520**A even though the flows have similar magnitude. Interaction boundary **550**B would likely be unstable due to the counter, opposed flows.

Flow interaction **550**C illustrates yet another example where flows are in the same direction, but have different magnitudes. Flow **510**C has a vector field that is aligned with the vector field of flow **520**C where aligned is considered parallel. However, flow **510**C has a vector field of greater magnitude (e.g., rate, speed, etc.) than that of flow **520**C.

Flow interaction boundaries **550** can be constructed to have discontinuities within the contemplated plasma simulator, which also allows for generating gradients between flows. For example, referring back to FIG. **4**, toroidal flow **410** could have a substantially different rate of flow than flow **420** and could also be a counter toroidal flow to flow **420**. When modeling such a system, interesting dynamics can be observed at interaction boundary **450**. The inventive subject matter is considered to include generating substantial gradients, discontinuities, or discontinuities in gradients between plasma flows resulting from differences in direction, speed, angular momentum, or other plasma flow parameter.

To generate desired plasma flows, an operator of the plasma simulator can control each conducting loop independently according to a desired sequence. FIG. **6** provides an illustration of loop control circuit **660** providing current to rib **610**. The operator can programmatically instruct loop control circuit **660** to direct power from power source **670** to rib conducting loop **610** to generate a desired magnetic field. In some embodiments, loop control circuit **660** comprises a computer controlled amplifier capable of directing current from power source **670**, under controlled conditions, to rib conducting loop **610**. For example, when first initiating flows, small magnitude pulses would likely be required, then as the flows ramp up to speed, stronger pulses would be required. Once a desired flow has been established, maintenance pulses can be used to maintain a substantially stable flow. Thus, a regimen or a program of pulses can change with time. Furthermore, each conducting loop can have its own loop control circuit and power supply so each conducting loop can properly cooperate with other conducting loops.

To achieve high flow rates, power supply **670** and control circuit **660** can be configured to support a substantially smooth ramp up from zero to high rates (e.g., 1 MHz or greater) at nominal operating parameters. In more preferred embodiments a single control circuited **660** can support the ramp up without requiring multiple control circuits that switch at over to another at each operational stage.

For laboratory desktop environments, a power supply **670** capable of supplying up to 4000 W of power would be sufficient, where greater power would be more preferable. Naturally, the materials used in construction of the conducting coils must be able to withstand nominal operating conditions. For example, rib or coil conducting loops should be able to support currents necessary to generate desired magnetic fields while also dissipating heat.

Contemplated plasma interaction simulators can also include one or more of sensor **685** positioned proximate to the plasma vessel. In the example shown in FIG. **6**, sensor **685** is positioned near rib conducting loop **610** in a manner where sensor **685** will be adjacent to the plasma vessel when rib **610** is placed into position. Although sensor **685** is shown in a position to be near the plasma vessel, sensor **685** can also be positioned further away depending on the sensor or desired data to be collected. One or more of sensor **685** can send collected raw data to data acquisition system **680** for storage or analyses. Data acquisition system **680** can include one or more computers or databases.

Sensor **685** is presented to euphemistically represent various types of sensors that can be used in conjunction with modeling plasma flow interactions. Example sensors include optical sensors configure to capture light emanating from plasma flow interactions, particle detectors for charged particles or neutral particles (e.g., photo tubes, CR-39 film, CCDs, etc.), Langmuir probes to measure electron density properties, magnetometers to measure magnetic fields, Hall effect sensors, pressure or temperature gauges to measure state of plasma, mass spectrometers, scintillation counters, calorimeters, or other sensors that would be appropriate for a given experiment. In some embodiments, sensors can be position along the axis of the simulator to gain access to the plasma vessel.

Although the disclosed techniques are directed toward gas-based plasma, it is contemplated that one could apply similar techniques to ferromagnetic fluids or fluids that could be ionized.

It should be apparent to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the scope of the appended claims. Moreover, in interpreting both the specification and the claims, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms “comprises” and “comprising” should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Where the specification claims refers to at least one of something selected from the group consisting of A, B, C . . . and N, the text should be interpreted as requiring only one element from the group, not A plus N, or B plus N, etc.

What is claimed is:

**1**. A plasma flow simulator, the simulator comprising

a spherical plasma vessel having an upper hemisphere and a lower hemisphere, and containing a plasma;

conducting loops disposed circumferentially around the spherical plasma vessel, the conducting loops including a first rib conducting loop substantially orthogonal to a plurality of coils and configured to yield orthogonal magnetic fields that magnetically induce a first toroidal plasma flow in the upper hemisphere of the plasma vessel, and a second toroidal plasma flow in the lower hemisphere of the plasma vessel;

wherein rib conducting loop currents are configured to cause the plasma to flow, and wherein the plurality of coils currents are configured to guide the plasma through an axis of the first and second toroidal plasma flows within the spherical plasma vessel; and

wherein the first and second toroidal plasma flows form a counter-flow interaction boundary between the flows.

**2**. The simulator of claim **1**, wherein the interaction boundary comprises an opposed flow interaction between the first and the second plasma flows.

**3**. The simulator of claim **1**, wherein the interaction boundary comprises a substantially aligned flow interaction between the first and the second plasma flows.

**4**. The simulator of claim **3**, wherein a speed of the first plasma flow is different than that of the second plasma flow.

**5**. The simulator of claim **1**, wherein the plurality of coils includes inner and outer coils, and wherein the first rib conducting loop is disposed between the inner and outer coils.

**6**. The simulator of claim **1**, wherein the plasma vessel comprises a drawn crystal sphere.

**7**. The simulator of claim **1**, further comprising a gas ionization source.

**8**. The simulator of claim **1**, further comprising at least one sensor.

**9**. The simulator of claim **1**, wherein at least some of the plurality of coils are disposed about an axis of the vessel.

**10**. The simulator of claim **1**, further comprising at least one loop control circuit configured to adjust a current in at least one of the conducting loops.

**11**. The simulator of claim **10**, wherein the current comprises a pulsed on-off current.

**12**. The simulator of claim **10**, wherein at least the first plasma flow circulates at least one megahertz under influence of the at least one loop control circuit.

**13**. The simulator of claim **1**, wherein the rib conducting loop and at least some of the plurality of coils contact one another.

**14**. The simulator of claim **1**, wherein the plurality of coils include inner coils, and wherein the inner coils thread through and fill an interior region of the first rib conducting loop.

**15**. The simulator of claim **1**, wherein the rib conducting loop includes a first and second portion, and wherein the first portion is disposed closer to the vessel than the second portion and conforms to the spherical shape of the vessel.

**16**. The simulator of claim **15**, wherein the plurality of coils includes outer coils, and wherein an outer coil threads through a space between the spherical vessel and the first portion.

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