



(51) International Patent Classification:
G06Q 10/00 (2012.01)

(21) International Application Number:
PCT/US2012/033623

(22) International Filing Date:
13 April 2012 (13.04.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/476,134 15 April 2011 (15.04.2011) US

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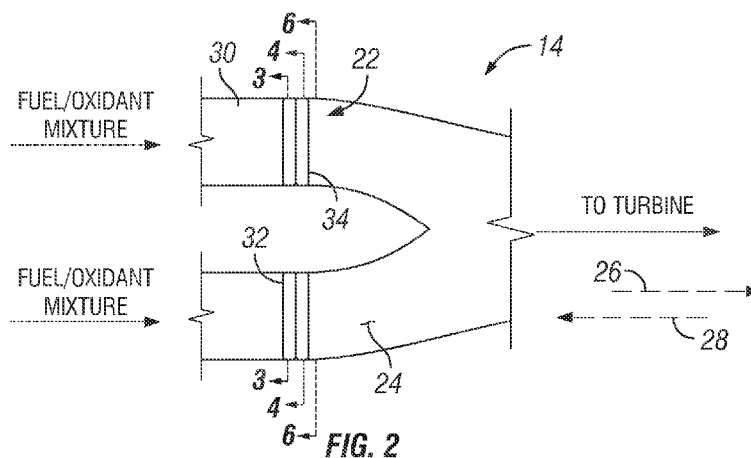
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: CONTINUOUS DETONATION COMBUSTION ENGINE AND SYSTEM



(57) Abstract: One embodiment of the present invention is a gas turbine engine. Another embodiment is a unique combustion system. Another embodiment is a unique engine. Other embodiments include apparatuses, systems, devices, hardware, methods, and combinations for employing continuous detonation combustion processes. Further embodiments, forms, features, aspects, benefits, and advantages of the present application will become apparent from the description and figures provided herewith.

CONTINUOUS DETONATION COMBUSTION ENGINE AND SYSTEM**Cross Reference to Related Applications**

The present application claims benefit of U.S. Provisional Patent Application No. 61/476,134, filed April 15, 2011, entitled CONTINUOUS DETONATION COMBUSTION ENGINE AND SYSTEM, which is incorporated herein by reference.

Field of the Invention

The present invention relates to heat engines, and more particularly, to heat engines employing continuous detonation combustion.

Background

Engine and combustion systems that effectively employ continuous detonation combustion processes remain an area of interest. Some existing systems have various shortcomings, drawbacks, and disadvantages relative to certain applications. Accordingly, there remains a need for further contributions in this area of technology.

Summary

One embodiment of the present invention is a gas turbine engine. Another embodiment is a unique combustion system. Another embodiment is a unique engine. Other embodiments include apparatuses, systems, devices, hardware, methods, and combinations for employing continuous detonation combustion processes. Further embodiments, forms, features, aspects, benefits, and advantages of the present application will become apparent from the description and figures provided herewith.

Brief Description of the Drawings

The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

FIG. 1 schematically depicts some aspects of a non-limiting example of an engine in accordance with an embodiment of the present invention.

FIG. 2 schematically depicts some aspects of a non-limiting example of a combustion system in accordance with an embodiment of the present invention.

FIGS. 3-5 schematically depict some aspects of a non-limiting example of a fluid diode in accordance with an embodiment of the present invention.

FIG. 6 schematically depicts some aspects of a non-limiting example of a combustion system in accordance with an embodiment of the present invention.

FIGS. 7, 7A and 7B schematically depict some aspects of a non-limiting example of a fluid diode in accordance with an embodiment of the present invention.

FIG. 8 schematically depicts some aspects of a non-limiting example of a fluid diode in accordance with an embodiment of the present invention at two different time periods during operation.

FIG. 9 schematically depicts some aspects of a non-limiting example of a fluid diode in accordance with an embodiment of the present invention, illustrating regions of alignment and misalignment.

Detailed Description

For purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings, and specific language will be used to describe the same. It will nonetheless be understood that no limitation of the scope of the invention is intended by the illustration and description of certain embodiments of the invention. In addition, any alterations and/or modifications of the illustrated and/or described embodiment(s) are contemplated as being within the scope of the present invention. Further, any other applications of the principles of the invention, as illustrated and/or described herein, as would normally occur to one skilled in the art to which the invention pertains, are contemplated as being within the scope of the present invention.

Referring to the drawings, and in particular FIG. 1, some aspects of a non-limiting example of an engine 10 in accordance with an embodiment of the present invention are schematically depicted. In one form, engine 10 is a gas turbine engine. Engine 10 includes a compressor system 12, a combustion system 14 in fluid communication with compressor system 12, and a turbine system 16 in fluid communication with combustion system 14. In one form, compressor system 12, combustion system 14 and turbine system 16 are disposed about an engine centerline 18, e.g., the axis of rotation of compressor 12 and turbine 16. In other embodiments, other arrangements may be employed. In various embodiments, engine 10 may or may not have a compressor system and/or a turbine system, or may have additional turbomachinery components in addition to a compressor system and/or a turbine system. In some embodiments, engine 10 may be a direct propulsion engine that produces thrust directly from

combustion system 14, e.g., wherein engine 10 may not include a turbine system 16. In other embodiments, combustion system 14 may form a gas generator for a gas turbine propulsion system, or may be employed in a gas turbine engine topping cycle. In still other embodiments, engine 10 may be one or more of other types of engines that may employ combustion systems such as combustion system 14, such as, for example, a rocket engine. In yet still other embodiments, combustion system 14 may be configured as a direct propulsion engine, and may not include a compressor, e.g., except for engine starting purposes.

Referring to FIG. 2 in conjunction with FIG. 1, some aspects of a non-limiting example of combustion system 14 in accordance with an embodiment of the present invention are described. In one form, combustion system 14 is a pressure-gain combustion system. In other embodiments, combustion system 14 may not be a pressure-gain combustion system. In one form, combustion system 14 is a continuous detonation combustion system. In other embodiments, combustion system 14 may not be a continuous detonation combustion system.

Combustion system 14 includes a supply portion 20, a fluid diode 22 and a combustion chamber 24. In one form supply portion 20 is configured to supply a fuel/oxidant mixture to fluid diode 22. The fuel/oxidant mixture is supplied from supply portion 20 to fluid diode 22 generally in a primary flow direction 26. In other embodiments, supply portion 20 may be configured to supply only a fuel or only an oxidant to fluid diode 22. Combustion takes place in combustion chamber 24 on the opposite side of fluid diode 22 from supply portion 20. In one form, combustion

chamber 24 is a walled annular chamber. In other embodiments, combustion chamber 24 may take other forms.

Fluid diode 22 is configured to allow a fluid flow in primary flow direction 26 to supply the fluid flow into combustion chamber 24 for use by the combustion process(es) taking place in combustion chamber 24. In one form, the fluid flow is a fuel/oxidant mixture flow. In other embodiments, the fluid flow may be a fuel flow only, e.g., a gaseous and/or vaporous fuel flow, without an oxidant added thereto. In still other embodiments, the fluid flow may be an oxidant flow only, without a fuel added thereto. Fluid diode 22 is configured to prevent or reduce fluid flow in a back-flow direction 28 opposite to primary flow direction 26 at the location(s) of the combustion process(es). In one form, the fuel is a conventional fuel typically employed in gas turbine engines. In other embodiments, one or more other fuel types may be employed in addition to or in place of conventional gas turbine engine fuel. In one form, the oxidant is air. In other embodiments, one or more other oxidants may be employed in addition to or in place of air.

In one form, fluid diode 22 is disposed in an annulus 30 downstream of compressor 12. In other embodiments, fluid diode 22 may be disposed at other locations. In one form, fluid diode 22 includes a diode structure 32 and a diode structure 34 positioned adjacent to diode structure 32. In other embodiments, more than two diode structures e.g., akin to diode structure 32 and diode structure 34, may be employed. In one form, diode structure 32 is positioned immediately adjacent to diode structure 34, e.g., with a small gap between diode structure 32 and diode structure 34 to limit contact between diode structure 32 and diode structure 34. The size of the gap

may vary with the needs of the application. In other embodiments, diode structure 32 may be spaced apart from diode structure 34 by some larger amount. In some embodiments, e.g., embodiments employing low friction materials, diode structure 32 and diode structure 34 may be positioned to allow contact therebetween, thereby eliminating or reducing any gap therebetween.

Referring to FIGS. 3-5, some aspects of non-limiting examples of diode structure 32 and diode structure 34 in accordance with an embodiment of the present invention are described. In one form, diode structure 32 and diode structure 34 are rings or disks disposed in annulus 30. In other embodiments, one or both diode structures 32 and 34 may take other forms, and may be, for example, cylinders, conical structures or may have any shape defined as a body of revolution. In still other embodiments, diode structures 32 and 34 may take any shape, and may or may not be disposed in an annulus. In one form, diode structures 32 and 34 are formed of a metal alloy, e.g., such as the types of alloys employed in the manufacture of turbine disks. In other embodiments, diode structures 32 and 34 may be formed of one or more other materials, e.g., one or more composite materials and/or a matrix composite materials in addition to or in place of a metal or metal alloy.

Diode structures 32 and 34 include a plurality of fluid flow passages interspersed with a plurality of fluid flow blockages. In the example illustrated in FIG. 3, diode structure 32 includes three (3) circumferential rows of fluid flow passages 36, 38 and 40 interspersed with three circumferential rows of fluid flow blockages 42, 44 and 46. In other embodiments, any number and orientation of rows of fluid flow passages and fluid flow blockages may be employed. In one form, fluid flow passages 36, 38 and 40 are

equally spaced circumferentially around diode structure 32, and fluid flow blockages 42, 44 and 46 are equally spaced circumferentially around diode structure 32. In other embodiments, the fluid flow passages and/or the fluid flow blockages may not be equally spaced.

Fluid flow passages 36, 38 and 40 are configured to permit fluid flow through diode structure 32 at the locations of fluid flow passages 36, 38 and 40, e.g., in primary flow direction 26. Fluid flow blockages 42, 44 and 46 are configured to prevent flow through diode structure 32 at the locations of fluid flow blockages 42, 44 and 46. In one form, fluid flow passages 36, 38 and 40 are in the form of circular holes in diode structure 32, whereas the fluid flow blockages 42, 44 and 46 are in the form of the physical material of diode structure 32 that extends circumferentially between respective fluid flow passages 36, 38 and 40. In other embodiments, the fluid flow passages and the fluid flow blockages may take other geometric forms or shapes, e.g., depending upon the needs of the particular application. For example, some embodiments may include fluid flow blockages in the form of spokes of a diode structure in the form of a spoked rotor, whereas the fluid flow passages of such an embodiment may be the spaces between the spokes.

In some embodiments, the fluid flow passages may be configured for a greater pressure drop in one direction than the opposite, e.g., for a greater pressure drop in back-flow direction 28 than in primary flow direction 26. For example, entrance and exit effects, such as rounded and sharp corners, may be formed on appropriate ends of the fluid flow passages to yield a higher pressure drop in back-flow direction 28 than in primary flow direction 26. In addition, the shape of the fluid flow passages may be

otherwise configured to yield a higher pressure drop in back-flow direction 28 than in primary flow direction 26. In various embodiments, the fluid flow passages may be angled, e.g., may have centerlines that are not parallel to the axis of rotation of the diode structure in which the fluid flow passages are formed, which in the depicted embodiment is engine centerline 18, e.g., in order to reduce losses in the fluid flow passing through diode 22 in primary flow direction 26. Also, in some embodiments, the fluid flow passages may have other shapes or features configured to enhance flow through fluid diode 22 in primary flow direction 26 and/or inhibit flow through fluid diode 22 in back-flow direction 28.

In the example illustrated in FIG. 4, diode structure 34 includes three (3) circumferential rows of fluid flow passages 56, 58 and 60 interspersed with three circumferential rows of fluid flow blockages 62, 64 and 66. In other embodiments, any number and orientation of rows of fluid flow passages and fluid flow blockages may be employed. In one form, fluid flow passages 56, 58 and 60 are equally spaced circumferentially around diode structure 34, and fluid flow blockages 62, 64 and 66 are equally spaced circumferentially around diode structure 34. In other embodiments, the fluid flow passages and/or the fluid flow blockages may not be equally spaced. Fluid flow passages 56, 58 and 60 are configured to permit fluid flow through diode structure 34 at the locations of fluid flow passages 56, 58 and 60, e.g., in primary flow direction 26. Fluid flow blockages 62, 64 and 66 are configured to prevent flow through diode structure 34 at the locations of fluid flow blockages 62, 64 and 66.

In one form, fluid flow passages 56, 58 and 60 are in the form of circular holes in diode structure 34, whereas the fluid flow blockages 62, 64 and 66 are in the form of the

physical material of diode structure 34 that extends circumferentially between respective fluid flow passages 56, 58 and 60. In other embodiments, the fluid flow passages and the fluid flow blockages may take other geometric forms or shapes, e.g., depending upon the needs of the particular application. For example, some embodiments may include fluid flow blockages in the form of spokes of a diode structure in the form of a spoked rotor, whereas the fluid flow passages of such an embodiment may be the spaces between spokes of the rotor.

In some embodiments, the fluid flow passages may be configured for a greater pressure drop in one direction than the opposite, e.g., for a greater pressure drop in back-flow direction 28 than in primary flow direction 26. For example, entrance and exit effects, such as rounded and sharp corners, may be formed on appropriate ends of the fluid flow passages to yield a higher pressure drop in back-flow direction 28 than in primary flow direction 26. In addition, the shape of the fluid flow passages may be otherwise configured to yield a higher pressure drop in back-flow direction 28 than in primary flow direction 26. In various embodiments, the fluid flow passages may be angled, e.g., may have centerlines that are not parallel to the axis of rotation of the diode structure in which the fluid flow passages are formed, which in the depicted embodiment is engine centerline 18, e.g., in order to reduce losses in the fluid flow passing through diode 22 in primary flow direction 26. Also, in some embodiments, the fluid flow passages may have other shapes or features configured to enhance flow through fluid diode 22 in primary flow direction 26 and/or inhibit flow through fluid diode 22 in back-flow direction 28.

Diode structures 32 and 34 are configured for relative motion between each other, e.g., via a drive mechanism (not shown). In one form, the motion between diode structures 32 and 34 is a rotating motion, e.g., about engine centerline 18. In other embodiments, other forms of motion may be employed in addition to or in place of rotation, e.g., including translation in one or more directions and oscillatory motion in one or more directions. In addition, the rotating motion or rotation motion component may be about an axis other than engine centerline 18. In one form, both diode structures 32 and 34 are in motion during the operation of combustion system 14, e.g., rotational motion. In other embodiments, only one of diode structures 32 and 34 may be in motion. In embodiments having more than two diode structures, at least one of the diode structures is in motion during the operation of combustion system 14. In some embodiments having more than two diode structures, more than one or all of the diode structures may be in motion during the operation of combustion system 14. In one form, both diode structures 32 and 34 rotate in the same direction. In other embodiments, diode structures 32 and 34 may rotate in opposite directions.

Diode structures 32 and 34 rotate at different speeds, yielding relative motion between them. In addition, the number of fluid flow passages 36, 38 and 40 per circumferential row, respectively, and the number of fluid flow passages 56, 58 and 60 per circumferential row, respectively, are different, and hence, the number of fluid flow blockages 42, 44 and 46 per row and the number of fluid flow blockages 62, 64 and 66 per row are also different. The relative motion between diode structures 32 and 34, in conjunction with the number and spacing of fluid flow passages and fluid flow blockages, yields moving regions of relative alignment and misalignment of fluid flow

passages 36, 38 and 40 in diode structure 32 with corresponding fluid flow passages 56, 58 and 60 in diode structure 34. In one form, the regions of alignment and misalignment rotate around fluid diode 22, e.g., about engine centerline 18 in the depicted embodiment. The rotating regions of relative alignment and misalignment rotate at a different speed than the rotational speed of either diode structure 32 or diode structure 34. In particular, the rotating regions of relative alignment and misalignment rotate substantially faster than diode structures 32 and 34. The rotational speed of the regions of alignment and misalignment are dependent various factors, which in the present embodiment include the number of fluid flow passages (and corresponding fluid flow blockages) in each of diode structures 32 and 34, and the rotational speed of each of diode structures 32 and 34. In other embodiments, other factors may be involved determining the speed of rotation and/or other type of motion of regions of alignment and misalignment, e.g., depending upon the type or types of relative motion that takes place between the diode structures. The regions of relative misalignment of the fluid flow passages (relative alignment of fluid flow blockages with fluid flow passages) are employed to block one or more rotating continuous detonation waves, i.e., to reduce or prevent flow in back-flow direction 28 in the vicinity of the rotating continuous detonation wave(s). The regions of relative alignment of the fluid flow passages (with corresponding relative alignment of fluid flow blockages) are employed to allow fluid flow through fluid diode 22 in primary flow direction 26 at locations spaced apart, e.g., circumferentially, in the depicted embodiment, from the rotating continuous detonation wave(s).

For example, referring also to FIG. 6, some aspects of a non-limiting example of combustion system 14 in accordance with an embodiment of the present invention are described. During operation, combustion system 14 includes a plurality of rotating continuous detonation waves 70. In the depicted embodiment, two rotating continuous detonation waves 70 are formed. Other embodiments may employ a single rotating continuous combustion wave or a plurality of rotating combustion waves greater in number than two. Rotating continuous detonation waves 70 are referred to as “rotating” because they rotate around annulus 30, e.g., rotating or spinning about engine centerline 18 in a generally circumferential direction 72. Rotating continuous detonation waves 70 are referred to as “continuous” because they are continuous combustion processes, as opposed pulsed combustion processes, such as those exhibited by pulse detonation systems. Rotating continuous detonation waves 70 are referred to as “detonation” waves because they have flame fronts that progress at speeds associated with detonation combustion, as opposed to the lower speeds associated with deflagration combustion. For instance, in one example, detonation waves 70 move at approximately 6,000 linear feet per second. In other embodiments, detonation waves 70 may move at other speeds associated with detonation combustion.

Fluid diode 22 is configured to permit and restrict flow through various portions thereof, e.g., as discussed herein. For example, in one form, fluid diode 22 is configured to form rotating regions 74 and rotating regions 76. Rotating regions 76 are interspersed between rotating regions 74. Rotating regions 74 correspond to areas of relative misalignment of a subset of the fluid flow passages of diode structure 32 with a subset of the fluid flow passages of diode structure 34 (relative alignment of a subset of

the fluid flow passages of diode structure 32 with a subset of the fluid flow blockages of diode structure 34, and relative alignment of a subset of the fluid flow passages of diode structure 34 with a subset of the fluid flow blockages of diode structure 32). Rotating regions 76 correspond to areas of relative alignment of a subset of the fluid flow passages of diode structure 32 with a subset of the fluid flow passages of diode structure 34 (relative alignment of a subset of the fluid flow blockages of diode structure 32 with a subset of the fluid flow blockages of diode structure 34). Some embodiments may employ only a single region 74 and a single region 76. The quantities of regions 74 and 76 may vary with the needs of the application.

Fluid diode 22 is configured to rotate rotating regions 74 and 76 at the same speed as rotating continuous detonation waves 70, wherein rotating region 74 is positioned and remains adjacent to rotating continuous detonation waves 70, and wherein rotating regions 76 are disposed between, e.g., circumferentially, rotating continuous detonation waves 70. Rotating regions 74 have, on average, a flow area that is less than the flow area of rotating regions 76. In one form, rotating regions 74 include the smallest regional flow area through fluid diode 22, whereas rotating regions 76 include the largest regional flow area through fluid diode 22. In some embodiments, the flow area through some or all of regions 74 may be zero or nearly so.

Rotating continuous combustion waves 70 form rotating higher pressure zones 78 in the vicinity of the flame fronts. Higher pressure zones 78 have a higher pressure than that of the fuel/oxidant supply mixture. Lower pressure zones 80 are formed between rotating continuous detonation waves 70. The pressure in combustion chamber 24 decreases with increasing distance from the combustion wave fronts of

rotating continuous combustion waves 70. Because rotation regions 74 are positioned adjacent to rotating continuous detonation waves 70, higher pressure zones 78 are generally in the same locations as rotating regions 74. Similarly, lower pressure zones 80 are generally in the same locations as rotating regions 76, which are spaced apart from the higher pressures associated with detonation waves 70. The pressure in lower pressure zones 80 between rotating continuous combustion waves 70 is less than the supply pressure of the fuel/oxidant mixture. That is, the supply pressure of the fuel/oxidant mixture is selected to be higher than the pressure in pressure zones 80.

By positioning regions 74 adjacent to rotating continuous detonation waves 70, back-flow resulting from the higher pressure zones 78 associated with the detonation combustion waves is reduced or eliminated. By positioning regions 76 in lower pressure zones 80 away from rotating continuous detonation waves 70, where the fuel/oxidant supply pressure is higher than the pressure in lower pressure zones 80, flow into combustion chamber 24 is permitted. Thus, in various embodiments, one or more portions of fluid diode 22 may restrict or prevent flow in back-flow direction 28, while at the same time one or more other portions of fluid diode 22 permit flow through to combustion chamber 24 in primary flow direction 26, e.g., depending upon circumferential location in a moving reference frame associated with rotating continuous detonation waves 70 and regions 74 and 76. The fuel/oxidant mixture admitted into combustion chamber 24 is combusted upon the approach of the next rotating continuous detonation waves 70 to arrive at the location of the admitted fuel/oxidant mixture, thus continuing the detonation process.

Referring now to FIGS. 7, 7A and 7B, some aspects of a non-limiting example of fluid diode 22 in accordance with an embodiment of the present invention are schematically depicted. FIGS. 7, 7A and 7B represent developed sectional views taken circumferentially from the indicated dashed circular line of FIG. 6, illustrating portions of rotating regions 74 (FIG. 7A) and 76 (FIG. 7B) at the middle rows of the fluid flow passages and the fluid flow blockages of diode structures 32 and 34. A rotating continuous detonation wave 70 is illustrated as proceeding in circumferential direction 72. Adjacent to diode structure 32 is the fuel/oxidant mixture 82 that is supplied at pressure to fluid diode 22. The fuel/oxidant pressure may vary with the needs of the application.

At regions 74, wherein fluid diode 22 is exposed to the higher pressure zones 78 in the vicinity of detonation waves 70, which are at a higher pressure than the fuel/oxidant 82 supply pressure, the relative misalignment of fluid flow passages 38 of diode structure 32 with fluid flow passages 58 of diode structure 34 prevents or reduces the back-flow of gases and combustion products from the combustion detonation waves 70 through regions 74. Some back-flow may occur due to a gap 84 between diode structures 32 and 34, indicated by arrows 86. Some back-flow may also occur at locations where there is not a complete overlap of the fluid flow passages with the fluid flow blockages. Some embodiments may provide complete overlap of fluid flow passages with fluid flow blockages at one or more locations, whereas other embodiments may not. Thus, in some embodiments, little or no back-flow may be realized, e.g., at locations of complete overlap and where gap 84 is small or non-existent, whereas in other embodiments, some greater, although acceptable, amount of

back-flow may occur. In one form, the degree of misalignment of fluid flow passages of diode structure 32 and diode structure 34 varies from a maximum at the center of regions 74 to a minimum at the designated boundaries of regions 74. In other embodiments, the degree of misalignment may be constant or may vary in one or more other directions, e.g., depending upon the numbers and sizes of the fluid flow passages and fluid flow blockages on diode structures 32 and 34, and the type or types of relative motion between diode structures 32 and 34.

At regions 76, wherein fluid diode 22 is exposed to the lower pressure zones 80 between detonation waves 70, which are at a lower pressure than the fuel/oxidant 82 supply pressure, the relative alignment of fluid flow passages 38 of diode structure 32 with fluid flow passages 58 of diode structure 32 allows fuel/oxidant mixture 82 to flow through regions 76 in primary direction 26 through diode 22 and into combustion chamber 24. The fuel/oxidant 82 flow is indicated in FIG. 7B with arrows 88. In one form, the degree of alignment between fluid flow passages of diode structure 32 and diode structure 34 varies from a maximum at the center of regions 76 to a minimum at the designated boundaries of regions 76. In other embodiments, the degree of alignment may be constant or may vary in one or more other directions, e.g., depending upon the numbers and sizes of the fluid flow passages and fluid flow blockages on diode structures 32 and 34, and the type or types of relative motion between diode structures 32 and 34.

Although rotating regions 74 and 76 rotate at a speed to match the speed of rotation of rotating continuous detonation waves 70 through annulus 30, e.g., 6,000 linear feet per second, e.g., at the radially outermost portion of detonation waves 70,

neither of diode structure 32 and 34 rotate at such a speed. Rather the number and spacing of fluid flow passages and the relative rotation rate between diode structure 32 and diode structure 34 form the rotating regions with a higher rate of rotation than either of diode structure 32 and diode structure 34, akin to the operation of a vernier scale, wherein regions of alignment and misalignment of two different scales traverse a greater distance than the distance traversed by one or both of the scales.

The number of fluid flow passages per row for each of diode structures 32 and 34 and the speed of rotation of diode structures 32 and 34 may be determined by various means, e.g., depending upon the configuration of the fluid diode. One way of making such a determination is via Equation 1, below:

$$\frac{N_1}{N_2} = \frac{\omega - \omega_2}{\omega - \omega_1} \quad (\text{Equation 1})$$

Wherein, N_1 is the number of holes per row of diode structure 32; N_2 is the number of fluid passages per row of diode structure 34; ω is the rotational speed of rotating continuous detonation waves 70; ω_1 is the rotational speed of diode structure 32, and ω_2 is the rotational speed of diode structure 34. The rotational speeds and number of fluid passages may be readily determined using Equation 1. In the present example, N_1 is 28, N_2 is 30, ω_1 is $2\omega/7$ and ω_2 is $\omega/3$, which is one of many potential solutions to Equation 1. Thus, in the depicted example, diode structure 32 rotates at one third of the rotation rate of the rotating continuous detonation waves 70, and diode structure 34 rotates at two-sevenths of the rotation rate of the rotating continuous detonation waves 70. Other embodiments may employ other solutions to Equation 1. In still other embodiments, N_1 , N_2 , ω_1 and ω_2 may be determined in one or more other

manners. Assuming a tip speed of 6000 feet per second for rotating continuous detonation waves 70, the above solution to Equation 1 yields a tip speed of 2000 feet per second for diode structure 32, and 1714 feet per second for diode structure 34, both of which are within the capabilities of current gas turbine engine high strength metallic alloys and composite or matrix composite materials.

Referring to FIG. 8, some aspects of a non-limiting example of fluid diode 22 in accordance with an embodiment of the present invention are schematically illustrated. FIG. 8 is not drawn to scale. FIG. 8 illustrates, in a developed view, the alignment/misalignment of one row of fluid flow passages of diode structure 32 with a corresponding row of fluid passages of diode structure 34 at a time T_1 , and the alignment/misalignment of the same row of fluid flow passages of diode structure 32 with the same row of fluid flow passages of diode structure 34 at a time T_2 . In the illustration of FIG. 8, the middle rows of fluid flow passages of diode structures 32 and 34 are shown, that is fluid flow passages 38 of diode structure 32 and fluid flow passages 58 of diode structure 34.

The rotational speed of diode structure 34 is $6/7$ of the rotational speed of diode structure 32, since $\omega_1/\omega_2 = (2\omega/7)/(\omega/3) = 6/7$, as set forth in the above example. As illustrated in FIG. 8, at time T_1 , fluid flow passages 38 and 58 are aligned at the left end of the view. At time T_2 , diode structure 32 has moved a unit distance of 1. Since the rotational speed of diode structure 34 is $6/7$ of the rotational speed of diode structure 32, at time T_2 , diode structure 34 has moved $6/7$ of a unit distance. However, at time T_2 , the next alignment of fluid flow passages 38 and 58 occurs 3 units of distance from the initial point of alignment at time T_1 . Thus, between time T_1 and T_2 , the region of

alignment has moved 3 times the distance of diode structure 32, and $3/(6/7) = (21/6)$ times the distance of diode structure 34. As is illustrated in FIG. 8, the regions of misalignment of the fluid flow passages moves in the same manner, that is 3 times the rate of diode structure 32 and $(21/6)$ times the rate of diode structure 34. Accordingly, in the depicted embodiment, regions 74 and 76 rotate around fluid diode 22 in annulus 30 at three times the speed of the fastest spinning diode structure. One or more control systems (not shown) employing one or more sensors, such as position sensors, pressure sensors, vibration sensors, acoustic sensors, temperature sensors and/or other sensors may be used to control the speed and position of diode structures 32 and 34 to ensure that regions 74 are positioned adjacent to detonation waves 70 (i.e., to ensure that regions 74 rotate with and remain at the same circumferential locations as rotating continuous detonation waves 70) in order to present the maximum impediment to back-flow in back-flow direction 28. In some embodiments, diode structures 32 and 34 may be coupled at a fixed ratio, e.g., via one or more gearsets, to ensure, without external control, the relative speed between diode structures 32 and 34. In some embodiments, the relative speed of diode structures 32 and 34 and/or the absolute speed of diode structures 32 and/or 34 may be controlled to vary, e.g., depending on operating conditions, such as based on a measured or calculated speed of detonation waves 70, e.g., under different operating conditions.

Referring to FIG. 9, a developed view of another example of diode members in the form of disks is illustrated, each disk having 7 rows of fluid flow passages, e.g., the top rows of which include passages 100 of a disk 1 (28 fluid flow passages 100 per circumferential row of disk 1, interspersed with fluid flow blockages) and passages 102

of a disk 2 (30 fluid flow passages 102 per circumferential row of disk 2, interspersed with fluid flow blockages). Fig. 9 illustrates regions of alignment of fluid flow passages alternating with regions of misalignment of fluid flow passages.

Various embodiments of the present invention include a fluid diode that provides one or more regions of reverse flow control that traverse circumferentially (spin) in a typically, but not exclusively, annular shaped region for a continuous detonation combustor. The fluid diode restricts back or reverse flow in one of more moving regions immediately adjacent to the traveling detonation or detonations of a continuous detonation combustor. The fluid diode operates on the principle of two (or more) disks or plates or spoked rotors or other fluid diode elements having sets of holes, slots, or openings through the plate, which move relative to each other. They move at different but related mechanical speeds. The difference in speeds together with the number, spacing and patterns of the openings creates open and closed regions that travel around the annulus or other combustion area shape at a speed greater than either of the disks. Thus the speed of the region of closed area may be made to match the speed of the detonation wave without requiring either of the plates to travel at the speed of the detonation wave. The fluid diode works on the principles akin to the vernier scale in which the position of markings in alignment moves a greater distance than the traveling distance of the sliding element. In embodiments of the present invention, the position of holes or features in alignment (or greatest misalignment) moves a greater distance than the plates having the holes. It is envisioned that the flow direction through the fluid diode may either be predominately axial or predominately radial, or a combination of both (also with some amount of swirl, in some embodiments). It is also

envisioned that the orientation of the plates, disks, or elements may be either flat plate, cylinder, conical or other body of revolution configuration including curved surfaces for any of the types. One of the elements may be stationary. Although rotation is envisioned as the primary method of achieving the intended motion, methods other than rotation or used in combination with rotation are envisioned. Furthermore, the rotation or translation of one or more of the plates relative to each other is envisioned to be either in the same direction or counter in direction to each other.

The performance of a continuous detonation engine or pressure gain combustor was previously held to a low level by employing a high level of flow restriction, resulting in unnecessary pressure loss in the downstream direction required in any diode valve or controlling orifice (aero valve) of previous design. Embodiments of the present invention may allow the back-flow region adjacent to the detonation to be sufficiently blocked locally to allow proper combustor and/or engine operation, while also providing a relatively low level of flow restriction (pressure loss) to the fresh incoming fuel, air, or fuel and air mixture (as compared to previous detonation combustion systems). This causes the pressure onto which the detonation adds (that is the pressure into which the detonation travels) to be significantly higher than is previously attainable for a given supply pressure. This higher initial pressure causes a higher post detonation pressure. Thus, this well know limiter of continuous detonation engine performance is mitigated, and combustion systems in accordance with embodiments of the present invention may enable a new class of engines (both gas turbine and direct thrust producing) to be developed using this higher pressure gain across the engine or combustor using the constant volume combustion principles of the continuous detonation type.

The low flow loss characteristic of embodiments of the present invention in the region or regions of inflow of unburned reactants allows a higher through flow of mass per unit cross sectional area of the device, thus creating a more compact unit, relative to previous detonation combustion systems. In addition, the low flow loss characteristic of embodiments of the present invention in the region or regions of inflow of unburned reactants allows the detonation wave which travels into the flow to be oriented in a manner more normal to the direction into which the combusted gas is intended to travel, thus creating a momentum component to the flow more in line with the engine axis. This may increase the performance potential of the combustion system relative to previous combustion systems.

Although it may be possible to employ a moving mechanical blocker traveling at the speed of the detonate wave, such an approach would require tip speeds of approx. 6000 feet per second in the annulus, and is thus undesirable because the resulting stresses in the moving mechanical blocker would be higher than those allowable by known materials under the expected operating conditions. In embodiments of the present invention, the regions of translating or rotating high flow restriction and low flow restriction are made to travel at a velocity equal to that of the detonation wave without causing a mechanical component to travel at such high velocities, which would result in high, likely prohibitively high, stress levels in the moving mechanical component. Through the use of embodiments of the present invention, it is anticipated that the stresses within the mechanical components may be made to be within those of known design practice using known materials.

In addition, a moving mechanical blocker traveling at the speed of the detonation wave would experience a continuously high heat flux from the detonative combustion wave that it would be blocking. However, embodiments of the present invention contemplated herein do not have that continuous high heat flux on any given location of the fluid diode, since at no given location on the structure does the detonation continuously reside. Thus in embodiments of the present invention, no location on the structure of the fluid diode is continuously heated by the detonation wave but instead all positions are intermittently heated by the passing detonation wave and then cooled by the arriving flow of unburned reactants traversing through the fluid diode.

The fluid diode may utilize the rotation of the disk or plate on the same or differing axis of rotation to create the intended motion of the single or multiple regions. The relative rotational position of the two or multiple disks or plates or other-shaped fluid diode elements may be indexed (made to have required relative positions) either mechanically or by position control in order to create the desired regions of relatively more open area and relatively more closed area traversing the annulus. Also the fluid diode may utilize the simultaneous translation and rotation of the disks, plates or other shaped diode elements to create the traveling regions of greater fraction of open area and greater fraction of closed area. In this way the fluid diode creates the regions of relatively more open area and relatively more closed area traversing an annulus or other combustion zone shape at velocities sufficient to correspond to the tangential velocity of the traveling or spinning detonation wave(s) in the continuous detonation combustor, while the disks or plates or elements travel at a lower tangential velocity than that of the detonation event or events. The speeds or motion of the disks, plates or

other fluid diode elements may be driven by known methods, and may be controlled by sensors detecting the velocity and/or position of the detonation or detonations via known techniques to match either the velocity, position or both of the regions with that of the detonation or detonations. This allows the fluid diode which creates the preferred regions to couple with the spinning detonation in the continuous detonation combustor and to act to restrict the backflow of combusted gasses produced by the detonation in the region adjacent to and trailing the detonation wave or waves.

The fluid diode then carries or reacts the pressure forces generated by the detonation wave and pressure field trailing it via the more closed region having high flow pressure loss characteristics, and thus transmits the reacted forces to the non rotating structure of the combustor by bearings or other known means. The moving more open or less restrictive regions created by the fluid diode are similarly coupled with the inflow of unreacted fuel, air or oxidizer, or un-reacted fuel and air mixture admitted ahead of the spinning detonation and downstream of the fluid diode prior to arrival of the spinning detonation wave which then combusts the mixture. In summary, by this unique means the fluid diode creates single or multiple regions of relatively more open area (less restrictive to fluid flow) and relatively more closed area (more restrictive to fluid flow) that traverse the annulus or other combustion zone and couple with the single spinning detonation wave or multiple detonation waves in the continuous detonation combustor.

The fluid diode may be part of a continuous detonation thrust producing engine, a continuous detonation pressure gain combustor, or any other device utilizing continuous detonation traveling in a continuous path. It is intended to include oxidizers other than air in its application.

The spacing of the open areas within the elements is intended to be highly regular and even with deviations from this tolerated by the design. This allows creation of the more open and closed regions to travel at a near constant velocity. It is envisioned that irregular spacing together with an oscillatory component to the various element's speed could be used to create a near constant velocity of the regions.

The distance between open areas in the direction of detonation wave travel is targeted to be near that of the open area or less to give the greatest available open area in the regions of alignment and near alignment of the areas. Lesser spacing is preferred in some embodiments, in that complete blockage of flow in the regions of misalignment of areas is not required. The areas of open flow may be circular, oval, slot, or of other shape consistent with creating a low stress rotating fluid diode elements or set of rotating fluid diode elements. Across the width of the flow channel, the rows of holes may be spaced in an inline or staggered arrangement, with staggered giving a relatively higher percentage of open area in some embodiments.

Embodiments of the present invention include a combustion system configured for a rotating continuous detonation wave, comprising: a fluid diode including a first diode structure and a second diode structure disposed adjacent to the first diode structure; wherein the first diode structure includes a plurality of first fluid flow passages; wherein the second diode structure includes a plurality of second fluid flow passages; wherein a number of the first fluid flow passages is different than a number of the second fluid flow passages; wherein the fluid diode is configured for relative motion between the first diode structure and the second diode structure to form: a first rotating region having a first flow area through the fluid diode formed by at least a partial

misalignment of a first subset of the plurality of first fluid flow passages with a first subset of the second plurality of fluid flow passages, wherein the first rotating region is configured to rotate around the fluid diode at a same speed as the rotating continuous detonation wave and to be positioned adjacent to the rotating continuous detonation wave during operation of the combustion system; and a second rotating region having a second flow area through the fluid diode formed by at least a partial alignment of a second subset of the plurality of first fluid flow passages with a second subset of the second plurality of fluid flow passages, wherein the second rotating region is configured to rotate around the fluid diode at the same speed as the rotating continuous detonation wave and to be spaced apart from the rotating continuous detonation wave during operation of the combustion system, wherein the first flow area is less than the second flow area.

In a refinement, the first diode structure is configured to rotate at a first speed, and the second diode structure is configured to rotate at a second speed different than the first speed.

In another refinement, the first diode structure and the second diode structure are configured as disks.

In yet another refinement, the first diode structure and the second diode structure are configured to rotate about a same axis of rotation.

In still another refinement, the first rotating region of the first flow area through the fluid diode and the second rotating region of the second flow area rotate at a higher speed than a rotational speed of either the first diode structure or the second diode structure.

In yet still another refinement, the first flow area is approximately zero not including leakage between the first diode structure and the second diode structure; and wherein the second flow area is greater than zero.

In a further refinement, the combustion system has a primary flow direction and a back-flow direction, wherein the fluid diode is configured to restrict a flow through the first flow area in the back-flow direction and to pass a flow through the second flow area in the primary flow direction.

In a yet further refinement, the fluid diode is configured to pass a flow of a fuel through the second flow area for reaction within the rotating continuous detonation wave.

In a still further refinement, the fluid diode is configured to pass a flow of an oxidant through the second flow area for reaction within the rotating continuous detonation wave.

In a yet still further refinement, the fluid diode is configured to pass a flow of an oxidant and a fuel through the second flow area for reaction within the rotating continuous detonation wave.

In an additional further refinement, the fluid diode is configured to form a plurality of the first rotating regions, each having the first flow area; wherein the fluid diode is configured to form a plurality of the second rotating regions, each having the second flow area; wherein each first rotating region rotates around the fluid diode and remains positioned adjacent to a corresponding rotating continuous detonation wave, and wherein each second rotating region is positioned between two first rotating regions.

In another further refinement, the combustion system has a primary flow direction and a back-flow direction, wherein the fluid diode is configured to restrict and/or prevent a flow of combustion products and/or a combustion process from the rotating continuous detonation wave through the first flow area in the back-flow direction, and is configured to permit a flow of a fuel and/or oxidant through the second flow area in the primary flow direction.

Embodiments of the present invention include a gas turbine engine, comprising: a compressor system; a combustion system in fluid communication with the compressor system; and a turbine system in fluid communication with the combustion system, wherein the combustion system is configured for having a rotating continuous detonation wave; wherein the combustion system includes a fluid diode having a first diode structure and a second diode structure disposed adjacent to the first diode structure; wherein the fluid diode is configured for relative motion between the first diode structure and the second diode structure to form a first rotating region having a first flow area through the fluid diode, wherein the first rotating region is configured to rotate around the fluid diode adjacent to the rotating continuous detonation wave, and to form a second rotating region having a second flow area through the fluid diode, wherein the second rotating region is configured to rotate around the fluid diode spaced apart from the rotating continuous detonation wave; and wherein the first flow area is less than the second flow area.

In a refinement, the first diode structure includes a plurality of first fluid flow passages; the second diode structure includes a plurality of second fluid flow passages; the first flow area through the fluid diode is formed by at least a partial misalignment of a

first subset of the plurality of first fluid flow passages with a first subset of the second plurality of fluid flow passages; and the second flow area through the fluid diode is formed by at least a partial alignment of a second subset of the plurality of first fluid flow passages with a second subset of the second plurality of fluid flow passages.

In another refinement, a number of the first fluid flow passages is different than a number of the second fluid flow passages.

In yet another refinement, the first diode structure and the second diode structure are configured to rotate about a same axis of rotation.

In still another refinement, the first rotating region and the second rotating region rotate at a higher speed than a rotational speed of either the first diode structure or the second diode structure.

Embodiments of the present invention include an engine, comprising: a combustion chamber configured for combusting a fuel and an oxidant in a moving detonation wave; and means for supplying the fuel and/or the oxidant to the combustion chamber and for preventing or reducing back-flow from the combustion chamber.

In a refinement, the means for supplying and for preventing or reducing includes a first structure and a second structure configured for relative motion therebetween and configured to form a first moving region having a first flow area, wherein the first moving region is configured to move at the same speed as the moving detonation wave and is positioned adjacent to the moving detonation wave, and to form a second moving region having a second flow area, wherein the second moving region is configured to move at

the same speed as the moving detonation wave and is spaced apart from the moving detonation wave, and wherein the first flow area is less than the second flow area.

In another refinement, the combustion chamber is an annular combustion chamber.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment(s), but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as permitted under the law. Furthermore it should be understood that while the use of the word preferable, preferably, or preferred in the description above indicates that feature so described may be more desirable, it nonetheless may not be necessary and any embodiment lacking the same may be contemplated as within the scope of the invention, that scope being defined by the claims that follow. In reading the claims it is intended that when words such as "a," "an," "at least one" and "at least a portion" are used, there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. Further, when the language "at least a portion" and/or "a portion" is used the item may include a portion and/or the entire item unless specifically stated to the contrary.

Claims

What is claimed is:

1. A combustion system configured for a rotating continuous detonation wave, comprising:

a fluid diode including a first diode structure and a second diode structure disposed adjacent to the first diode structure;

wherein the first diode structure includes a plurality of first fluid flow passages;

wherein the second diode structure includes a plurality of second fluid flow passages;

wherein a number of the first fluid flow passages is different than a number of the second fluid flow passages;

wherein the fluid diode is configured for relative motion between the first diode structure and the second diode structure to form:

a first rotating region having a first flow area through the fluid diode formed by at least a partial misalignment of a first subset of the plurality of first fluid flow passages with a first subset of the second plurality of fluid flow passages, wherein the first rotating region is configured to rotate around the fluid diode at a same speed as the rotating continuous detonation wave and to be positioned adjacent to the rotating continuous detonation wave during operation of the combustion system; and

a second rotating region having a second flow area through the fluid diode formed by at least a partial alignment of a second subset of the plurality of first fluid flow passages with a second subset of the second plurality of fluid flow

passages, wherein the second rotating region is configured to rotate around the fluid diode at the same speed as the rotating continuous detonation wave and to be spaced apart from the rotating continuous detonation wave during operation of the combustion system,

wherein the first flow area is less than the second flow area.

2. The combustion system of claim 1, wherein the first diode structure is configured to rotate at a first speed, and the second diode structure is configured to rotate at a second speed different than the first speed.

3. The combustion system of claim 1, wherein the first diode structure and the second diode structure are configured as disks.

4. The combustion system of claim 1, wherein the first diode structure and the second diode structure are configured to rotate about a same axis of rotation.

5. The combustion system of claim 1, wherein the first rotating region of the first flow area through the fluid diode and the second rotating region of the second flow area rotate at a higher speed than a rotational speed of either the first diode structure or the second diode structure.

6. The combustion system of claim 1, wherein the first flow area is approximately zero not including leakage between the first diode structure and the second diode structure; and wherein the second flow area is greater than zero.

7. The combustion system of claim 1, having a primary flow direction and a back-flow direction, wherein the fluid diode is configured to restrict a flow through the first flow area in the back-flow direction and to pass a flow through the second flow area in the primary flow direction.

8. The combustion system of claim 7, wherein the fluid diode is configured to pass a flow of a fuel through the second flow area for reaction within the rotating continuous detonation wave.

9. The combustion system of claim 7, wherein the fluid diode is configured to pass a flow of an oxidant through the second flow area for reaction within the rotating continuous detonation wave.

10. The combustion system of claim 7, wherein the fluid diode is configured to pass a flow of an oxidant and a fuel through the second flow area for reaction within the rotating continuous detonation wave.

11. The combustion system of claim 1, wherein the fluid diode is configured to form a plurality of the first rotating regions, each having the first flow area; wherein the

fluid diode is configured to form a plurality of the second rotating regions, each having the second flow area; wherein each first rotating region rotates around the fluid diode and remains positioned adjacent to a corresponding rotating continuous detonation wave, and wherein each second rotating region is positioned between two first rotating regions.

12. The combustion system of claim 1, having a primary flow direction and a back-flow direction, wherein the fluid diode is configured to restrict and/or prevent a flow of combustion products and/or a combustion process from the rotating continuous detonation wave through the first flow area in the back-flow direction, and is configured to permit a flow of a fuel and/or oxidant through the second flow area in the primary flow direction.

13. A gas turbine engine, comprising:

- a compressor system;
- a combustion system in fluid communication with the compressor system; and
- a turbine system in fluid communication with the combustion system,

wherein the combustion system is configured for having a rotating continuous detonation wave;

wherein the combustion system includes a fluid diode having a first diode structure and a second diode structure disposed adjacent to the first diode structure;

wherein the fluid diode is configured for relative motion between the first diode structure and the second diode structure to form a first rotating region having a first flow

area through the fluid diode, wherein the first rotating region is configured to rotate around the fluid diode adjacent to the rotating continuous detonation wave, and to form a second rotating region having a second flow area through the fluid diode, wherein the second rotating region is configured to rotate around the fluid diode spaced apart from the rotating continuous detonation wave; and

wherein the first flow area is less than the second flow area.

14. The gas turbine engine of claim 13, wherein:

the first diode structure includes a plurality of first fluid flow passages;

the second diode structure includes a plurality of second fluid flow passages;

the first flow area through the fluid diode is formed by at least a partial misalignment of a first subset of the plurality of first fluid flow passages with a first subset of the second plurality of fluid flow passages; and

the second flow area through the fluid diode is formed by at least a partial alignment of a second subset of the plurality of first fluid flow passages with a second subset of the second plurality of fluid flow passages.

15. The gas turbine engine of claim 14, wherein a number of the first fluid flow passages is different than a number of the second fluid flow passages.

16. The gas turbine engine of claim 13, wherein the first diode structure and the second diode structure are configured to rotate about a same axis of rotation.

17. The gas turbine engine of claim 13, wherein the first rotating region and the second rotating region rotate at a higher speed than a rotational speed of either the first diode structure or the second diode structure.

18. An engine, comprising:

a combustion chamber configured for combusting a fuel and an oxidant in a moving detonation wave; and

means for supplying the fuel and/or the oxidant to the combustion chamber and for preventing or reducing back-flow from the combustion chamber.

19. The engine of claim 18, wherein the means for supplying and for preventing or reducing includes a first structure and a second structure configured for relative motion therebetween and configured to form a first moving region having a first flow area, wherein the first moving region is configured to move at the same speed as the moving detonation wave and is positioned adjacent to the moving detonation wave, and to form a second moving region having a second flow area, wherein the second moving region is configured to move at the same speed as the moving detonation wave and is spaced apart from the moving detonation wave, and wherein the first flow area is less than the second flow area.

20. The engine of claim 18, wherein the combustion chamber is an annular combustion chamber.

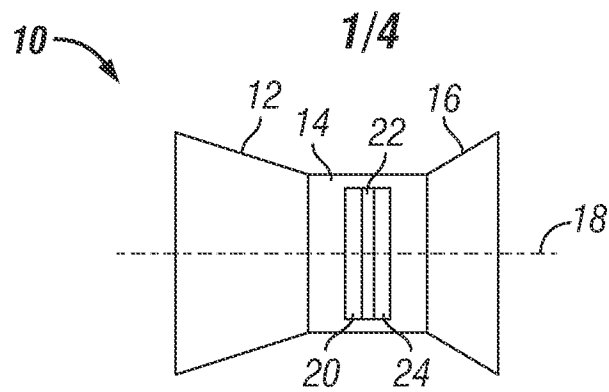


FIG. 1

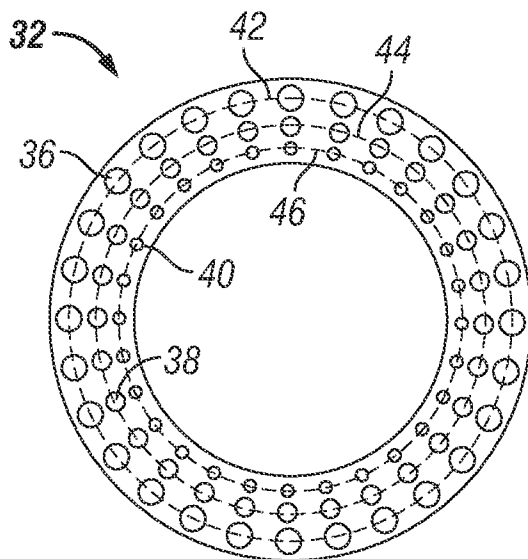
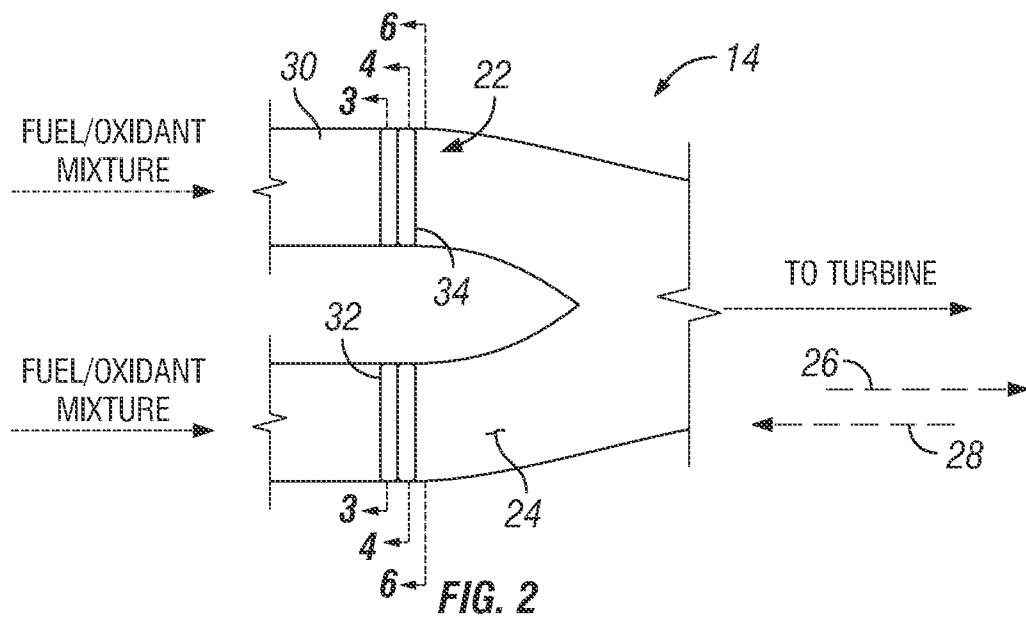


FIG. 3

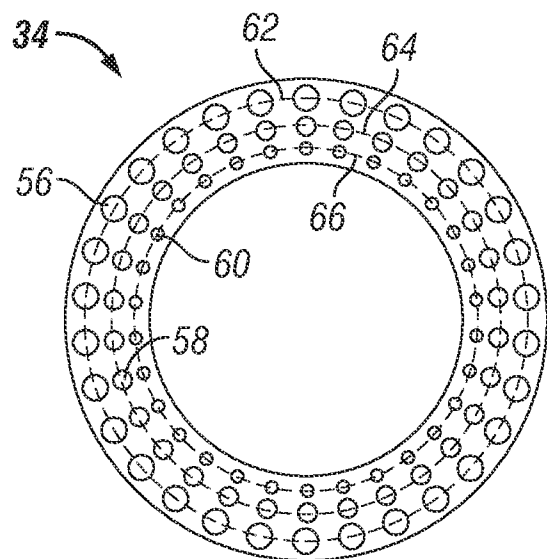
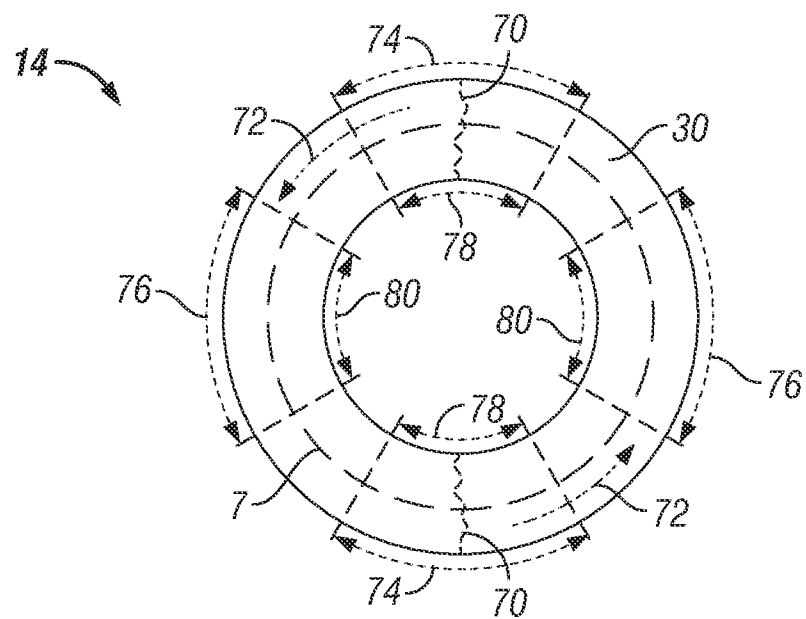
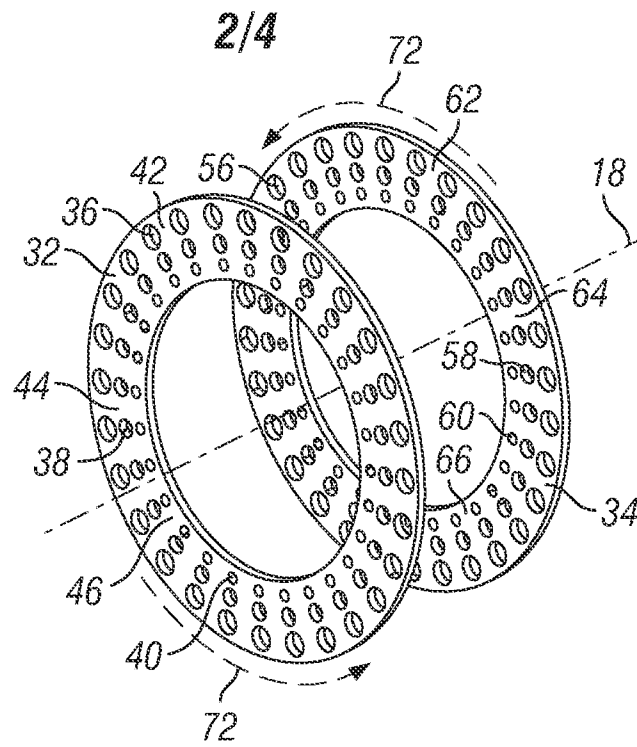
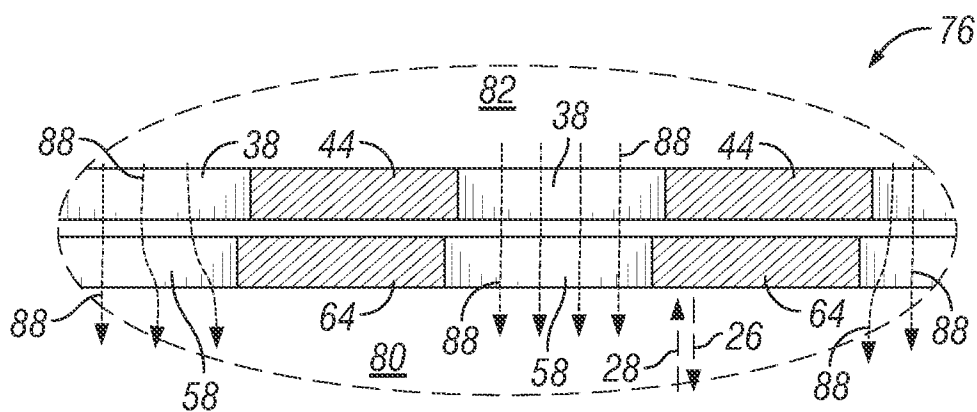
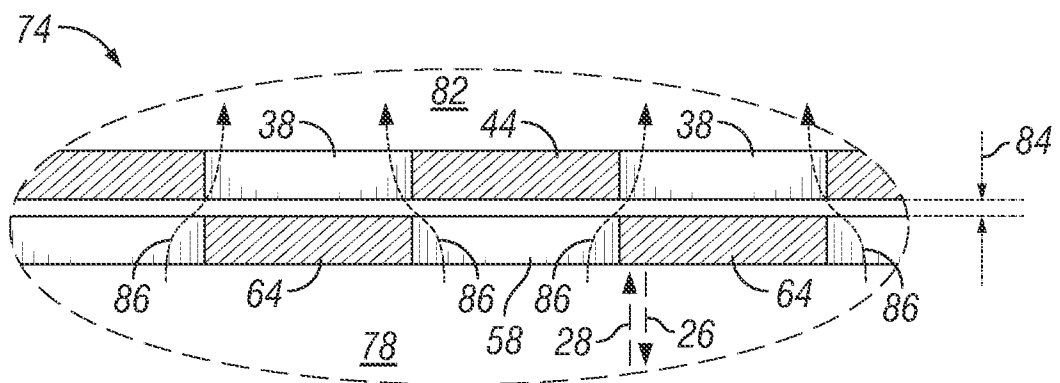
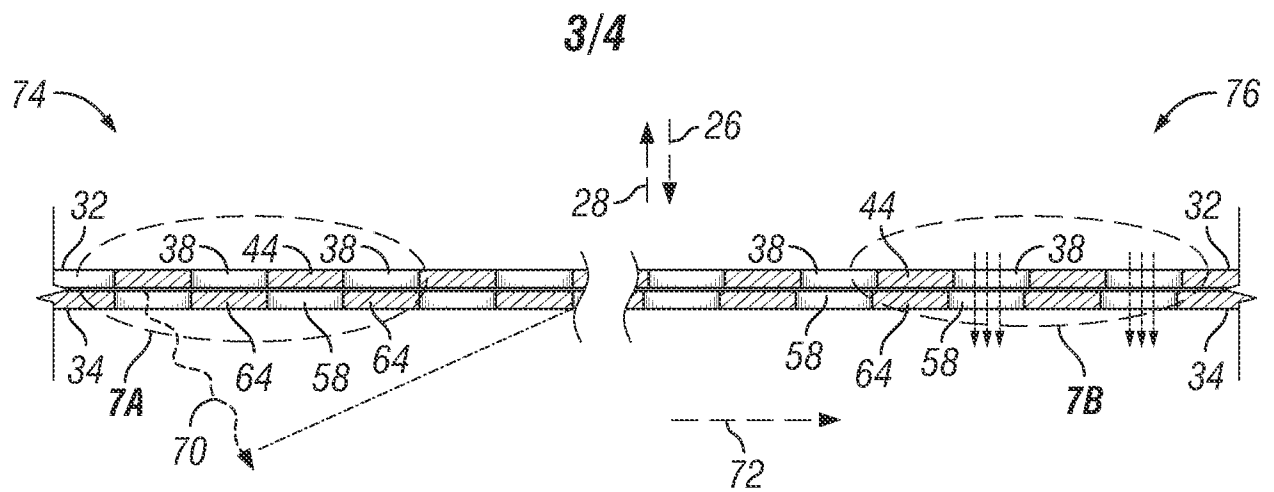


FIG. 4





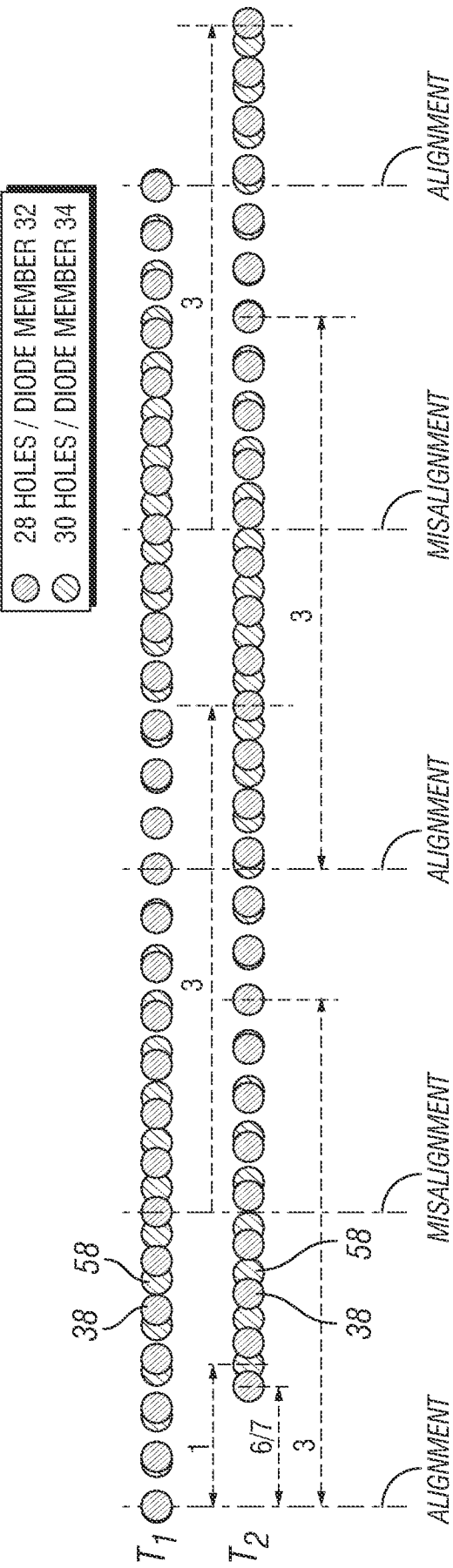


FIG. 8

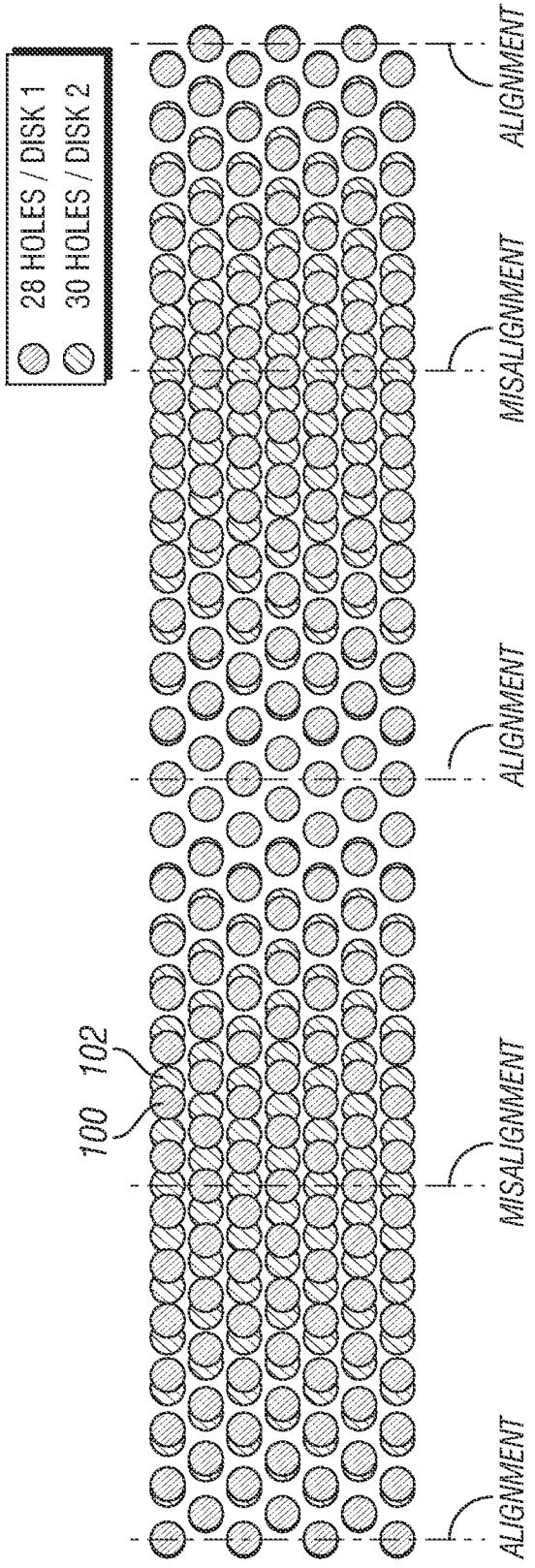


FIG. 9