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**(54) Title**: SYSTEMS AND METHODS FOR REDUCING VORTEX INDUCED VIBRATIONS

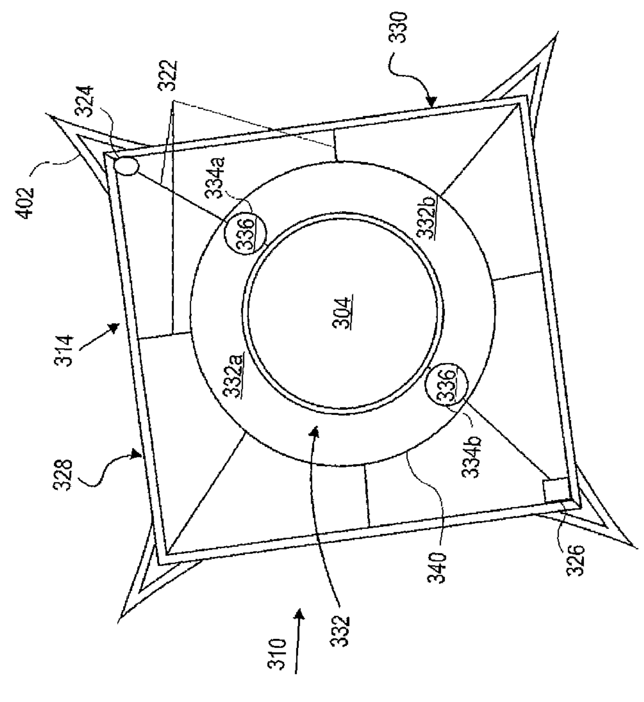


FIG. 4

**(57) Abstract**: A system for reducing drag and/or vortex induced vibration of a structure, the system comprising a multiple sided device comprising from 4 to 6 sides; and at least one blade located extending from the multiple sided device.

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# SYSTEMS AND METHODS FOR REDUCING VORTEX INDUCED VIBRATIONS

## Field of the Invention

The present invention relates to systems and methods for reducing drag and/or vortex-induced vibration ("VIV").

## Background of the Invention

Whenever a bluff body, such as a cylinder, experiences a current in a flowing fluid environment, it is possible for the body to experience vortex-induced vibration (VIV). These vibrations may be caused by oscillating dynamic forces on the surface, which can cause substantial vibrations of the structure, especially if the forcing frequency is at or near a structural natural frequency.

Drilling for and/or producing hydrocarbons or the like from subterranean deposits which exist under a body of water exposes underwater drilling and production equipment to water currents and the possibility of VIV. Equipment exposed to VIV includes structures ranging from the smaller tubes of a riser system, anchoring tendons, or lateral pipelines to the larger underwater cylinders of the hull of a mini spar or spar floating production system (hereinafter “spar”).

The magnitude of the stresses on the riser pipe, tendons or spars may be generally a function of and increases with the velocity of the water current passing these structures.

It is noted that even moderate velocity currents in flowing fluid environments acting on linear structures can cause stresses. Such moderate or higher currents may be readily encountered when drilling for offshore oil and gas at greater depths in the ocean or in an ocean inlet or near a river mouth.

There are generally two kinds of current-induced stresses in flowing fluid environments. The first kind of stress may be caused by vortex-induced alternating forces that vibrate the structure ("vortex-induced vibrations") mainly in a direction perpendicular to the direction of the current. When fluid flows past the structure, vortices may be alternately shed from each side of the structure. This produces a fluctuating force on the structure transverse to the current. If the frequency of this harmonic load is near the resonant frequency of the structure, large vibrations transverse to the current can occur. These vibrations can, depending on the stiffness and the strength of the structure and any welds, lead to unacceptably short fatigue lives. In fact, stresses caused by high current conditions in marine environments have been known to cause structures such as risers to break apart and fall to the ocean floor.

The second type of stress may be caused by drag forces, which push the structure in the direction of the current due to the structure's resistance to fluid flow. The drag forces may be amplified by vortex-induced vibration of the structure. For instance, a riser pipe that is vibrating due to vortex shedding will generally disrupt the flow of water around it more than a stationary riser. This may result in more energy transfer from the current to the riser, and hence more drag.

Many types of devices have been developed to reduce vibrations of sub sea structures. Some of these devices used to reduce vibrations caused by vortex shedding from sub sea structures operate by stabilization of the wake. These methods include use of streamlined fairings, wake splitters and flags.

Devices used to reduce vibrations caused by vortex shedding from sub-sea structures may operate by modifying the boundary layer of the flow around the structure to prevent the correlation of vortex shedding along the length of the structure. Examples of such devices include sleeve-like devices such as helical strakes, shrouds, fairings and substantially cylindrical sleeves.

Elongated structures in wind in the atmosphere can also encounter VIV and/or drag, comparable to that encountered in aquatic environments. Likewise, elongated structures with excessive VIV and/or drag forces that extend far above the ground can be difficult, expensive and dangerous to reach by human workers to install VIV and/or drag reduction devices.

Fairings may be used to suppress VIV and reduce drag acting on a structure in a flowing fluid environment. Fairings may be defined by a chord to thickness ratio, where longer fairings have a higher ratio than shorter fairings. Long fairings are more effective than short fairings at resisting drag, but may be subject to instabilities. Short fairings are less subject to instabilities, but may have higher drag in a flowing fluid environment.

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Co-pending patent application, published as WO 2009/023624, and having attorney docket number TH3245, discloses a system for reducing drag and/or vortex induced vibration of a structure, the system comprising a multiple sided device comprising from 4 to 6 sides. WO 2009/023624 is herein incorporated by reference in its entirety.

Co-pending patent application, published as WO 2009/046166, and having attorney docket number TH3350, discloses a system for reducing drag and/or vortex induced vibration of a structure, the system comprising a multiple finned device comprising from 4 to 6 fins substantially aligned along a longitudinal axis of the structure. WO 2009/046166 is herein incorporated by reference in its entirety.

Co-pending PCT patent application PCT/US2009/061156, having attorney docket number TH3353, discloses a system for reducing drag and/or vortex induced vibration of a structure, the system comprising a multiple sided device comprising from 4 to 6 sides, the multiple sided device comprising a first portion and a second portion, the first portion and the second portion adapted to attach to each other about the structure. PCT patent application PCT/US2009/061156 is herein incorporated by reference in its entirety.

There are needs in the art for one or more of the following: apparatus and methods for reducing VIV on structures in flowing fluid environments, which do not suffer from certain disadvantages of the prior art apparatus and methods; improved VIV suppression devices; high stability devices; devices which delay the separation of the boundary layer, and/or devices which provide decreased VIV and/or devices which provide reduced drag; devices suitable for use at a variety of fluid flow velocities; devices that can achieve a high degree of VIV suppression with a low coverage density; and/or devices that have a high stability.

These and other needs in the art will become apparent to those of skill in the art upon review of this specification, including its drawings and claims.

## Summary of the Invention

One aspect of the invention provides a system for reducing drag and/or vortex induced vibration of a structure, the system comprising a multiple sided device comprising from 4 to 6 sides; and at least one blade located extending from the multiple sided device.

Advantages of the invention may include one or more of the following: improved VIV reduction; improved device stability; delaying the separation of the boundary layer over the device body; lower cost devices; devices that are easier to install; and/or lighter weight devices.

These and other aspects of the invention will become apparent to those of skill in the art upon review of this specification, including its drawings and claims.

Brief Description of the Figures

Figure 1 illustrates a side view of plurality of VIV suppression devices installed along a tubular structure.

Figure 2 illustrates a top view of a tubular structure having buoyancy material attached thereto.

Figure 3 illustrates a top view of a multiple sided VIV suppression device.

Figure 4 illustrates a top view of a multiple sided VIV suppression device.

Figure 5 illustrates a top view of a multiple sided VIV suppression device.

Figure 6 illustrates a top view of a VIV suppression device.

Figure 7 illustrates a perspective view of a multiple sided VIV suppression device.

Figure 8 illustrates a side view of a tubular structure having a plurality of VIV suppression devices and buoyancy material attached thereto.

Figure 9a illustrates a top view of a VIV suppression device.

Figure 9b illustrates a top view of a VIV suppression device.

Figure 10a illustrates a top view of a VIV suppression device.

Figure 10b illustrates a side view of a VIV suppression device.

Detailed Description

Conventional vortex-induced vibration (VIV) suppression devices may include, for example, long and short fairings. Fairings may be defined by a chord to thickness ratio, where long fairings have a higher ratio than short fairings. Long fairings are more effective than short fairings at resisting drag, but may be subject to instabilities. Short fairings are less subject to instabilities, but may have higher drag in a flowing fluid environment. Regardless of their size, VIV suppression devices such as fairings and strakes may have a high coverage density meaning they must cover a substantial portion of the underlying structure to suppress VIV. In this aspect, running and retrieving tubulars, e.g. drilling risers, from the sea floor with fairings attached becomes difficult due to the added weight of the fairings. Accordingly, VIV suppression devices which perform well at lower coverage densities and may replace fairings are disclosed herein. The VIV suppression devices may have a buoyancy component to provide added support to the tubular without adding unnecessary weight.

Figure 1:

Referring now to Figure 1 there is illustrated offshore system 100. System 100 includes surface structure 102 near a water surface. Surface structure 102 is connected to subsurface structure 103 adjacent to seafloor 108 by a tubular structure 104. In some embodiments, tubular structure 104 may be a riser, for example a drilling riser. Tubular structure 104 may be a drilling riser requiring a modest amount of VIV suppression and little or no drag reduction.

The water has current 110, which may cause VIV of tubular structure 104. To counter VIV, VIV suppression devices 114 may be installed along tubular structure 104. In some embodiments, collars (not shown) may be provided between adjacent VIV suppression devices 114 or placed between every few devices to prevent them from sliding along a length of tubular structure 104 and/or to provide a bearing surface for the device to rotate. In other embodiments, collars may be omitted and VIV suppression devices 114 may be allowed to freely slide along a length of tubular structure 104 since device 114 performance does not require dense coverage of tubular structure 104.

Devices 114 have a height 124 and distance 126 between adjacent devices. Devices 114 each have a length 128. Devices 114 may have the same or different heights and lengths.

Devices 114 may cover from about 5% to about 100% of a height of tubular structure 104. For example, devices 114 may cover from 10% to 90% of a height of tubular structure 104, from 15% to 80%, or from 20% to 50%. The coverage may be defined as the sum of all the device heights 124 divided by a length of structure 104.

Length 128 may be from about 0.75 times the diameter of tubular structure 104 to about 4 times. For example, the length may range from 1.25 times the diameter to 3 times the diameter. In another example, the length may range from 1.5 times to 2 times the diameter.

Height 124 may be less than the diameter of tubular structure 104 or from about 1 times the diameter of tubular structure 104 to about 6 times. For example, the height may range from 1.1 to 5 times the diameter of tubular structure 104. In another embodiment, the height may range from 1.25 to 3 times the diameter or from 1.5 times to 2 times the diameter.

Distance 126 may be the same or different between devices 114. Distance 126 may be from about 0.5 times the diameter of tubular structure 104 to about 100 times. For example, distance 126 may range from 1 times the diameter to 50 times the diameter of tubular structure 104, from 1.5 times to 25 times the diameter of tubular structure 104 or from 2 times to 10 times the diameter.

Exterior to tubular structure 104 is buoyancy material 106, such as foam, which may serve to insulate and/or provide buoyancy to tubular structure 104.

One or more lines 112 (e.g. hydraulic lines, electrical lines, choke and kill lines) may extend along buoyancy material 106 between surface structure 102 and subsurface structure 103. In some embodiments, lines 112 are added after the installation of buoyancy material 106 such that they are exterior to buoyancy material 106. In other embodiments, lines 112 are installed before buoyancy material 106 such that they are interior to or within buoyancy material 106. In this aspect, buoyancy material 106 may include pockets, as will be described more fully in the following description, to hold lines 112.

Figure 2:

Referring now to Figure 2, a cross-sectional view of a tubular, for example a riser with buoyancy material is illustrated. Tubular structure 204 is shown with buoyancy material 206 exterior to tubular structure 204. Buoyancy material 206 is illustrated as two sections, 206a and 206b. Sections 206a and 206b may be connected around riser 204. Internal pockets 222a and 222b house lines 220. Representatively, internal pockets 222a and 222b house hydraulic lines, electrical lines, choke and kill lines, pipes, umbilicals, and/or other lines as are needed. Split-half pockets 226a and 226b, defined between sections 206a and 206b, also house lines 220. Lines 220 may further be housed in external pockets 224a and 224b. Although six pockets are illustrated, it is contemplated that any larger or smaller number of internal pockets, split-half pockets and/or external pockets may be provided.

Figure 3:

Referring to Figure 3, a top view of a VIV suppression device is illustrated. In this embodiment, VIV suppression device 314 is a multiple sided VIV suppression device. Multiple sided VIV suppression devices have been found to perform well at lower coverage densities than fairings. Tubular structure 304 may be in a flowing fluid environment with flow of fluid (e.g. sea water) in direction 310, where tubular structure 304 may be subject to vortex induced vibration. Tubular structure 304 is, for example, a drilling riser, a pipe or other offshore structure. Device 314 may be used to suppress the vortex induced vibration of tubular structure 304.

Device 314 has chord 306 and thickness 308, which may vary if device 314 rotates relative to tubular structure 304. Chord 306 is measured parallel to flow direction 310 and thickness 308 is measured perpendicular to flow direction 310. Chord to thickness ratio of device 314 shown in Figure 3 may be less than about 1.5. For example, chord to thickness ratio of device 314 may be less than 1.25, or less than 1.1, for example about 1. Chord to thickness ratio of device 314 shown in Figure 3 may be greater than about 0.6. For example, chord to thickness ratio of device 314 may be greater than 0.75, or greater than 0.9, for example about 1.

Device 314 includes four sides and brace members 322 connected to the sides. Brace members 322 may extend from the sides of device 314 in a direction of tubular structure 304. Brace members 322 may be positioned at any angle with respect to the axis of tubular structure 304. Each of the four sides of the embodiment illustrated may have the same length, three of the sides may have the same length, two of the sides may have the same length or each side may have a different length. The sides may be substantially straight, or may have a slight convex or concave curvature. Each of the sides may have a length from about 0.6 to about 5 times a diameter of tubular structure

304, for example from 0.75 to 4 times, or from 0.9 to 2 times, or from 1 to 1.5 times, or 1.25 times.

The sides may make an angle from about 30 to about 150 degrees with each other, for example from 60 to 120 degrees, or from 75 to 105 degrees, or 90 degrees.

Device 314 may be able to rotate about tubular structure 304 or it may be in a fixed angular orientation. Device 314 may have a collar mounted above and/or below device 314 to secure device 314 at a fixed location along the length of tubular structure 304 and/or to provide a bearing surface for device 314 to rotate.

Device 314 may have two sides aligned substantially parallel with flow 310.

Device 314 may be molded, welded, bent, cast, glued, or otherwise formed with manufacturing techniques as are known in the art. Device 314 may be made of metals such as steel or aluminum, polymers such as polyethylene or polypropylene, or composite materials such as fiberglass or carbon fiber composites, or other conventional materials. In some embodiments, device 314 may be made of plastic or foam material to add minimal weight about tubular structure 304 and/or provide buoyancy to tubular structure 304. In addition, copper, antifouling paint or other antifouling measures (e.g. copper mixed with a material on the inner and/or outer surface of the device or adjacent collars) can be used to mitigate marine growth about device 314.

In the embodiment illustrated in Figure 3, device 314 includes first portion 328 and second portion 330 each having a generally triangular cross-section adapted to conform to a shape of tubular member 304 and brace member 322. Although first portion 328 and second portion 330 are shown having a generally triangular cross-section, it is contemplated that they may have other shapes depending upon how device 314 is split to form portions which can be opened and closed. For example, where device 314 is split perpendicular to a side of device 314, first and second portions having generally rectangular cross-sections may be formed. It is further noted that the shape of first portion 328 and second portion 330 may vary with the overall shape of device 314. In another embodiment, first portion 328 may have a U-shape, with second portion 330 having just a single side to cover the open portion of the U-shaped first portion 328.

Device 314 may include hinge 324 to open and close device 314. Device 314 may further include attachment mechanism 326 to secure first portion 328 to second portion 330 in the closed position. In some embodiments, attachment mechanism 326 may be a clamp, clasp, bolt, serrated latch pin or any other type of attachment mechanism suitable for securing first portion 328 and second portion 330 in a closed position. Hinge 324 and attachment mechanism 326 may be attached to device 314 such that hinge 324 and attachment mechanism 326 are positioned within the space provided in a corner of device 314 when device 314 is in a closed position. In still further embodiments, hinge 324 and attachment mechanism 326 may be exterior to a surface of device 314. Hinge 324 may be positioned at one corner of device 314 and attachment mechanism 326 may be positioned at an opposite corner of device 314. In still further embodiments, hinge 324 may be positioned at one corner of device 314 and attachment mechanism 326 positioned at an adjacent corner of device 314. In another embodiment, hinge 324 may be positioned in the middle of one side of device 314 and attachment mechanism 326 positioned in the middle of an opposite side of device 314.

Hinge 324 allows first portion 328 and second portion 330 of device 314 to pivot about hinge 324 from a closed position to an open position and from an open position to a closed position. In some embodiments, first portion 328 or second portion 330 of device 314 may pivot 270 degrees or less about hinge 324 to the open or closed position. In other embodiments, first portion 328 or second portion 330 may pivot 270 degrees or more about hinge 324. Device 314 is shown in the closed position in Figure 3.

Device 314 may have a variety of shapes. For example, device 314 may be a square, a rectangle, a triangle, a parallelogram, a trapezoid or a diamond shape. Space may be provided in corners of device 314 to accommodate additional components, such as wires, cables, pipes, umbilicals, etc. that are run along the length of tubular 304. Representatively, marine growth protection components such as copper may be positioned within the corners. In other embodiments, hardware (e.g. attachment mechanism 326) may be positioned within the corners. In still further embodiments, buoyancy material (e.g. foam or buoyancy cans) may be attached to corners or other spaces provided in device 314 to provide additional insulation or buoyancy to tubular structure 304.

Buoyancy material may be attached to other portions of device 314 to provide additional insulation or buoyancy to tubular structure 304. In this aspect, device 314 may have sleeve 340 for holding buoyancy material 332. Sleeve 340 separates the sides of device 314 and tubular structure 304. In some embodiments, sleeve 340 may have a cylindrical shape dimensioned to fit around tubular structure 304. In this aspect, sleeve 340 may form a cylindrical channel or chamber within which buoyancy material 332 may be positioned.

In one embodiment, sleeve 340 may be divided into portions corresponding to first and second portions 328 and 330 of device 314 so that sleeve 340 can be opened along with device 314 to fit around tubular structure 304. Sections 332a and 332b of buoyancy material 332 may further be positioned within each portion of sleeve 340. Brace members 322 may connect the sides of device 314 to sleeve 340. Sleeve 340 may be made out of a similar material to that of device 314.

In some embodiments, sleeve 340 may be fitted over a slick joint of tubular structure 304 (e.g. portion of tubular structure 304 without buoyancy material) and allow device 314 to weather vane around tubular structure 304.

Buoyancy material 332 is illustrated in Figure 3 having split-half pockets 334a and 334b for housing lines 336 (e.g. umbilicals). Although not illustrated, it is further contemplated that buoyancy material 332 may have other pockets such as those disclosed in Figure 2 (e.g. internal pockets and external pockets) to hold lines 336. Buoyancy material 332 may be made out of any material suitable for providing buoyancy to tubular structure 304. Representatively, buoyancy material 332 may be made of a plastic or foam material.

Although sleeve 340 is illustrated in Figure 3, it is contemplated that in some embodiments sleeve 340 may be omitted and buoyancy material 332 may be adjacent members 322 or sides of device 314. Representatively, buoyancy material 332 may have a cylindrical inner surface dimensioned to fit around tubular structure 304 and an outer surface dimensioned to be adjacent to brace members 322.

Device 314 having buoyancy material 332 attached thereto may be positioned around tubular structure 304 in place of or in addition to other buoyancy materials (e.g. see buoyancy material 206 of Figure 2) positioned around tubular structure 304. Representatively, in embodiments where sections of buoyancy material are positioned around tubular structure 304, device 314 having buoyancy material 332 may be positioned between or over sections of the buoyancy material.

In some embodiments, device 314 may have a cover or lid over the top and/or bottom of the device to maintain buoyancy 332 within the device.

Figure 4:

Referring now to Figure 4, the VIV suppression device 314 of Figure 3a is illustrated having blade attachments. VIV suppression device 314 is the same as that described in reference to Figure 3 except that blades 402 are attached to device 314 to improve performance and/or to keep the device from rotating too quickly. It is contemplated that the device may rotate too quickly when used on a bare rotating drill pipe. In this aspect, blades 402 are attached to corners of device 314. Blades 402 may be made of the same or a different material as device 314. Blades 402 may have a height (which may be the same as height 124 from Figure 1) similar to that of device 314 such that they extend along the height of the corners of device 314.

Blades 402 may have any shape suitable for attaching to corners of device 314 and increasing the cross-sectional area of device 314. Representatively, in some embodiments, blades 402 may have a triangular cross section. In this aspect, the base portions of blades 402 may be attached to sides of device 314 adjacent the corners. In other embodiments, blades 402 may have a base portion which conforms to the dimensions of device 314 corners and a substantially planar fin portion that extends from a center of the base portion.

Blades 402 may be attached to the corners of device 314 by bolts. In other embodiments, channels for receiving ends of blades 402 may be formed in an outer surface of the sides of device 314 and blades 402 may be slid within the channels to attach blades 402 to device 314. In other embodiments, blades 402 may be welded to the corners of device 314. In other embodiments, blades 402 may be adapted to telescope out from the corners of device 314.

Although four blades 402 are illustrated in Figure 4, it is contemplated that blades may not be attached to each corner of device 314. Representatively, three blades 402 may be attached to three of the corners, two blades 402 may be attached to two of the corners or one blade 402 may be attached to one of the corners.

Blades 402 may extend a distance or height from the corner of device 314 from about 0.25 to about 5 times a diameter of tubular structure 304, for example from 0.5 to 4 times, or from 0.75 to 2 times, or from 0.9 to 1.5 times, or 1 times.

Figure 5:

Figure 5 illustrates a multiple sided VIV suppression device and buoyancy material. VIV suppression device 514 is substantially similar to device 314 described in reference to Figure 3 except that a cross-sectional dimension of buoyancy material 532 is different from that of tubular structure 504.

Device 514 is positioned around tubular structure 504. Tubular structure 504 may be in a flowing fluid environment with flow 510, where tubular structure 504 may be subject to vortex induced vibration. Tubular structure 504 is, for example, a drilling riser, a pipe or other tubular structure. Device 514 may be used to suppress the vortex induced vibration of tubular structure 504.

Device 514 has chord 506 and thickness 508, which may vary if device 514 rotates relative to tubular structure 504. Chord to thickness ratio of device 514 shown in Figure 5 may be less than about 1.5. For example, chord to thickness ratio of device 514 may be less than 1.25, or less than 1.1, for example 1. Chord to thickness ratio of device 514 shown in Figure 5 may be greater than about 0.6. For example, chord to thickness ratio of device 314 may be greater than 0.75, or greater than 0.9, for example 1.

Device 514 includes four sides and brace members 522 connected to the sides. Brace members 522 may extend from the sides of device 514 to tubular structure 504 or to sleeve 540. Brace members 522 may be positioned at any angle with respect to the axis of tubular structure 504. All of the sides may have the same length, three of the sides may have the same length, two of the sides may have the same length or each side may have a different length. The sides may be substantially straight, or may have a slight convex or concave curvature. Each of the sides may have a length from about

0.5 to about 4 times a diameter of tubular structure 304, for example from 0.6 to 3 times, or from 0.75 to 2 times, or from 1 to 1.5 times, or 1.25 times.

The sides may make an angle from about 30 to about 150 degrees with each other, for example from 60 to 120 degrees, or from 75 to 105 degrees, or 90 degrees.

Device 514 may be able to rotate about tubular structure 504 or it may be in a fixed angular orientation. Device 514 may have a collar mounted above and/or below device 514 to secure device 514 at a fixed location along the length of tubular structure 504 and/or to provide a bearing surface for device 514 to rotate.

Device 514 may have two sides aligned substantially parallel with flow 510.

Device 514 may be molded, welded, bent, cast, glued, or otherwise formed with manufacturing techniques as are known in the art. Device 514 may be made of metals such as steel or aluminum, polymers such as polyethylene or polypropylene, or composite materials such as fiberglass or carbon fiber composites, or other conventional materials. In some embodiments, device 514 may be made of a buoyant material such as plastic or foam. In addition, copper, antifouling paint or other antifouling measures (e.g. copper mixed with a material on the inner and/or outer surface of the device or adjacent collars) can be used to mitigate marine growth about device 514.

In the embodiment illustrated in Figure 5, device 514 includes first portion 528 and second portion 530 each having a generally triangular cross-section. Device 514 may include hinge 524 to open and close device 514. Device 514 may further include attachment mechanism 526 to secure first portion 528 to second portion 530 in the closed position. In some embodiments, attachment mechanism 526 may be a clamp, clasp, bolt, serrated latch pin or any other type of attachment mechanism suitable for securing first portion 528 and second portion 530 in a closed position. Hinge 524 and attachment mechanism 526 may be attached to device 514 such that hinge 524 and attachment mechanism 526 are positioned within the space provided in a corner of device 514 when device 514 is in a closed position. In still further embodiments, hinge 524 and attachment mechanism 526 may be exterior to a surface of device 514. Hinge 524 may be positioned at one corner of device 514 and attachment mechanism 526 may be positioned at an opposite corner of device 514. In still further embodiments, hinge 524 may be positioned at one corner of device 514 and attachment mechanism 526 positioned at an adjacent corner of device 514.

Hinge 524 allows first portion 528 and second portion 530 of device 514 to pivot about hinge 524 from a closed position to an open position and from an open position to a closed position. Device 514 is shown in the closed position in Figure 5.

Device 514 may have a variety of shapes. For example, device 514 may be a square, a rectangle, a triangle, a parallelogram, a trapezoid or a diamond shape. Space may be provided in corners of device 514 to accommodate additional components. Representatively, marine growth protection components such as copper may be positioned within the corners. In other embodiments, hardware (e.g. attachment mechanism 526) may be positioned within the corners. In still further embodiments, buoyancy material (e.g. foam) may be attached to corners or other spaces provided in device 514 to provide additional insulation or buoyancy to tubular structure 504.

Buoyancy material 532 may also be attached to other portions of device 514 to provide additional insulation or buoyancy to tubular structure 504. In this aspect, device 514 may have a sleeve 540 for holding buoyancy material 532. Sleeve 540 may have any shape dimensioned to fit around tubular structure 504 and any lines 536 (umbilicals, choke lines, kill lines, etc.) running along tubular structure 504. Representatively, sleeve 540 may have a substantially square cross-section as shown in Figure 5. Lines 536 may be positioned between corners of sleeve 540 and an outer surface of tubular structure 504. Although square and cylindrical shaped sleeves have been discussed herein, it is contemplated that sleeve 540 may have any shape suitable for fitting around tubular structure 504 and any lines 536 running along tubular structure 504. For example, other suitable shapes may include that of an ellipse, a rectangle, a triangle, a parallelogram, a trapezoid or a diamond shape.

Sleeve 540 may form a channel or chamber within which buoyancy material 532 may be positioned. Sleeve 540 may be divided into portions corresponding to first and second portions 528 and 530 of device 514 so that sleeve 540 can be opened along with device 514 to fit around tubular structure 504. Sections 532a and 532b of buoyancy material 532 may further be positioned within each portion of sleeve 540.

Brace members 522 may connect the sides of device 514 to sleeve 540. Sleeve 540 may be made out of a similar material as device 514.

In some embodiments, sleeve 540 may be fitted over a slick joint of tubular structure 504 (e.g. portion of tubular structure 504 without buoyancy material) and allow device 514 to weather vane around tubular structure 504. It is noted that device 514 need only rotate about 45 degrees to properly line up with the current and suppress VIV. Accordingly, the effectiveness of device 514 will not be diminished if rotation of device 514 about tubular structure 504 is partially impeded by, for example, lines 536.

Although not illustrated, it is further contemplated that buoyancy material 532 may have pockets such as those disclosed in Figure 2 (e.g. half-split pockets, internal pockets and external pockets) to hold lines 536.

Although sleeve 540 is illustrated in Figure 5, it is contemplated that in some embodiments sleeve 540 may be omitted and buoyancy material 532 may be attached directly to brace members 522 of device 514. Representatively, buoyancy material 532 may have an inner surface dimensioned to fit around tubular structure 504 and lines 536 and an outer surface dimensioned to connect to brace members 522. Device 514 may have a top or lid between tubular 504 and sleeve 540 to keep buoyancy from floating away.

Device 514 having buoyancy material 532 attached thereto may be positioned around tubular structure 504 in place of or in addition to other buoyancy materials (e.g. see material 206 of Figure 2) positioned around tubular structure 504. Representatively, in embodiments where sections of buoyancy material are positioned around tubular structure 504, device 514 having buoyancy material 532 may be positioned between or over sections of the buoyancy material.

<u>Figure 6:</u>

Figure 6 illustrates a VIV suppression device having blades. Device 614 is shown installed about tubular structure 604. Tubular structure 604 may be in a flowing fluid environment where structure 614 may be subject to vortex induced vibration. Device 614 may be used to suppress the vortex induced vibration of tubular structure 604.

Body 606 of device 614 is substantially cylindrical. Blades 610 are positioned parallel to a length dimension of body 606 and extend outward from body 606. Although four blades 610 are illustrated in Figure 6, it is contemplated that any number of blades suitable for suppressing VIV of tubular structure 604 may be used, for example from 1 to 10, 2 to 8, 3 to 6, or 4 to 5 blades. All of blades 610 may extend the same distance from body 606, some may extend the same distance or they may extend different distances from body 606. Blades 610 may be substantially straight. Each of blades may extend a distance from body 606 of, for example, 0.25 to about 5 times a diameter of tubular structure 604.

Blades 610 may extend a distance or height from the outside wall of device 614 from about 0.1 to about 10 times a diameter of tubular structure 604, for example from 0.25 to 5 times, or from 0.5 to 3 times, or from 0.75 to 1.5 times, or 1 times.

In some embodiments, blades 610 are integrally formed with body 606. In other embodiments, blades 610 may be installed about body 606 by inserting them into rings positioned adjacent body 606 that have receptacles for receiving blades 610. The rings may or may not be temporarily locked to tubular structure 604 or adjacent collars during installation.

Device 614 may be able to rotate about tubular structure 604 or it may be in a fixed angular orientation. Device 614 may have a collar mounted above and/or below device 614 to secure device 614 at a fixed location along the length of tubular structure 604 and/or to provide a bearing surface for device 614 to rotate.

Device 614 may be molded, welded, bent, cast, glued, or otherwise formed with manufacturing techniques as are known in the art. Device 614 may be made of metals such as steel or aluminum, polymers such as polyethylene or poly propylene, or composite materials such as fiberglass or carbon fiber composites, or other conventional materials including plastic or foam. In addition, copper, antifouling paint or other antifouling measures (e.g. copper mixed with a material on the inner and/or outer surface of the device or adjacent collars) can be used to mitigate marine growth about device 614.

Device 614 may include hinge 624 to open and close device 614. Device 614 may further include attachment mechanism 626 to secure first portion 628 to second portion 630 in the closed position. In some embodiments, attachment mechanism 626 may be a clamp, clasp, bolt, serrated latch pin or any other type of attachment mechanism suitable for securing first portion 628 and second portion 630 in a closed position. Hinge 624 and attachment mechanism 626 may be attached to device 614 such that hinge 624 and attachment mechanism 626 are positioned substantially between device 614 and tubular structure 604 in a closed position. Alternatively, hinge 624 and attachment mechanism 626 may be positioned exterior to a surface of device 614. Device 614 is shown in the closed position in Figure 6.

Although device 614 is illustrated having hinge 624, it is further contemplated that hinge 624 may be omitted and device 614 may include two separable portions 628 and 630. In this aspect, an additional attachment mechanism may be provided to facilitate attachment of first portion 628 to second portion 630.

In addition, although braces extending from device 614 to tubular structure 604 are not illustrated in Figure 6, it is contemplated that braces similar to those previously discussed may be included to help support device 614 about tubular structure 604.

Buoyancy material may further be attached to device 614 to provide additional insulation or buoyancy to tubular structure 604. In this aspect, device 614 may have a sleeve 640 for holding buoyancy material 632. In some embodiments, sleeve 640 may have a cylindrical shape dimensioned to fit around tubular structure 604. In other embodiments, sleeve 640 may have any shape dimensioned to fit around tubular structure 604 and any lines 636 (umbilicals, choke lines, kill lines, etc.) running along tubular structure 604. Half-split pockets 634a and 634b may be formed in buoyancy material 632 to hold lines 636. Although not shown, it is contemplated that other types of pockets (e.g. internal pockets and external pockets) may be included in buoyancy material 632 to hold lines 636.

Sleeve 640 may form a channel or chamber within which buoyancy material 632 may be positioned. Sleeve 640 may be divided into sections corresponding to first and second portions 628 and 630 of device 614 so that sleeve 640 can be opened along with device 614 to fit around tubular structure 604. Sections 632a and 632b of buoyancy material 632 may further be positioned within each portion of sleeve 640. Brace members such as those previously discussed may connect the sides of device

614 to sleeve 640. Alternatively, sleeve 640 may be attached directly to body 606 of device 614. Sleeve 640 may be made out of a similar material to that of device 614.

In some embodiments, sleeve 640 may be fitted over a slick joint of tubular structure 604 (e.g. portion of tubular structure 604 without buoyancy material) and allow device 614 to weather vane around tubular structure 604.

Although sleeve 640 is illustrated in Figure 6, it is contemplated that in some embodiments sleeve 640 may be omitted and buoyancy material 632 may be attached directly to body 606 of device 614.

Device 614 having buoyancy material 632 attached thereto may be positioned around tubular structure 604 in place of or in addition to other buoyancy materials (e.g. see material 206 of Figure 2) positioned around tubular structure 604. Representatively, in embodiments where sections of buoyancy material are positioned around tubular structure 604, device 614 having buoyancy material 632 may be positioned between or over sections of the buoyancy material.

Device 614 may have a cover on the top and/or bottom between structure 604 and sleeve 640 to retain buoyancy.

In some embodiments, blades 610 are substantially aligned with a longitudinal axis of structure 604, for example blades 610 may make an angle with the longitudinal axis of structure 604 of less than 10 degrees, less than 5 degrees, less than 1 degree, or about 0 degrees.

In some embodiments, blades 610 are hinged at their base adjacent body 606, and moveable from a retracted position (not shown) to an extended position as shown in Figure 6 by rotating the blades 610 about the hinge. In some embodiments, blades 610 are collapsible.

In some embodiments, device 614 acts to suppress VIV of structure 604 and add buoyancy to structure 604, with the use of buoyancy material 632.

Figure 7:

Figure 7 illustrates a perspective view of a multiple sided VIV suppression device attached to a tubular structure structure. VIV suppression device 714 is shown in a closed position around tubular structure 704. VIV suppression device 714 is formed by first portion 728 and second portion 730. In this embodiment, first portion 728 and second portion 730 are sealed halves which define chambers 736 and 738, respectively, therein. Buoyant substances, such as air, other gases, and/or foam, are sealed within chambers 736 and 738 to provide buoyancy to tubular structure 704.

Channels 732 and 734 are formed along adjoining surfaces of first portion 728 and second portion 730, respectively. Channels 732 and 734 are dimensioned to accommodate tubular structure 704 when first portion 728 and second portion 730 are closed together. Representatively, channels 732 and 734 are half cylinders such that when first portion 728 and second portion 730 are joined together they form a cylindrical opening through which tubular structure 704 passes. Although a cylindrical opening is illustrated in Figure 7, it is further contemplated that the opening may have any dimension suitable for receiving tubular structure 704 therein. The opening may further be dimensioned to fit around tubular structure 704 having lines (e.g. umbilicals) extending along its surface. For example, the opening may have a square shaped cross-section or any of the other shapes previously discussed. In some embodiments, the lines may extend through device 714. For example, device 714 may include additional channels formed through it parallel to channels 732 and 734 to receive lines extending along tubular structure 704.

Device 714 may have a variety of shapes. For example, a cross-section of device 714 may have a square, a rectangle, a triangle, a parallelogram, a trapezoid or a diamond shape. Device 714 may further have a cylindrical shape with blades.

First portion 728 and second portion 730 may be attached along one side by hinge 724. In this aspect, first portion 728 and second portion 730 are able to rotate between open and closed positions. Hinge 724 is substantially similar to those which have been previously discussed. Attachment mechanism 726 similar to those previously discussed may further be provided to attach first portion 728 and second portion 730 together when in the closed position.

Device 714 may be able to rotate about tubular structure 704 or it may be in a fixed angular orientation. Device 714 may have a collar mounted above and/or below device 714 to secure device 714 at a fixed location along the length of tubular structure 704 and/or to provide a bearing surface for device 714 to rotate.

Device 714 may be molded, welded, bent, cast, glued, or otherwise formed with manufacturing techniques as are known in the art. Device 714 may be made of metals such as steel or aluminum, polymers such as polyethylene or poly propylene, or composite materials such as fiberglass or carbon fiber composites, or other conventional materials including plastic or foam. In addition, copper, antifouling paint or other antifouling measures (e.g. copper mixed with a material on the inner and/or outer surface of the device or adjacent collars) can be used to mitigate marine growth about device 714.

Figure 8:

Figure 8 illustrates a VIV suppression device and buoyancy material positioned around a tubular structure. In this embodiment, sections of buoyancy material 802 substantially similar to buoyancy material 206 of Figure 2 are shown positioned around tubular structure 804. VIV suppression devices 814 are further shown positioned around tubular structure 804 between sections of buoyancy material 802. In this aspect, VIV suppression devices 814 may be used in place of or in addition to sections of buoyancy material 802. Although VIV suppression devices 814 are positioned between sections of buoyancy material 802, it is further contemplated that they may be positioned over buoyancy material 802. VIV suppression devices 814 may be the same as any of the previously disclosed VIV suppression devices. Although not shown, collars such as thrust collars may be positioned between VIV suppression devices 814 and buoyancy material 802 to keep devices 814 from sliding along a length of tubular structure 304. Alternatively, collars may be omitted and the axial position of VIV suppression devices 814 may be maintained by buoyancy material 802 positioned between devices 814.

Figures 9a & 9b

Referring now to Figures 9a and 9b, structure 904 is illustrated surrounded by buoyancy 932. Within buoyancy 932 there is provided opening 912. Opening 912 has blade 910 within it. Blade 910 is attached to tubular 904 and/or buoyancy 932 by biasing device 914, such as a spring or piston. As shown in Figure 9a, blade 910 is in a retracted position, and as shown in Figure 9b, blade 910 is in an extended position.

In a first embodiment, biasing device 914 is in tension holding blade 910 in the retracted position within opening 912. At a desired time and/or water depth, a human diver, ROV, and/or biasing device 914 may be used to pull or push blade 910 into the extended position. Blade 910 may be held in the extended position with the use of lock 918, which could be a locking pin, a clamp, a wedge, or other locking members as are known in the art.

In another embodiment, biasing device 914 is in compression pushing blade 910 out of the retracted position within opening 912. Lock 916 is used to overcome compression force and keep blade 910 contained within opening 912. At a desired time and/or water depth, a human diver, ROV, and/or other device may be used to disable lock 916, and allow biasing device 914 to push blade 910 into the extended position. Blade 910 may be held in the extended position with the use of lock 918, which could be a locking pin, a clamp, a wedge, or other locking members as are known in the art. Lock 916 could be a locking pin, a sleeve which slides over opening 912, hooks, bolts, or other locking members as are known in the art.

Although only one opening 912 and blade 910 are illustrated, it is contemplated that from 1 to 8, for example from about 2 to about 6, about 3 to about 5, or about 4 blades may be used about the circumference of structure 904.

<u>Figures 10a & 10b</u>

Referring now to Figures 10a and 10b, structure 1004 is illustrated surrounded by VIV suppression and buoyancy device 1002. Device 1002 includes inner shell 1040 and outer shell 1030 connected by braces 1022. Between inner shell 1040 and outer shell 1030 is buoyancy 1032. Within outer shell 1030 and buoyancy 1032 there is provided opening 1012. Opening 1012 has blade 1010 within it. Blade 1010 is attached to inner shell 1040 and/or buoyancy 1032 by biasing device 1014, such as a spring or piston. As shown in Figures 10a and 10b, blade 1010 is in an extended position. Openings are also provided within buoyancy 1032 for lines 1036.

In a first embodiment, biasing device 1014 is in tension holding blade 1010 in a retracted position within opening 1012. At a desired time and/or water depth, a human diver, ROV, and/or biasing device 1014 may be used to pull or push blade 1010 into the extended position. Blade 1010 may be held in the extended position with the use of locking pin 1018, or could also be held in place with other devices such as a clamp, a wedge, or other locking members as are known in the art.

In another embodiment, biasing device 1014 is in compression pushing blade 1010 out of the retracted position within opening 1012. A lock (not shown) may be used to overcome compression force and keep blade 1010 contained within opening 1012. At a desired time and/or water depth, a human diver, ROV, and/or other device may be used to disable lock 1016, and allow biasing device 1014 to push blade 1010 into the extended position. Blade 1010 may be held in the extended position with the use of locking pin 1018, or a clamp, a wedge, or other locking members as are known in the art. Other locks could be a sleeve which slides over opening 1012, hooks, bolts, or other locking members as are known in the art.

Although only one opening 1012 and blade 1010 are illustrated, it is contemplated that from 1 to 8, for example from about 2 to about 6, about 3 to about 5, or about 4 blades may be used about the circumference of structure 1004.

<u>Alternative Embodiments:</u>

When the devices disclosed herein are to be installed around an umbilical or a structure with sensitive coating, one or more inner rings or friction pads may be installed between the device and the structure to prevent damage to the sensitive coating.

The VIV suppression devices disclosed herein may be attached to the underlying tubular structure prior to installation of the tubular structure or by retrofitting with a diver or remotely operated vehicle (ROV). Representatively, prior to running the tubular structure down to the sea floor, the VIV devices may be placed in an open configuration, positioned adjacent the tubular structure and then closed around the tubular structure. The tubular structure may then be lowered down through the water to the sea floor. For retrofit installation, the VIV device in an open configuration may be lowered down to the desired region of the tubular structure by a diver, ROV, winch line or other suitable mechanism. Once at the desired position, the diver or ROV may be used to close the VIV device around the tubular structure.

Suitable sleeves, suitable collars, and suitable devices to install exterior to structures, and methods of their installation are disclosed in U.S. Patent Application Publication Number 2006/0021560, having attorney docket number TH1433; U.S.

Patent Number 7,406,923, having attorney docket number TH0541; U.S. Patent Application Publication Number 2006/0280559, having attorney docket number TH2508; U.S. Patent Application Publication Number 2007/0003372, having attorney docket number TH2876; U.S. Patent Application Publication Number 2009/0242207, having attorney docket number TH2969; U.S. Patent Application Number 12/305,212, having attorney docket number TH1500; U.S. Patent Application Number 12/515,911, having attorney docket number TH3112; U.S. Patent Application Number 12/515,922, having attorney docket number TH3190; U.S. Patent Number 5,410,979; U.S. Patent Number 5,410,979; U.S. Patent Number 5,421,413; U.S. Patent Number 6,179,524; U.S. Patent Number 6,223,672; U.S. Patent Number 6,561,734; U.S. Patent Number 6,565,287; U.S. Patent Number 6,571,878; U.S. Patent Number 6,685,394; U.S. Patent Number 6,702,026; U.S. Patent Number 7,017,666; and U.S. Patent Number 7,070,361, which are herein incorporated by reference in their entirety.

Suitable methods for installing fairings, collars, and other devices to install exterior to structures, are disclosed in U.S. Patent 7,578,038, having attorney docket number TH1853.04; U.S. Patent Application Publication Number 2005/0254903, having attorney docket number TH2463; U.S. Patent Application Publication Number 2008/0056828, having attorney docket number TH2900; U.S. Patent Application Publication Number 2007/0125546, having attorney docket number TH2926; U.S. Patent Application Publication Number 2007/0140797, having attorney docket number TH2875; U.S. Patent Application Publication Number 2010/0014922, having attorney docket number TH2879; U.S. Patent Application Number 12/442,015, having attorney docket number TH2842; U.S. Patent Number 6,695,539; U.S. Patent Number 6,928,709; and U.S. Patent Number 6,994,492; which are herein incorporated by reference in their entirety.

Further devices are disclosed in OTC paper number 19881, which is herein incorporated by reference in its entirety.

<u>Illustrative Embodiments:</u>

In one embodiment, there is disclosed a system for reducing drag and/or vortex induced vibration of a structure, the system comprising a multiple sided device comprising from 4 to 6 sides; and at least one blade located extending from the multiple sided device. In some embodiments, the device comprises a chord to thickness ratio of less than 1.5, for example less than 1.25. In some embodiments, the at least one blade is substantially aligned along a longitudinal axis of the structure. In some embodiments, the device is installed about the structure. In some embodiments, the device comprises a height from 0.5 to 10 times a diameter of the structure. In some embodiments, the at least one blade extends from an intersection of two of the sides. In some embodiments, the number of blades equals the number of sides of the device. In some embodiments, the blade is extendable from a first retracted position within the device to a second extended position extended outwardly from the device. In some embodiments, the system also includes a plurality of multiple sided devices along a length of the structure.

In another embodiment, there is disclosed a system for reducing drag and/or vortex induced vibration of a structure, the system comprising a structure defining an interior of the system; a layer of buoyancy material exterior to the structure; the layer of buoyancy material comprising an opening along a longitudinal axis of the structure; a fin disposed within the opening; the fin moveable from a first retracted position within the layer, to a second extended position extending exterior to the layer. In some embodiments, the fin comprises a height from about 5% to about 200% of a diameter of the structure. In some embodiments, the device comprises a length along the longitudinal axis of the structure from 0.5 to 10 times a diameter of the structure. In some embodiments, the device comprises 4 fins located within 4 openings. In some embodiments, the device comprises an even number of fins. In some embodiments, the system also includes a biasing device connected to the fin and to at least one of the buoyancy material and the structure.

In one embodiment, there is disclosed a method for modifying a structure subject to drag and/or vortex induced vibration, said method comprising positioning at least one multiple sided device around the structure, the multiple sided device comprising from 4 to 6 sides, and at least one blade extending from the device. In some embodiments, the positioning comprises positioning at least two multiple sided devices about the structure. In some embodiments, the method also includes positioning a collar, a buoyancy module, and/or a clamp around the structure. In some embodiments, the device comprises a four sided shape. In some embodiments, the method also includes locking the device at a preferred angular orientation based on ambient expected currents acting on the structure. In some embodiments, the method also includes extending the blade from a retracted position to an extended position.

While the devices have been described as being used in aquatic environments, they may also be used for VIV and/or drag reduction on elongated structures in atmospheric environments.

While the illustrative embodiments of the invention have been described with particularity, it will be understood that various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the spirit and scope of the invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the examples and descriptions set forth herein but rather that the claims be construed as encompassing all the features of patentable novelty which reside in the invention, including all features which would be treated as equivalents thereof by those skilled in the art to which this invention pertains.

# CLAIMS

1. A system for reducing drag and/or vortex induced vibration of a structure, the system comprising:

    a multiple sided device comprising from 4 to 6 sides; and

    at least one blade located extending from the multiple sided device.

2. The system of claim 1, wherein the device comprises a chord to thickness ratio of less than 1.5, for example less than 1.25.

3. The system of one or more of claims 1-2, wherein the at least one blade is substantially aligned along a longitudinal axis of the structure.

4. The system of one or more of claims 1-3, wherein the device is installed about the structure.

5. The system of one or more of claims 1-4, wherein the device comprises a height from 0.5 to 10 times a diameter of the structure.

6. The system of one or more of claims 1-5, wherein the at least one blade extends from an intersection of two of the sides.

7. The system of one or more of claims 1-6, wherein the number of blades equals the number of sides of the device.

8. The system of one or more of claims 1-7, wherein the blade is extendable from a first retracted position within the device to a second extended position extended outwardly from the device.

9. The system of one or more of claims 1-8, further comprising a plurality of multiple sided devices along a length of the structure.

10. A method for modifying a structure subject to drag and/or vortex induced vibration, said method comprising:

positioning at least one multiple sided device around the structure, the multiple sided device comprising from 4 to 6 sides, and at least one blade extending from the device.

11. The method of claim 10, wherein the positioning comprises positioning at least two multiple sided devices about the structure.

12. The method of one or more of claims 10-11, further comprising:

positioning a collar, a buoyancy module, and/or a clamp around the structure.

13. The method of one or more of claims 10-12, wherein the device comprises a four sided shape.

14. The method of one or more of claims 10-13, further comprising:

locking the device at a preferred angular orientation based on ambient expected currents acting on the structure.

15. The method of one or more of claims 10-14, further comprising:

extending the blade from a retracted position to an extended position.

16. A system for reducing drag and/or vortex induced vibration of a structure, the system comprising:

a structure defining an interior of the system;

a layer of buoyancy material exterior to the structure; the layer of buoyancy material comprising an opening along a longitudinal axis of the structure;

a fin disposed within the opening; the fin moveable from a first retracted position within the layer, to a second extended position extending exterior to the layer.

17. The system of claim 16, wherein the fin comprises a height from about 5% to about 200% of a diameter of the structure.

18. The system of one or more of claims 16-17, wherein the device comprises a length along the longitudinal axis of the structure from 0.5 to 10 times a diameter of the structure.

19. The system of one or more of claims 16-18, wherein the device comprises 4 fins located within 4 openings.

20. The system of one or more of claims 16-19, wherein the device comprises an even number of fins.

21. The system of one or more of claims 16-20, further comprising a biasing device connected to the fin and to at least one of the buoyancy material and the structure.

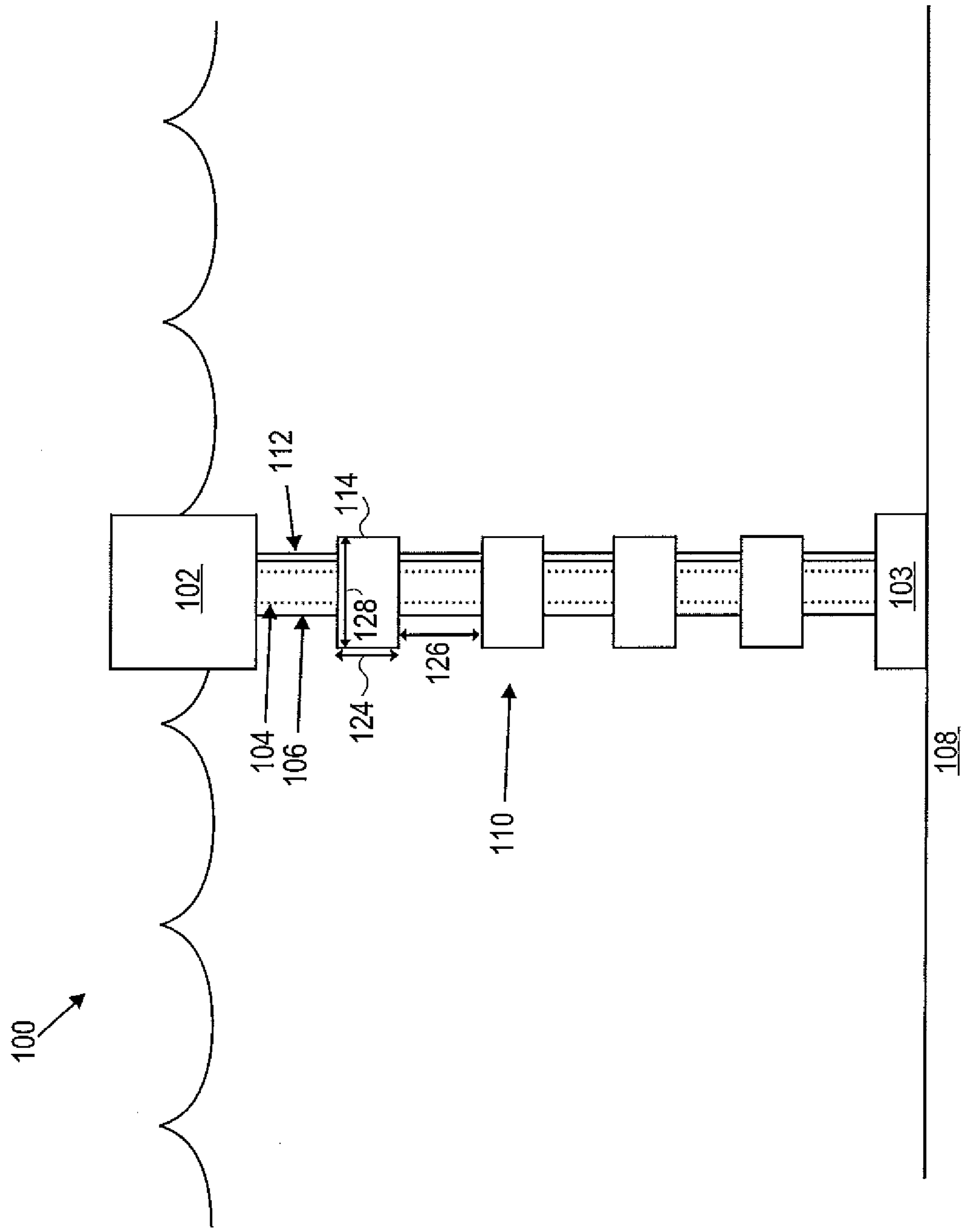


FIG. 1

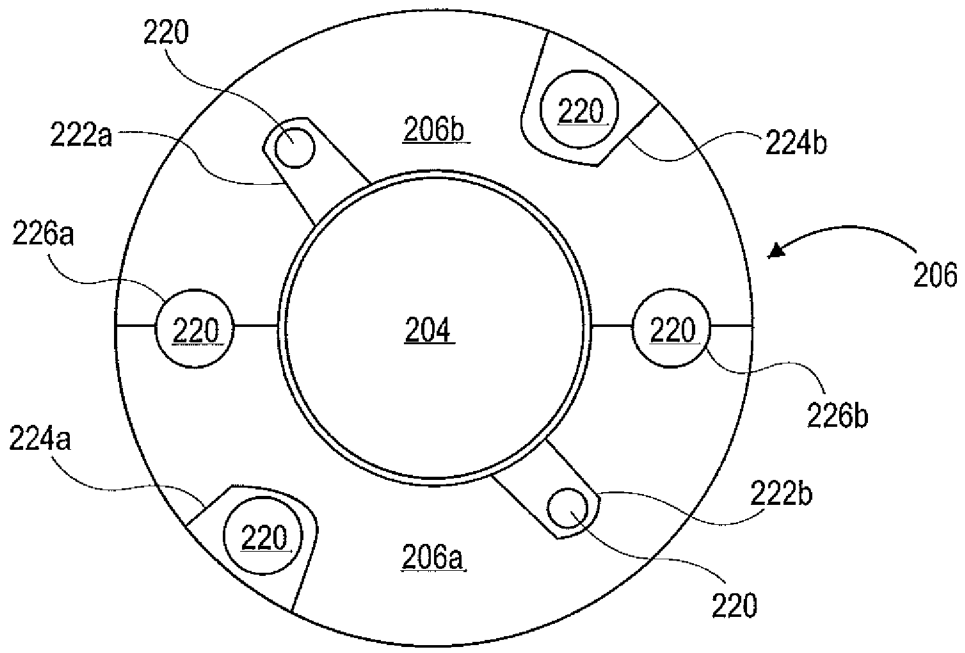
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FIG. 2

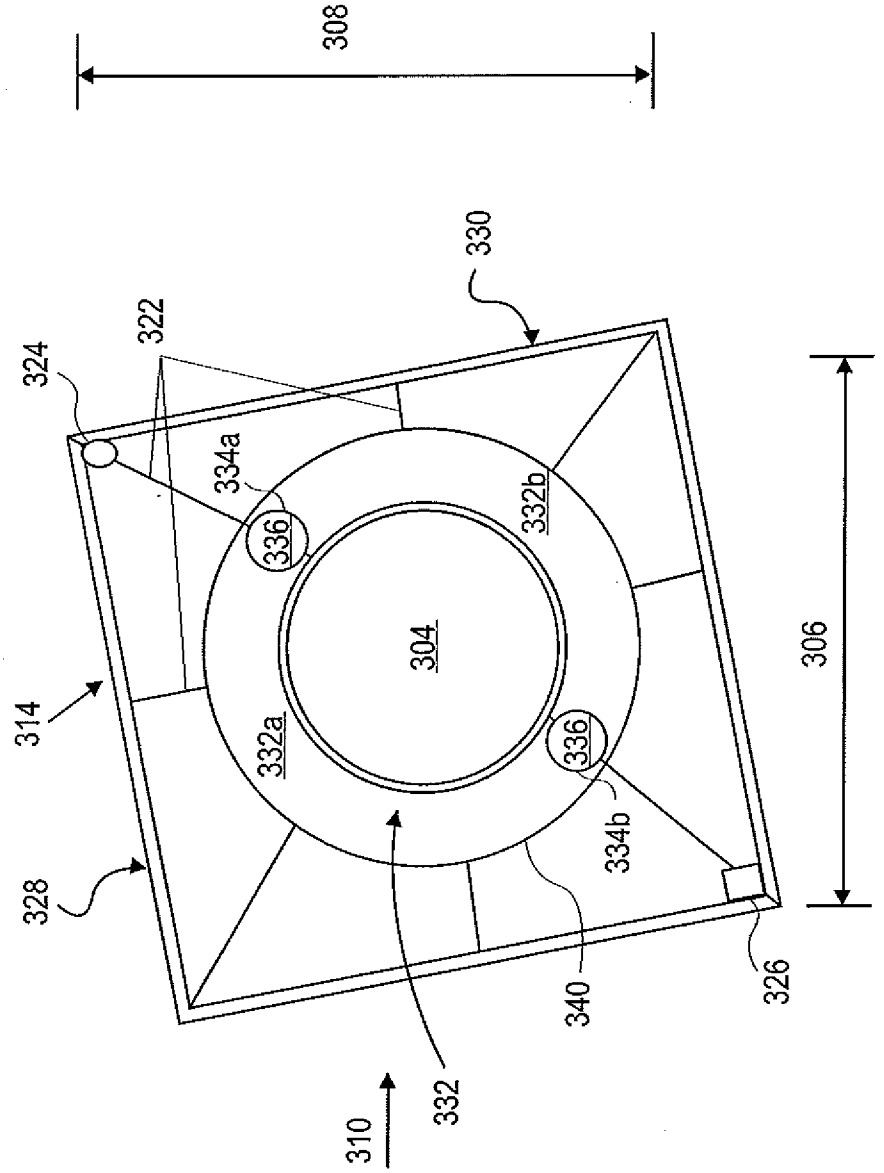
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FIG. 3

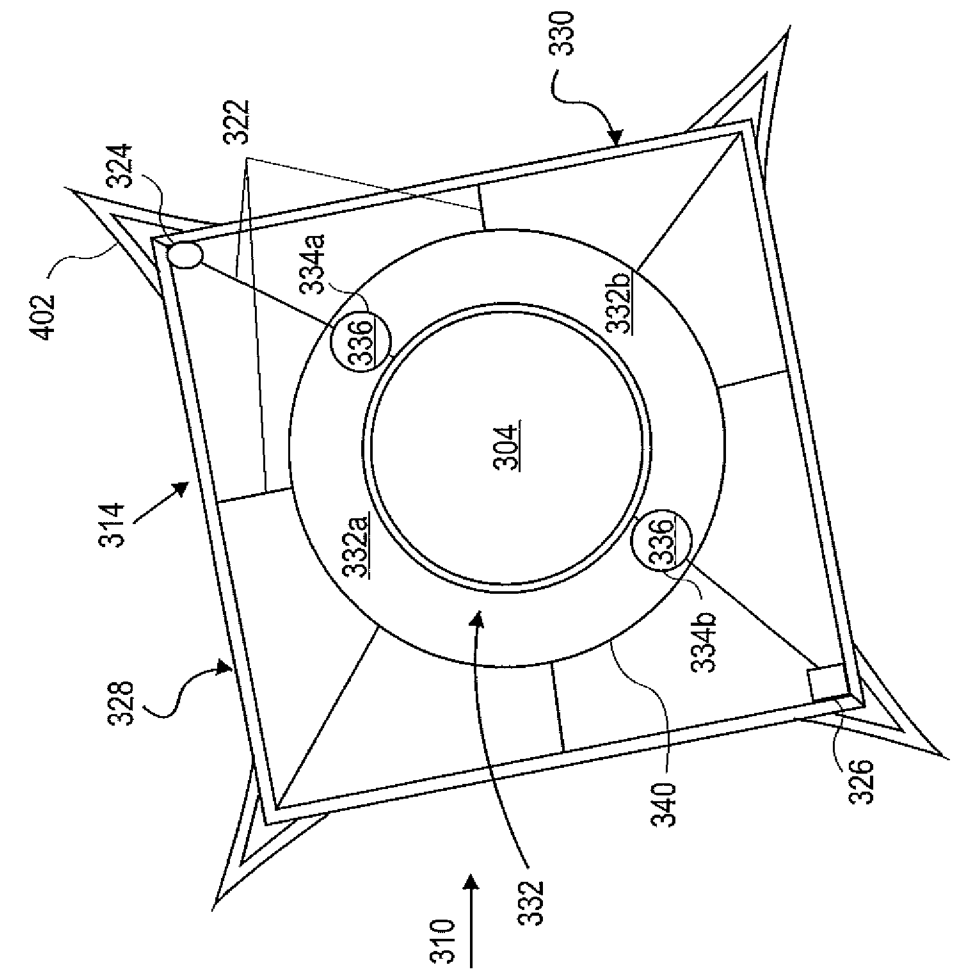
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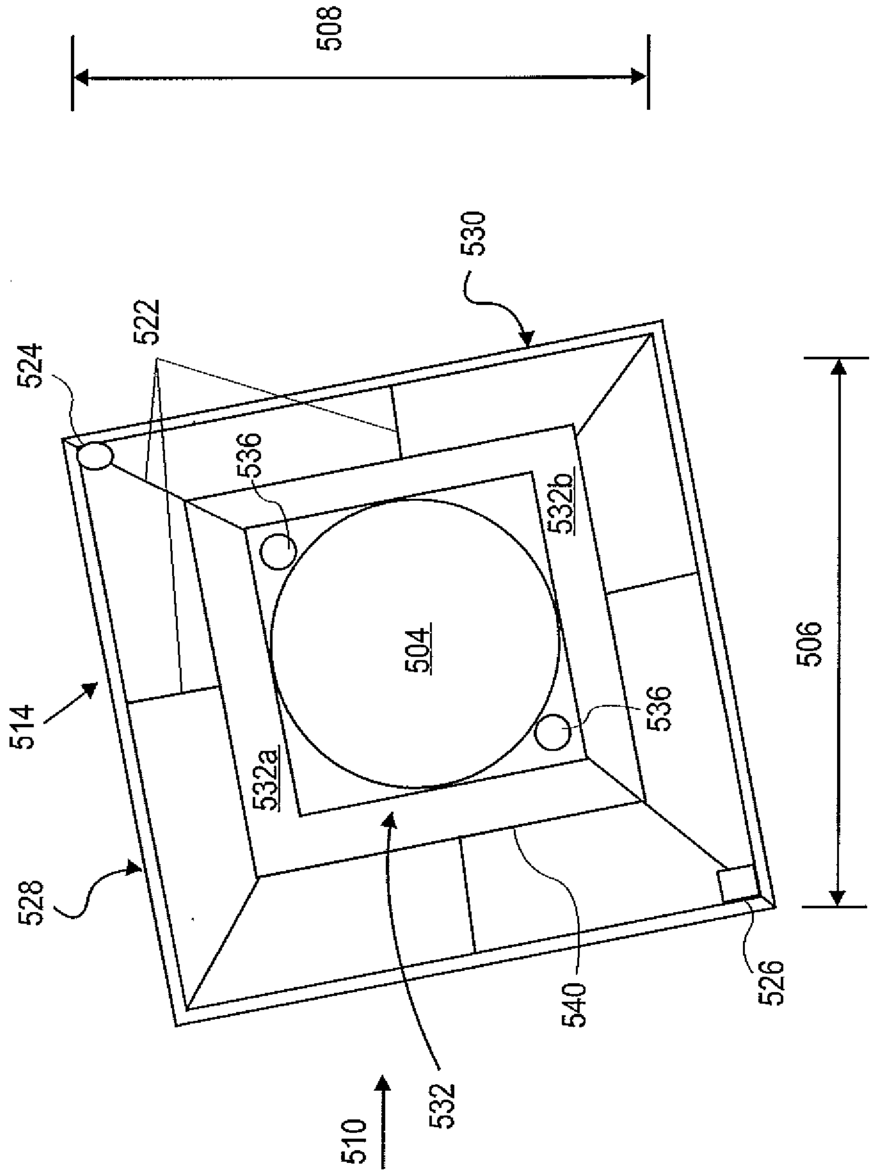
FIG. 4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532a
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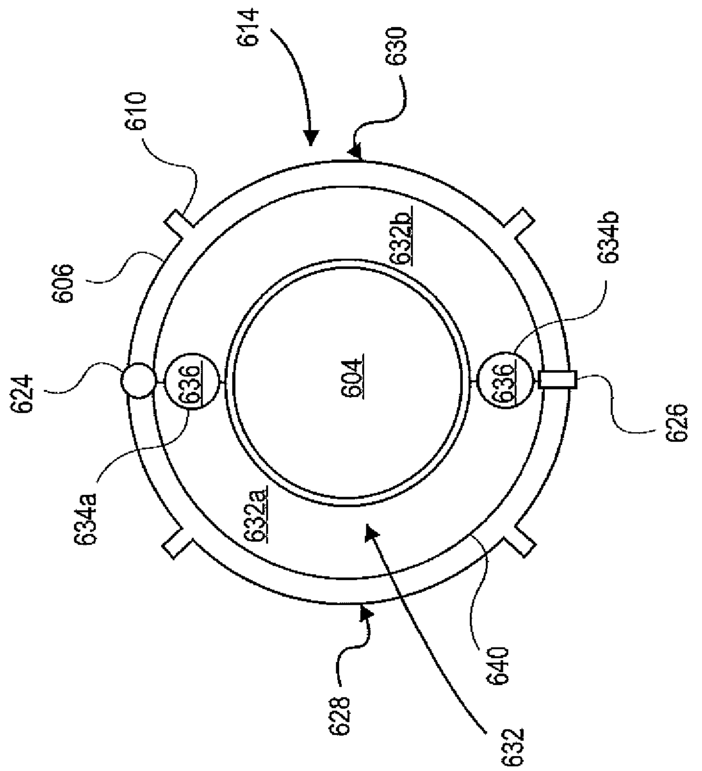
532
510

FIG. 5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632b
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636
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634a
632a
640
628
632

FIG. 6

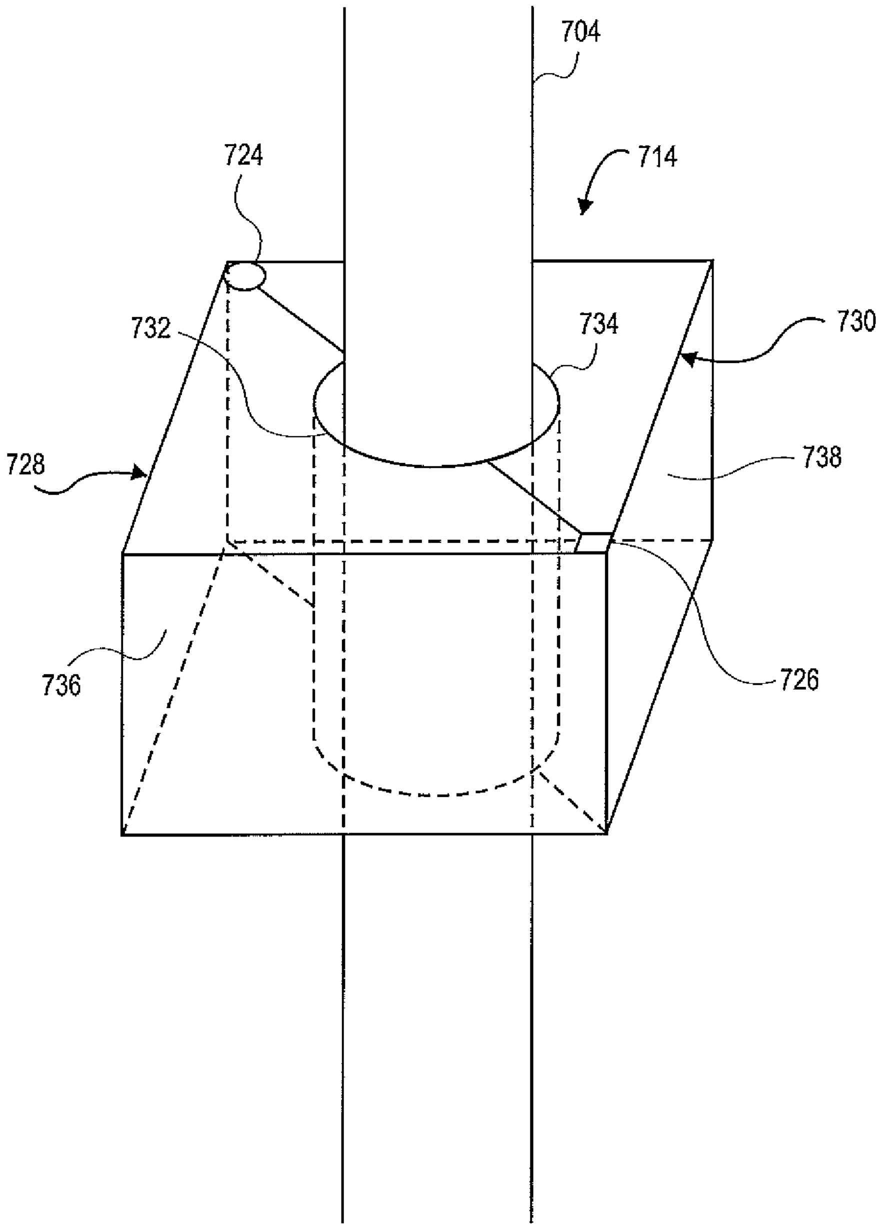


FIG. 7

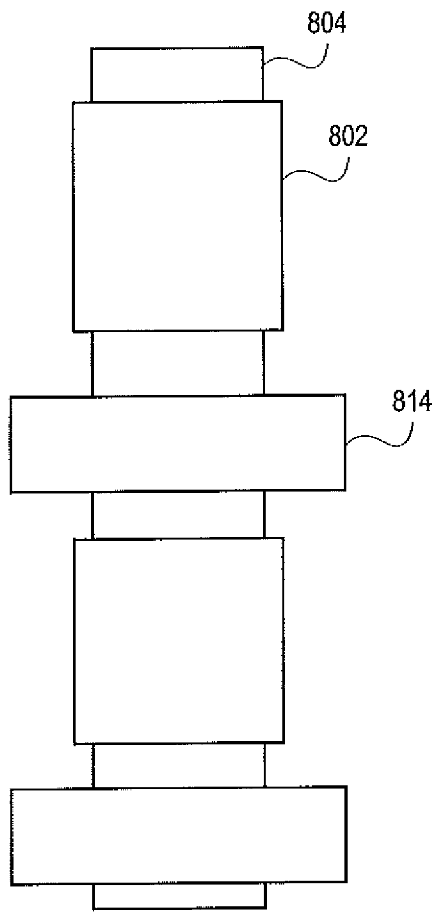


FIG. 8

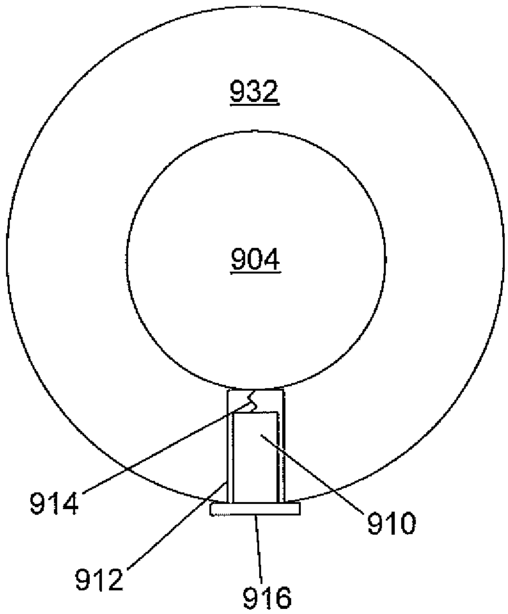


FIG. 9A

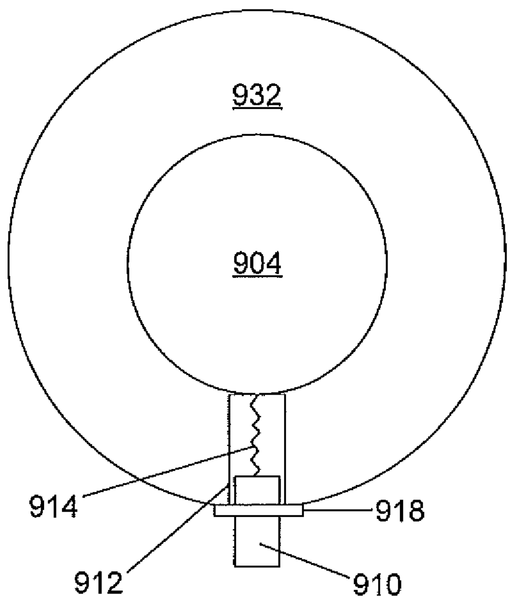


FIG. 9B

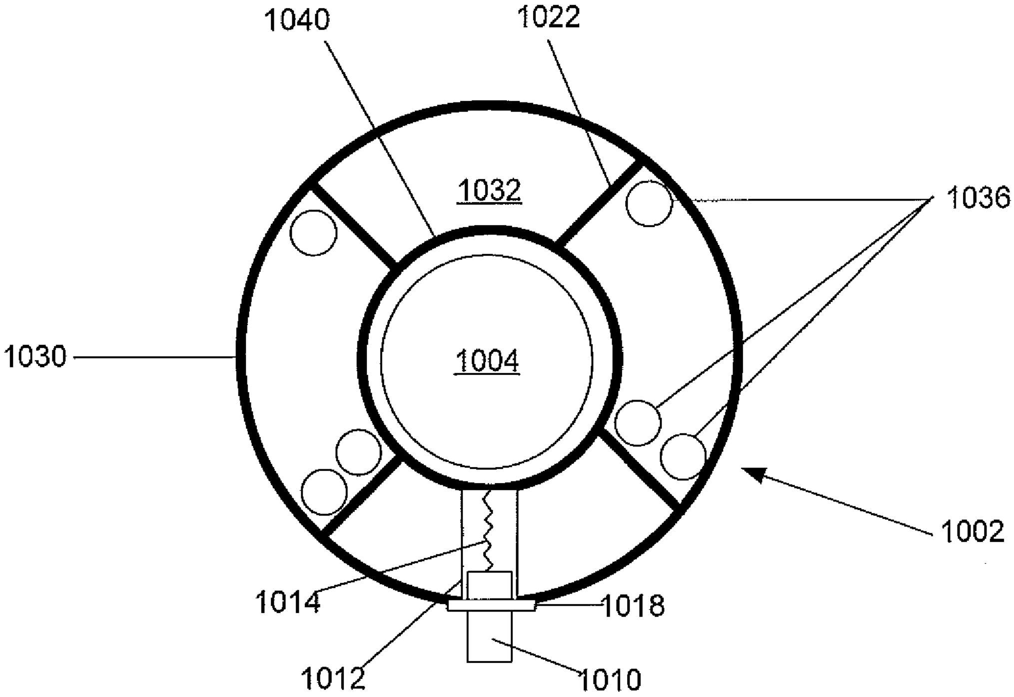


FIG. 10a

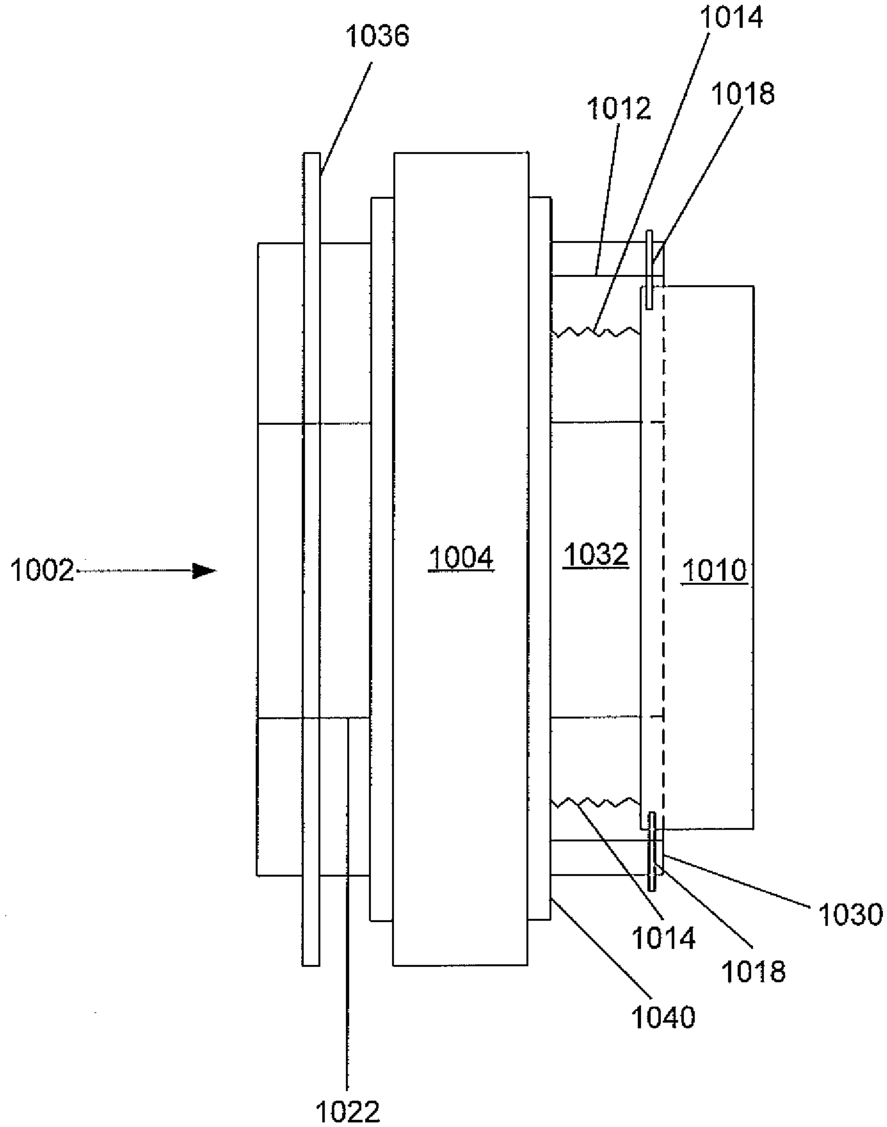
1036
1014
1018
1012
1002
1004
1032
1010
1030
1014
1018
1040
1022

FIG. 10b