



(11)

EP 4 741 574 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
13.05.2026 Bulletin 2026/20

(51) International Patent Classification (IPC):
E02B 17/00^(2006.01) E02B 17/02^(2006.01)

(21) Application number: **25215155.0**

(52) Cooperative Patent Classification (CPC):
E02B 17/027; E02B 17/0004; E02B 2017/0043; E02B 2017/0065

(22) Date of filing: **12.11.2025**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH LA MA MD TN

- **EIDE, Bjornar**
Houston, TX 77024 (US)
- **HØVIK, Jon**
Houston, TX 77024 (US)
- **JOHNSEN, Erik**
Houston, TX 77024 (US)
- **FERTIG, Tomas**
Houston, TX 77024 (US)
- **JOHNSEN, Eivind**
Houston, TX 77024 (US)

(30) Priority: **12.11.2024 US 202463719237 P**

(71) Applicant: **Entrion Wind, Inc.**
Houston, TX 77024 (US)

(74) Representative: **Patentgruppen A/S**
Aaboulevarden 31, 4th Floor
8000 Aarhus C (DK)

(72) Inventors:
• **LEE, Li**
Houston, TX 77024 (US)

(54) MULTI-USE FULLY RESTRAINED PLATFORMS

(57) A multi-use fully restrained platform system for offshore marine applications includes a monopile foundation, an interface piece mounted atop the monopile, and a deck structure coupled to the interface piece. The interface piece provides a standardized connection mechanism that enables various payload configurations to be mounted on the same foundational infrastructure, including wind turbines, oil and gas extraction equipment, hydrogen production facilities, offshore charging stations, electrical substations, offshore datacenters, and marine infrastructure such as bridges. The interface piece includes multiple receptacles configured to receive mounting columns from the deck structure, with the receptacles arranged to accommodate different deck geometries and payload requirements.

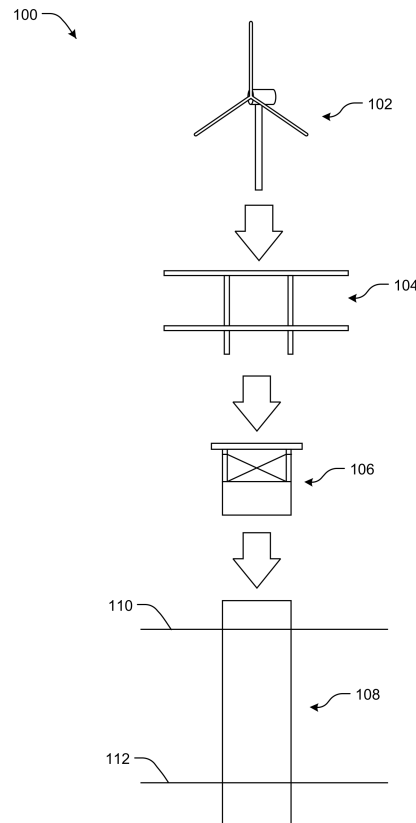


Fig. 1

Description

Cross-reference to related applications

[0001] This application claims priority to U.S. Provisional Application No. 63/719,237 filed on November 12, 2024 and entitled "MULTI-USE FULLY RESTRAINED PLATFORMS," which is incorporated herein by reference in its entirety.

Background

[0002] Offshore platforms serve as foundations for various marine operations, including energy production, resource extraction, and infrastructure support. These structures must withstand harsh environmental conditions while providing stable working surfaces for equipment and personnel. Traditional offshore platform designs have evolved to address the challenges of operating in marine environments where wind, waves, and currents create dynamic loading conditions that can affect structural integrity and operational performance.

[0003] As offshore operations expand into deeper waters and more challenging environments, there is a growing need for platform designs that can accommodate various payload types while maintaining structural efficiency and cost-effectiveness. The ability to support different operational requirements, from energy production to marine infrastructure, presents opportunities for more versatile platform configurations that can adapt to changing operational needs throughout their service life. Conventional offshore platform designs often require custom engineering and fabrication for specific applications, leading to increased costs and extended development timelines.

Summary of the invention

[0004] In an aspect, the invention relates to a fully restrained platform for ocean deployment. The fully restrained platform comprises a monopile configured to be driven into an ocean floor and extending vertically through a waterline, and an interface piece mounted atop the monopile, the interface piece including a first plurality of interface receptacles. The platform comprises a deck structure coupled to the interface piece, the deck structure including a second plurality of mounting columns configured to align with and engage the interface receptacles of the interface piece. A payload may preferably be mounted on the deck structure.

[0005] The interface piece may in various embodiments provide a standardized connection mechanism that enables various payload configurations to be mounted on the same foundational infrastructure, including, for example, wind turbines, oil and gas extraction equipment, hydrogen production facilities, offshore charging stations, electrical substations, offshore datacenters, and marine infrastructure such as bridges. The

interface piece includes multiple receptacles configured to receive mounting columns from the deck structure, with the receptacles for example advantageously arranged to accommodate different deck geometries and payload requirements.

[0006] The fully restrained platform may be a system of the monopile, interface piece and deck structure, configured to be installed as described in the ocean floor. The fully restrained platform may alternatively be a platform fully or partly installed in the ocean floor, comprising the monopile, interface piece and deck structure as described.

[0007] The interface piece may include a truss portion and a cap portion, the cap portion to mate over a top portion of the monopile. The top portion of the monopile may preferably be tapered to increase friction with regards to the cap of the interface piece when assembled.

[0008] The monopile may have a top portion including a cavity, and the interface piece may include a lower portion to mate within the cavity. Walls of the cavity may be arranged at an angle and/or tapered to increase friction between the monopile and the interface piece when assembled.

[0009] The monopile may in various embodiments further include a moonpool, and/or at least a portion of a wall of the monopile may be reinforced with at least one of string stiffeners or ring stiffeners.

[0010] The fully restrained platform may further comprise a tuned mass damper mounted on the monopile above the waterline. In a configuration, the tuned mass damper for example comprises a sloshing tank partially filled with liquid, the liquid configured to move within the sloshing tank in response to environmental loads impacting the fully restrained platform.

[0011] A number of the first plurality of interface receptacles of the interface piece may be greater than or equal to a number of the second plurality of mounting columns of the deck structure. Alternatively, a number of the second plurality of mounting columns of the deck structure may be greater than or equal to a number of the plurality of interface receptacles of the interface piece.

[0012] The interface piece, in any of the above configurations, may, for example, be secured to the monopile via grouting, and/or via one or more locking mechanisms.

[0013] In the various configurations, the monopile may include at least one top mooring assembly incorporating a hydraulic damper, the at least one top mooring assembly coupled to an anchor pile via a mooring line.

[0014] The fully restrained platform may in any of the configurations further comprise a support collar mounted around the monopile; and one or more braces extending between the deck structure and the support collar to provide additional structural stiffness and load transfer capabilities between the deck structure and the monopile.

[0015] In any of the above configurations, the monopile may include an open truss structure that extends from below the waterline to above the waterline.

[0016] The fully restrained platform may in any configuration further comprise a payload mounted on the deck structure. The payload may comprise one or more of a wind turbine, oil and gas extraction equipment, offshore charging stations, electrical substations, offshore data-centers, bridge structures, offshore substations, weather monitoring stations, or research facilities.

[0017] In an aspect, the invention relates to a fully restrained platform for ocean deployment comprising a monopile driven into a seabed floor and extending vertically upward past a waterline. An interface piece including a cap is mounted over a top portion of the monopile, the interface piece including a first plurality of interface receptacles. The platform comprises a deck structure including a second plurality of mounting columns coupled to corresponding one of the first plurality of the interface receptacles of the interface piece. This aspect may also be combined with any of the configurations described above or elsewhere herein.

[0018] In an aspect, the invention relates to a method of installing a fully restrained platform in a marine environment. The fully restrained platform for installation according to this method may be any of the configurations described herein. The installation method comprises driving a monopile into an ocean floor, mounting an interface piece atop the monopile, the interface piece including a plurality of interface receptacles, installing a deck structure atop the interface piece via mating a plurality of mounting columns of the deck structure and the plurality of interface receptacles of the interface piece, and securing a payload atop the deck structure.

[0019] The installation method may further comprise driving anchor piles into the ocean floor at predetermined distances from the monopile, securing the monopile to the anchor piles via one or more mooring lines, securing the interface piece to the monopile, and securing the deck structure to the interface piece.

Brief description of figures

[0020]

FIG. 1 illustrates a fully restrained platform in a marine environment, according to some implementations.

FIG. 2 illustrates another fully restrained platform supporting a payload in a marine environment, according to some implementations.

FIG. 3 illustrates detailed views of the coupling arrangement between the deck or platform structure and the interface piece, according to some implementations.

FIG. 4 illustrates a FRP configured to utilize an interface piece to secure a deck or platform structure to a monopile, according to some implementations.

FIG. 5 illustrates a FRP configured with an alternative coupling arrangement where the interface piece may be inserted into the interior of the monopile, according to some implementations.

FIG. 6 illustrates a FRP that incorporates multiple locking mechanisms to enhance the structural connection between the interface piece and the monopile, according to some implementations.

FIG. 7 illustrates a FRP that incorporates grouting to enhance the structural connection between the interface piece and the monopile, according to some implementations.

FIG. 8 illustrates a cap of an interface piece that incorporates structural stiffening elements to enhance the connection between the interface piece and monopile, according to some implementations.

FIG. 9 illustrates a driven monopile being installed into the ocean floor, according to some implementations.

FIG. 10 illustrates a fully restrained platform that incorporates a comprehensive mooring and damping system to enhance stability and motion control in marine environments, according to some implementations.

FIG. 11 illustrates a fully restrained platform that incorporates an expanded mooring configuration with additional damping elements to provide enhanced stability and motion control capabilities, according to some implementations.

FIG. 12 illustrates a fully restrained platform that incorporates structural bracing elements to enhance the connection between the deck structure and the monopile, according to some implementations.

FIG. 13 illustrates a FRP configured to support a bridge structure, demonstrating the versatility of the FRP system for marine infrastructure applications, according to some implementations.

FIG. 14 illustrates a FRP that incorporates a truss structure as an alternative structural configuration for supporting offshore operations, according to some implementations.

FIG. 15 illustrates a plan view of a FRP that incorporates a comprehensive multi-directional mooring system to provide enhanced omnidirectional stability and load distribution, according to some implementations.

FIG. 16 illustrates a monopile of a FRP that demon-

strates the attachment configuration for top mooring assemblies, according to some implementations.

FIG. 17 illustrates a monopile that incorporates structural reinforcement elements to enhance the load-bearing capacity and structural integrity of the cylindrical shell, according to some implementations.

FIG. 18 illustrates an assembly for coupling the deck structure to the monopile that demonstrates a comprehensive structural framework for connecting a deck or platform structure to a monopile, according to some implementations.

FIG. 19 illustrates a method for installing and deploying a fully restrained platform in a marine environment, according to some implementations.

FIG. 20 further illustrates in diagram a relationship between the natural frequencies of exemplary FRP-monopiles implemented as described herein and wave frequencies.

Detailed description

[0021] The following detailed description is directed to technologies for minimizing movement of offshore platforms that host payloads, such as wind turbines, oil and gas extraction sites, hydrogen production sites, offshore charging stations or other electrical substations, offshore datacenters, as well as other payloads for various functions (e.g., ocean bridges, and/or the like). For example, using the technologies described herein, various payloads may be mounted on a marine platform that is constructed and deployed to reduce movements and/or environmental loads (e.g., wind, waves, and the like) on the platform in both shallow water (e.g., less than 120 meters) and deep water (e.g., greater than 40 meters). According used herein, the terms fully restrained platform (FRP) refers to a platform that has motions restrained in 6 degrees-of-freedom (6DOF), FRP-monopile refers to a platform that includes a monopile, FRP-moonpool refers to a platform that includes a hollow monopile (e.g., for use in oil and gas extraction), and the term FRP-monohull refers to a platform that includes a buoyant structure.

[0022] For purposes of explanation, the main structural component of a platform can be viewed as a rigid body. Its motions are characterized by and measured 6DOFs including three translational (surge, sway and heave), and three rotational (roll, pitch, and yaw). The environmental loads may force the platform to move in one or more DOFs. Some of these loads are dynamic in nature such as those from the water waves, others are mainly steady such as the ocean current induced drag.

[0023] The platforms including the FRPs discussed herein, are configured to support a deck or structure that house the facilities and equipment for the various types of

payloads. The decks or platforms, discussed herein, are supported by columns, which are integrated into the deck structure itself and configured to couple to the FRP. For example, the columns of the platform are configured to align with corresponding mating points or receptacles on the FRP. In some examples, an interface piece may be configured between the FRP and the platform to allow the FRP to support multi-use applications.

[0024] In some implementation, the interface piece may include two component: a lower component that is configured to couple or fit into the monopile (MP) of the FRP and an upper component configured to connect to the platform to the interface piece and, thereby, the FRP. In some examples, a transitional component similar in shape and size to the monopile is mounted on top of the monopile after the monopile is in place and fully embedded in the ocean floor. The transitional component to achieve a desired height for the platform or deck. In some examples, the interface piece may couple to the transitional component, such that the combination of the driven monopile and the added transitional component be referred to as the monopile in this context.

[0025] In some examples, a lower portion of the interface piece may resemble a cap. Accordingly, the lower portion of the interface piece be substantially circular or cylindrical and designed to mate with the top of the monopile either internally or externally (e.g., as either a female-male or male-female coupling interface). In some examples, the lower portion of the interface piece may include a tapered interference or fit method, in which the ends of the two cylindrical components (e.g., the lower portion of the interface piece and the upper portion of the monopile) are machined with slight corresponding tapers, such that they may be press-fitted together, creating a tight connection through frictional forces. In some cases, the corresponding surfaces may be manufactured or treated to form a high friction surface (e.g., on the interior of the female component and exterior of the male component) to further enhance a stability of the coupling.

[0026] In some examples, an upper part of the interface piece may include a truss structure with three or more receptacles (e.g., hollow and conical cylinders) that mate with corresponding columns at the lower end of the platform or deck structure. In some cases, an installation frame may be integrated into the upper part to accommodate any installation hardware and facilitate the installation. In some examples, the installation frame may be temporary or removed after insulation of the platform.

[0027] During installation of the deck or platform with respect to the interface piece, bracings may be added between adjacent receptacles to provide additional stiffness. The interface piece may also have an opening throughout. The opening may form a moonpool allowing the FRP to be used as a wellhead platform for drilling and oil and gas production. In some cases, the conical receptacles guide the deck or platform columns into position. In this regard, the design of the interface piece-to-deck connection is versatile. For example, if the deck

structure has more or fewer than four columns, the interface piece may be adapted accordingly. In other words, the deck or platform structure may be arranged in different orientation or with direct alignments between the columns of the interface piece and the platform or deck structure.

[0028] In some examples, the deck or platform and/or the interface piece may be secured to the ocean floor via top mooring assemblies, cables, and anchor piles (driven into the ocean floor). In other examples, the interface piece may also include one or more tuned mass dampers (TMD), tuned liquid dampers (TLD), and/or hydraulic dampers (HD) to reduce vibrations of such an ocean platform and enhance the platforms strength, particularly in deeper waters. For example, the interface piece may include one or more sloshing liquid tank that utilizes a sloshing motion associated with a liquid to reduce vibrations in the corresponding structure. In some cases, the HDs, discussed herein, are damping elements (e.g., a pressure pipe filled with liquids such as oil, a piston system, an elastic element such as a spring, and/or the like) that convert kinetic energy of the moving parts into thermal energy. This avoids hard impacts or excessive vibration amplitudes. In some examples, the terms TMD and TLD are used interchangeably as TLD is a type of TMD. In some examples, the TLDs and HDs discussed herein are used on the offshore platforms to reduce dynamic motions of the platform, alleviate dynamic forces in mooring lines, and/or extend the lifespan of such structures when compared with conventional platforms. In some examples, when equipped with TLDs and HDs, discussed here, the fixed platforms such as monopiles and FRPs may be used in deeper water, have enhanced motion performance, expanded payload-carrying capabilities, and extended lifespan when compared with conventional platforms. Additionally, the TLDs and HDs are particularly useful on platforms including large diameter column structures.

[0029] In the following detailed description, references are made to the accompanying drawings that form a part hereof, and that show, by way of illustration, specific examples or examples. The drawings herein are not drawn to scale. Like numerals represent like elements throughout the several figures (which may be referred to herein as a "FIG." or "FIGS.").

[0030] FIG. 1 illustrates a fully restrained platform 100 in a marine environment, according to some implementations. The fully restrained platform 100 may be configured to support a payload 102, which may include various types of equipment or facilities such as wind turbines in the illustrated example, as well as oil and gas extraction equipment, hydrogen production facilities, offshore charging stations, electrical substations, offshore datacenters, or other marine infrastructure. The payload 102 may be mounted on a deck or platform structure 104 that provides a stable working surface and structural support for the payload operations. The deck or platform structure 104 may be configured in various shapes and configura-

tions to accommodate different operational requirements and may include various other structures such as buildings, control rooms, equipment housings, maintenance facilities, storage areas, or other operational infrastructure necessary for the specific payload application.

[0031] The deck or platform structure 104 may be coupled to an interface piece 106, which serves as a connection mechanism between the deck structure and the underlying support system (e.g., the monopile 108). The interface piece 106 may facilitate the mounting of various types of payloads and deck configurations, allowing the fully restrained platform 100 to be adapted for multi-use applications. In some aspects, the interface piece 106 may include receptacles or mounting points that align with corresponding columns or support members of the deck or platform structure 104.

[0032] The interface piece 106 may be mounted on or coupled to a monopile 108, which extends vertically through the waterline 110 and into the ocean floor 112. In some cases, the monopile 108 may provide a structural foundation for the fully restrained platform 100 and may be designed to resist environmental loads in all of the 6DOF caused by waves, currents, wind forces, and/or other environmental factors. In some cases, the monopile 108 may be driven or embedded into the ocean floor 112 to provide a secure foundation. Accordingly, the monopile 108 may extend from above the waterline 110, through the water, past the mudline of the ocean floor 112 where the monopile 108 may be embedded to provide stability and resistance the environmental loads.

[0033] In the current example, the interface piece 106 may allow for flexible deployment of various deck structures 104 and/or payloads 102. For example, the deck structure 104 and/or payloads 102 may be interchanged or utilize the same monopile structure 108 such that each type of payload 102 may no longer require custom manufacturing and installation procedures as is typical with conventional offshore platforms. In some aspects, the standardized design, discussed herein, may enable different payload configurations to be mounted on the same foundational infrastructure, reducing costs and installation complexity. The interface piece 106 may serve as a universal connection point that accommodates various deck geometries and payload requirements while maintaining structural integrity and stability required in offshore environments. In some cases, this modular design of the FRP 100 including the interface piece 104 may allow operators to reconfigure or upgrade payloads 102 without requiring complete platform 100 replacement, thereby extending the useful life of the underlying monopile 108 infrastructure and reducing environmental impact, costs, and construction time associated with new installations.

[0034] The arrangement shown in FIG. 1 demonstrates how the components of the fully restrained platform 100 may be vertically integrated to create a stable offshore structure. The monopile 108 may provide the foundational support, the interface piece 106 may enable

versatile payload mounting configurations, the deck or platform structure 104 may provide the working surface, and the payload 102 may house the operational equipment or facilities. This configuration may allow the fully restrained platform 100 to maintain stability and minimize motions in multiple degrees of freedom while supporting various types of offshore operations.

[0035] FIG. 2 illustrates another fully restrained platform 100 supporting a payload 102 in a marine environment, according to some implementations. In the current example, the FRP 200 that demonstrates the coupling between an interface piece 106 and the monopile 108. In this configuration, the interface piece 106 may be directly mounted to the upper portion of the monopile 108 to provide a connection interface for supporting a deck or platform structure 104 and its associated payload 102 (e.g., oil and gas extraction equipment in the current example). Again, the monopile 108 may extend vertically from below the ocean floor 112 to above the waterline 110 to provide foundational support for the platform assembly that resists environmental loads in one or more of the 6DOF.

[0036] In the current example, the interface piece 106 may be coupled to the monopile 108 via a capping mechanism in which the interface piece 106 fits or couples over the top portion of the monopile 108. In the current example, the interface piece 106 may act as a female portion of the coupling mechanism and the top portion of the monopile 108 may act as the male portion of the coupling mechanism.

[0037] In some implementations, the coupling between the interface piece 106 and the monopile 108 may incorporate an angled alignment configuration to enhance the connection stability and load transfer characteristics. The bottom portion of the interface piece 106 (e.g., the cap portion) and the corresponding top portion of the monopile 108 may be machined or formed with complementary angled surfaces that create an improved mechanical interface. The angled alignment may create a wedging effect that increases the normal forces between the interface piece 106 and monopile 108, thereby enhancing the frictional resistance to relative movement caused by environmental loads acting on the FRP 200. This increased friction may improve the ability of the connection to resist environmental loads such as lateral forces from waves, wind, and currents that might otherwise cause slippage or movement between the components.

[0038] In some cases, the angled alignment may also improve the fit tolerance between the interface piece 106 and monopile 108 by providing a self-centering mechanism during installation. The complementary angled surfaces may guide the interface piece 106 into proper alignment with the monopile 108, reducing installation complexity and ensuring consistent positioning. The angled configuration may also distribute loads more effectively across the interface, reducing stress concentrations that might occur with abrupt transitions in conven-

tional straight-walled connections.

[0039] The angle of inclination for these surfaces may be selected based on the specific application requirements and environmental conditions. In some implementations, the angle may range from a few degrees to more substantial inclinations, depending on the desired level of mechanical advantage and the magnitude of expected environmental loads. The angled surfaces may be combined with other connection enhancement features such as surface texturing, coatings, or mechanical interlocks to further improve the stability and reliability of the interface piece 106 to monopile 108 connection.

[0040] In the current example, the interface piece 106 includes multiple interface receptacles, such as a first interface receptacle 204(A) and a second interface receptacle 204(B), which may be configured to receive and secure corresponding mounting columns from the deck or platform structure 104. In some aspects, the deck or platform structure 104 may include a first mounting column 206(A) and a second mounting column 206(B) that align with and mate to the interface receptacles 204(A), 204(B) respectively. The mounting columns 206(A), 206(B) may be configured with complementary shapes or connection mechanisms that allow for secure engagement with the interface receptacles 204(A), 204(B). In some cases, the deck or platform structure 104 may be configured with various column arrangements to provide additional deployment flexibility. In some implementations, the deck structure 104 may include a different number or arrangement of mounting columns 206 than the number or arrangement of receptacles 204 provided by the interface piece 106. For example, the deck structure 104 may have more mounting columns 206 than available interface receptacles 204, allowing for selective engagement of specific columns based on the particular installation requirements or environmental conditions. Alternatively, the deck structure 104 may have fewer mounting columns 206 than the total number of receptacles available on the interface piece 106, which may again allow for different positioning options or future expansion capabilities.

[0041] In some cases, the mounting columns 206 may be arranged in various geometric patterns such as triangular, rectangular, hexagonal, or other configurations that may not directly correspond to the receptacle pattern of the interface piece 106. This arrangement flexibility may enable the same interface piece 106 to accommodate different deck designs or payload configurations without requiring custom interface modifications. The mounting columns 206 may be positioned to engage with a subset of the available receptacles, while unused receptacles 204 may remain available for future modifications or alternative deck configurations.

[0042] In some aspects, the interface piece 106 may include additional receptacles beyond what is immediately needed for a particular deck configuration, providing redundancy and future adaptability. This may allow operators to modify the deck structure 104 or change

payload configurations without replacing the interface piece 106 or the underlying monopile infrastructure. The flexible column 206 and receptacle 204 arrangement may also accommodate manufacturing tolerances and installation variations that might occur during offshore deployment operations.

[0043] In some cases, the interface piece 106 may incorporate structural reinforcement elements such as a bracing truss 208 that connects between adjacent receptacles or structural components to enhance the overall stiffness and load distribution capabilities of the connection system. In some cases, the bracing truss 208 may help transfer loads from the deck structure 104 to the monopile 202 while maintaining structural integrity under various environmental loading conditions. In some implementations, the bracing truss 208 may be configured based on expected environmental loads to improve the structural performance of the interface piece 106 and/or the FRP 200. The design parameters of the bracing truss 208, such as member sizing, material selection, and geometric configuration, may be tailored to accommodate the specific load conditions anticipated at the installation site. For example, in environments with high wave loads, the bracing truss 208 may incorporate larger cross-sectional members or additional diagonal bracing elements to enhance resistance to dynamic loading. In areas subject to strong currents or wind forces, the bracing truss 208 may be oriented or reinforced to provide improved lateral stability.

[0044] The configuration of the bracing truss 208 may also account for the magnitude and direction of each of the potential 6DOF environmental forces. In some specific implementations, the truss geometry may be asymmetric to provide enhanced resistance in a direction of prevailing loads while maintaining structural efficiency. The spacing and arrangement of truss members may be configured based on load distribution patterns expected during operation, with denser bracing in high-stress regions and more open configurations in areas experiencing lower loads.

[0045] In some aspects, the bracing truss 208 may incorporate variable member properties along its length or height to match the load distribution from the deck structure 104 to the monopile 202. The connection details between truss members and the interface receptacles 204 may also be designed to accommodate the specific load transfer requirements, with reinforced joints or additional connection hardware in areas experiencing higher stress concentrations.

[0046] The monopile 202 may include a moonpool 210 formed as a central opening that extends through the length of the structure to accommodate oil and gas production, as illustrated. The moonpool 210 may provide access for drilling operations, subsea equipment deployment, or other marine activities that require passage through the platform structure. The outer frame of the monopile 212 may provide the primary structural support while accommodating the moonpool 210 open-

ing. In some implementations, this configuration may allow the fully restrained platform 200 to function as a wellhead platform or support other operations that benefit from having a central access opening.

[0047] FIG. 3 illustrates detailed views of the coupling arrangement between the deck or platform structure 104 and the interface piece 106, according to some implementations. The figure shows both elevation view 302 and plan view 304 that demonstrate the structural configuration and connection mechanisms used to secure the deck structure to the interface piece 106. In the elevation view, shown as the first view of the coupled deck and interface piece 302, the interface piece 106 may be positioned to receive and support the deck or platform structure 104 through a series of mounting columns and receptacles.

[0048] The interface piece 106 may include a coupling cap 308 that forms the lower portion of the interface assembly and may be configured to mate with the upper portion of a monopile structure. The coupling cap 308 may provide a secure connection interface that transfers loads from the deck structure 104 through the interface piece 106 to the underlying monopile foundation. In some aspects, the coupling cap 308 may incorporate the angled alignment features or tapered interference fit mechanisms described previously to enhance connection stability.

[0049] In some implementations, the coupling cap 308 may be configured to fit around an exterior of the monopile, creating an external coupling arrangement where the cap 308 encompasses the outer circumference of an upper portion of the monopile. Alternatively, the coupling cap 308 may be configured to fit into an interior of the monopile, forming an internal coupling arrangement where the cap 308 may be inserted within the hollow interior of the monopile structure. In some cases, the coupling cap 308 may be designed with dual compatibility features that allow it to accommodate both external and internal coupling configurations, providing flexibility for different monopile designs or installation requirements. The choice between external or internal coupling may depend on factors such as a wall thickness of the monopile, internal diameter of the monopile, structural requirements, or specific operational needs of the FRP assembly.

[0050] The structural integrity of the interface piece 106 may be enhanced through the incorporation of a cross bracing truss 306 that connects between various components of the assembly. The cross bracing truss 306 may provide additional stiffness and load distribution capabilities, helping to transfer forces from the deck structure 104 to the interface piece 106 and ultimately to the monopile foundation. In some implementations, the cross bracing truss 306 may be configured with diagonal members, horizontal members, or a combination of both to optimize load transfer characteristics based on the expected environmental conditions and operational requirements.

[0051] The plan view, shown as the second view of the coupled deck and interface piece 304, illustrates the geometric arrangement of the mounting columns and their relationship to the interface piece 106. In this configuration, the deck or platform structure 104 may include four mounting columns arranged in a rectangular pattern: a first mounting column 206(A), a second mounting column 206(B), a third mounting column 206(C), and a fourth mounting column 206(D). This four-column arrangement may provide balanced load distribution and enhanced stability for various payload configurations.

[0052] The mounting columns 206(A), 206(B), 206(C), 206(D) may be positioned at strategic locations to optimize load transfer and structural performance. In some aspects, the rectangular arrangement may provide symmetric load distribution that helps minimize torsional forces and enhances the overall stability of the platform assembly. The spacing between the mounting columns may be configured based on the size and weight of the intended payload, as well as the environmental loads expected at the installation site.

[0053] A moonpool 210 may be formed in the central region of the assembly, providing an opening that extends through both the deck structure 104 and the interface piece 106. The moonpool 210 may serve multiple functions, including providing access for drilling operations, subsea equipment deployment, maintenance activities, or other marine operations that require passage through the interface piece structure 310. In some implementations, the moonpool 210 may be sized and configured to accommodate specific equipment or operational requirements associated with the intended payload application.

[0054] The interface piece 106 may include receptacles positioned to align with each of the mounting columns 206(A), 206(B), 206(C), 206(D). These receptacles may be configured with complementary shapes or connection mechanisms that allow for secure engagement with the mounting columns. In some cases, the receptacles may incorporate conical or tapered geometries that guide the mounting columns into proper alignment during installation, reducing installation complexity and ensuring consistent positioning.

[0055] The arrangement shown in FIG. 3 demonstrates how the modular design of the interface piece 106 may accommodate various deck configurations while maintaining structural integrity. The four-column configuration illustrated may represent one of several possible arrangements, and the interface piece 106 may be adapted to accommodate different numbers or arrangements of mounting columns based on specific application requirements. In some implementations, the interface piece 106 may include additional receptacles beyond the four shown, providing flexibility for alternative deck configurations or future modifications.

[0056] FIG. 4 illustrates a FRP 400 configured to utilize an interface piece 106 to secure a deck or platform structure 104 to a monopile 108, according to some

implementations. In the current example, the interface piece 106 may be mounted on the monopile 108 and configured to support the deck or platform structure 104. In the illustrated example, the interface piece 106 may be coupled over the top portion of the monopile 108, creating a cap-like connection that encompasses the upper end of the monopile 108. The interface piece 106 may be designed to fit securely around the exterior circumference of the monopile 108, forming a robust mechanical connection that can effectively transfer loads from the deck or platform structure 104 to the underlying monopile foundation.

[0057] As discussed herein, the coupling arrangement may utilize the tapered interference fit or angled alignment features described previously to enhance the connection stability between the interface piece 106 and the monopile 108. In some aspects, the interface piece 106 may be machined or formed with an internal geometry that complements the external profile of the monopile 108, creating a precise fit that minimizes relative movement under environmental loading conditions.

[0058] The over-the-top coupling configuration may provide several advantages for the FRP 400 assembly. The external mounting arrangement may allow for easier installation procedures, as the interface piece 106 can be positioned and secured without requiring access to the interior of the monopile 108. In some cases, this configuration may also facilitate maintenance or inspection activities, as the connection interface remains accessible from the exterior of the structure. In some cases, the load transfer characteristics of the over-the-top coupling may be optimized through the incorporation of contact surfaces that distribute forces effectively around the circumference of the monopile 108. In some implementations, the interface piece 106 may include internal features such as ribs, flanges, or other structural elements that enhance the load distribution and provide additional resistance to environmental forces acting on an exterior of the FRP 400.

[0059] FIG. 5 illustrates a FRP 500 configured with an alternative coupling arrangement where the interface piece 106 may be inserted into the interior of the monopile 108, according to some implementations. In this configuration, the interface piece 106 may be positioned within the hollow interior of the monopile 108, creating an internal coupling arrangement that differs from the external cap configuration shown in FIG. 4. The interface piece 106 may be designed to fit securely within the internal diameter of the monopile 108, forming a robust mechanical connection that can effectively transfer loads from the deck or platform structure 104 to the underlying monopile foundation.

[0060] Again, the internal coupling arrangement may utilize a tapered interference fit or angled alignment features to enhance the connection stability between the interface piece 106 and the monopile 108. In some aspects, the interface piece 106 may be machined or formed with an external geometry that complements the

internal profile of the monopile 108, creating a precise fit that minimizes relative movement under environmental loading conditions. The coupling cap portion of the interface piece 106 may be configured with a slightly tapered external surface that corresponds to a complementary tapered internal surface within the upper portion of the monopile 108.

[0061] The internal mounting configuration may provide several advantages for the FRP 500 assembly. In some cases, the internal coupling arrangement may offer improved protection of the connection interface from environmental exposure, as the joint may be shielded within the monopile structure. The internal configuration may also provide enhanced load transfer characteristics through the distribution of forces across the internal circumference of the monopile 108. In some implementations, the interface piece 106 may include external features such as ribs, flanges, or other structural elements that engage with the internal surface of the monopile 108 to enhance load distribution and provide additional resistance to environmental forces.

[0062] The choice between the internal coupling configuration shown in FIG. 5 and the external coupling configuration shown in FIG. 4 may depend on various factors including the wall thickness of the monopile 108, the internal diameter available within the monopile structure, specific structural requirements, or operational considerations associated with the intended payload application. In some cases, the internal coupling arrangement may be preferred when the monopile 108 has sufficient internal diameter to accommodate the interface piece 106 while maintaining adequate structural integrity of the connection.

[0063] In the examples of FIGS. 4 and 5 above, the tapered portions of the interface piece 106 and the monopile 108 may be secured via various methods or processes. For instance, the tapered portions may be secured using press fit, shrink fit, interference fit, thermal fit, or other type fitting techniques. For example, the press fit technique may include applying a pressure to the exterior of either the interface piece 106 and/or the monopile 108, coupling, and then releasing the pressure to secure the monopile to the interface piece 106. As another example, the shrink fit or thermal fit may utilize heat to cause portions or elements of the monopile 108 and/or the interface piece 106 to shrink or reduce in size after coupling to further secure the two components together.

[0064] Likewise, the receptacles 204 of the interface piece 106 may utilize various methods or processes to secure to the mounting columns 206 of the deck or platform structure 104. Again, the receptacles 204 and/or mounting columns 206 may be tapered and then secured using a press fit, shrink fit, interference fit, thermal fit, or other type fitting techniques.

[0065] FIG. 6 illustrates a FRP 600 that incorporates multiple locking mechanisms to enhance the structural connection between the interface piece 106 and the monopile 108, according to some implementations.

The FRP 600 includes a deck or platform structure 104 supported by the interface piece 106, which is secured to the monopile 108 through various locking mechanisms 602 positioned at different elevations along the structure.

[0066] In the illustrated example, the locking mechanisms 602 may include a first locking mechanism 602(A), a second locking mechanism 602(B), a third locking mechanism 602(C), and a fourth locking mechanism 602(D) that are positioned to provide enhanced structural stability and load transfer capabilities. In some aspects, these locking mechanisms 602 may comprise locking pins that extend through both the interface piece 106 and the monopile 108 to create a mechanical interlock that resists relative movement between the components. The locking pins may be configured as bolted connections that can be tightened to a specified torque to ensure adequate clamping force and connection integrity.

[0067] In some implementations, the locking mechanisms 602 may incorporate hydraulic clamps that apply controlled pressure to secure the interface piece 106 to the monopile 108. The hydraulic clamps may provide adjustable clamping forces that can be modified based on environmental conditions or operational requirements. In some cases, the hydraulic clamps may include pressure monitoring systems that allow operators to verify and maintain appropriate clamping forces throughout the operational life of the FRP 600.

[0068] The locking mechanisms 602 may also include other securing systems such as wedge-type connectors, cam-operated clamps, or spring-loaded retention devices that provide reliable connection between the interface piece 106 and monopile 108. In some aspects, these securing systems may be designed to accommodate thermal expansion and contraction of the structural components while maintaining connection integrity under varying environmental conditions.

[0069] The positioning of the locking mechanisms 602(A), 602(B), 602(C), and 602(D) at different elevations along the structure may provide distributed load transfer and enhanced resistance to overturning moments and lateral forces. In some implementations, the vertical spacing between locking mechanisms 602 may be configured based on the expected load distribution and structural requirements of the specific FRP 600 application. The multiple locking points may also provide redundancy in the connection system, ensuring that the structural integrity of the assembly is maintained even if individual locking mechanisms experience wear or require maintenance.

[0070] In the current example, four locking mechanisms 602(A), 602(B), 602(C), and 602(D) are illustrated, however the interface piece 106 and monopile 108 connection system may accommodate various numbers and arrangements of locking mechanisms based on specific structural requirements and operational conditions. In some implementations, the number of locking mechanisms may be increased or decreased depending on the magnitude of expected environmental loads, the size of

the monopile 108, or the weight and configuration of the payload being supported.

[0071] In some implementations, a horizontal placement of locking mechanisms 602 around the circumference of the interface piece 106 and monopile 108 may be configured in various patterns to improve resistance to environmental loads and improve stability. In some cases, locking mechanisms 602 may be positioned at regular angular intervals around the circumference, such as at 90-degree intervals for a four-point arrangement, 120-degree intervals for a three-point arrangement, or 60-degree intervals for a six-point arrangement. In some aspects, asymmetric horizontal arrangements may be utilized to provide enhanced resistance in directions of prevailing or expected environmental loads, with more locking mechanisms 602 positioned on the side of the structure that experiences higher forces from waves, currents, or wind.

[0072] In some implementations, vertical positioning of locking mechanisms 602 along differing heights of the interface piece 106 and monopile 108 may accommodate different structural requirements. In some examples, the locking mechanisms 602 may be concentrated near the top of the connection where loads from the deck structure 104 are transferred, while in other cases, the locking mechanisms 602 may be distributed more evenly along the vertical extent of the interface piece 106 and the monopile 108. The vertical spacing between locking mechanisms may be configured based on the expected bending moments and shear forces in the connection, with closer spacing in areas experiencing higher stress concentrations.

[0073] In some cases, the combination of horizontal and vertical positioning may create a three-dimensional array of locking mechanisms 602 that provides comprehensive restraint against movement in multiple degrees of freedom. This arrangement may be particularly beneficial in deep water applications where the FRP 600 may experience complex loading patterns from various environmental sources acting simultaneously.

[0074] FIG. 7 illustrates a FRP 700 that incorporates grouting 702 to enhance the structural connection between the interface piece 106 and the monopile 108, according to some implementations. The FRP 700 includes a deck or platform structure 104 supported by the interface piece 106, which is secured to the monopile 108 through injection of a grouting material that fills the spaces between the components.

[0075] In the illustrated example, the grouting 702 may be injected into the annular space or gap between the interface piece 106 and the monopile 108 to create a solid, continuous connection that eliminates voids and provides enhanced load transfer capabilities. The grouting material may comprise a fluid-like substance that flows into all available spaces during installation and subsequently hardens to form a rigid structural connection. In some aspects, the grouting 702 may include cement-based materials, epoxy resins, or other cemen-

titious compounds that provide high compressive strength and durability in marine environments.

[0076] The grouting process may involve injecting the fluid material under controlled pressure to ensure complete filling of all gaps and voids between the interface piece 106 and the monopile 108. In some implementations, the grouting 702 may be introduced through injection ports or access points positioned at strategic locations around the circumference of the connection interface. The injection process may be monitored to verify complete filling and proper distribution of the grouting material throughout the connection zone.

[0077] In some cases, the grouting 702 may work in conjunction with a locking mechanism 700 to provide both mechanical restraint and structural continuity between the interface piece 106 and monopile 108. The locking mechanism 700 may provide initial positioning and alignment of the components during installation, while the grouting 702 may provide the primary load transfer path and structural integrity for the completed connection.

[0078] The grouting 702 may be particularly effective at transferring loads from the deck or platform structure 104 through the interface piece 106 to the monopile 108 by creating a continuous load path that distributes forces over a larger contact area. In some implementations, the grouting material may be formulated to match or exceed the structural properties of the surrounding steel components, ensuring that the connection does not represent a weak point in the overall structural system. In some aspects, the grouting 702 may also provide corrosion protection by sealing the interface between the components and preventing the ingress of seawater or other corrosive substances. The grouting material may include additives that enhance the long-term performance of the connection in marine environments. In some examples, the grouting installation process may be performed after the interface piece 106 is positioned and aligned with the monopile 108, allowing for precise control of the final connection geometry and ensuring proper load transfer characteristics. In some implementations, the grouting 702 may be installed in multiple stages or lifts to accommodate the volume of material required and to ensure proper curing and strength development throughout the connection zone.

[0079] In some implementations, the locking mechanisms 602 of FIG. 6 and grouting 702 of FIG. 7 may be used in combination to provide enhanced resistance to environmental loads and improved long-term durability. The combined approach may leverage the immediate mechanical restraint provided by the locking mechanisms 602 with the continuous load distribution characteristics of the grouting 702 to create a robust connection system. In some aspects, the locking mechanisms 602 may provide initial structural stability during installation and serve as a backup restraint system, while the grouting 702 may handle the primary load transfer and provide uniform stress distribution across the interface. The combination

may also offer improved fatigue resistance under cyclic loading conditions, as the grouting 702 may reduce stress concentrations around individual locking points while the locking mechanisms 602 may provide redundant load paths in case of grouting degradation over time. In some cases, this hybrid connection approach may be particularly beneficial in harsh marine environments where the platform may experience sustained high loads or where long-term reliability is a primary concern.

[0080] FIG. 8 illustrates a cap of an interface piece 800 that incorporates structural stiffening elements to enhance the connection between the interface piece 106 and monopile 108, according to some implementations. The frame 800 may be applied to different components of the FRP assembly depending on the specific coupling configuration being utilized. In some cases, the stiffened frame may be applied to the coupling cap portion of the interface piece 106 when the interface piece is inserted into the interior of the monopile 108. Alternatively, the stiffened frame may be applied directly to the monopile 108 when the interface piece 106 is positioned externally over the top of the monopile structure.

[0081] The first view of the cap of the interface piece 802 shows the structural arrangement in elevation, demonstrating how the stiffening truss 806 may be integrated into the overall assembly. The stiffening truss 806 may comprise a network of structural members that provide additional rigidity and load distribution capabilities to the connection interface. In some implementations, the stiffening truss 806 may include diagonal bracing members, horizontal support elements, or a combination of both to optimize the structural performance based on the expected loading conditions and operational requirements.

[0082] The second view of the cap of the interface piece 804 illustrates the frame configuration in plan view, showing the geometric arrangement of the stiffening elements and their relationship to the deck or platform structure 104. The frame 804 may be configured to accommodate various operational requirements while providing enhanced structural stiffness to the overall assembly. In some aspects, the frame design may incorporate openings or slots that align with specific operational needs of the payload being supported.

[0083] For wellhead platform applications, the design of the interface piece 800 may include strategically positioned openings that correspond to opening of the moonpool in the top of the monopile. The frame configuration may ensure that designated areas remain unobstructed to accommodate drilling operations and subsea equipment access. In some implementations, the stiffening truss 806 may be arranged in a pattern that provides structural support while maintaining clear pathways for well installation and maintenance activities.

[0084] In some cases, the stiffened frame design may incorporate modular elements that can be customized based on the specific well pattern requirements for a particular installation. In some cases, the frame 800

may include removable or adjustable sections that allow for modifications to accommodate changes in well planning or operational requirements. The structural members of the stiffening truss 806 may be positioned to avoid interference with planned well locations while maintaining adequate load transfer capabilities between the deck or platform structure 104 and the underlying monopile.

[0085] In some implementations, the stiffened frame may provide enhanced resistance to environmental loads by distributing forces more effectively across the connection interface. The additional structural stiffness provided by the frame 800 may reduce deflections and improve the overall stability of the FRP assembly under various loading conditions. The frame design may also facilitate load transfer from the deck structure 104 to the monopile via the interface piece 800 by providing multiple load paths and reducing stress concentrations at various connections or coupling points.

[0086] FIG. 9 illustrates a driven monopile 900 being installed into the ocean floor, according to some implementations. The driven monopile 900 may be installed using pile driving techniques to establish a secure foundation for the platform assembly. In some aspects, the driven monopile 900 may be positioned and driven into the seabed using specialized marine construction equipment such as pile driving hammers, vibratory drivers, or other installation systems suitable for offshore operations.

[0087] A drive force 902 may be applied to the upper portion of the driven monopile 900 to advance the structure into the ocean floor. The drive force 902 may be generated by impact hammers, hydraulic systems, or vibratory equipment that delivers controlled energy to overcome soil resistance and achieve the required penetration depth. In some implementations, the magnitude and frequency of the drive force 902 may be adjusted based on soil conditions, monopile dimensions, and installation requirements to optimize the driving process while minimizing potential damage to the structure.

[0088] The driven monopile 900 may include a pointed base 904 at its lower end that facilitates penetration into various soil conditions encountered in marine environments. The pointed base 904 may be configured with a single or multiple projections (as illustrated) that assist the monopile 900 in penetrating through soil layers including but not limited to dense sand, clay, or mixed soil conditions. In some aspects, the pointed base 904 may be designed with a conical or pyramidal geometry that concentrates the driving forces at specific points to enhance penetration efficiency.

[0089] In some implementations, the pointed base 904 may incorporate multiple penetration points arranged around the circumference of the monopile to distribute the driving loads and improve stability during installation. The geometry of the pointed base 904 may be optimized based on expected soil conditions at the installation site, with sharper angles for harder soils and broader angles for softer sediments. In some cases, the pointed base

904 may include reinforced sections or wear-resistant materials to withstand the high stresses encountered during the driving process.

[0090] The installation process may involve monitoring the penetration rate and resistance encountered by the driven monopile 900 to ensure proper embedment depth and structural integrity. In some aspects, the driving operation may be controlled to achieve specific penetration criteria such as minimum embedment depth, bearing capacity requirements, or lateral resistance specifications. The driven monopile 900 may be installed to depths that provide adequate support for the anticipated loads from the deck structure, payload, and environmental forces acting on the completed FRP assembly.

[0091] FIG. 10 illustrates a fully restrained platform 1000 that incorporates a comprehensive mooring and damping system to enhance stability and motion control in marine environments, according to some implementations. The fully restrained platform 1000 includes a deck or platform structure 104 positioned at the upper portion of the assembly, which may be configured to support various types of payloads and operational equipment. The deck or platform structure 104 may be coupled to an interface piece 106 that provides the connection mechanism between the deck structure and the underlying monopile 108.

[0092] The monopile 108 extends vertically from above the waterline 110, through the water column, and into the ocean floor 112 where the monopile 108 may be embedded to provide foundational support for the platform assembly. In some aspects, the monopile 108 may be driven or installed using the techniques described in relation to FIG. 9, creating a secure foundation that resists environmental loads in multiple degrees of freedom.

[0093] The fully restrained platform 1000 incorporates a first top mooring assembly, which in the current example, includes a first hydraulic damper 1002(A) and a second top mooring assembly, which in the current example, includes a second hydraulic damper 1002(B) positioned on opposite sides of the monopile 108 to provide dynamic motion control capabilities. It should be understood that while not shown multiple other mooring assemblies may be utilized, such as illustrated below with respect to FIG. 15, around the circumference of the FRP 1000.

[0094] In some examples, the hydraulic dampers 1002(A), 1002(B) may be configured to reduce vibrations and dynamic responses of the platform assembly when subjected to environmental forces such as waves, currents, and wind loads. In some implementations, the hydraulic dampers 1002 may include pressure-filled cylinders, piston systems, or other damping mechanisms that convert kinetic energy from platform motion into thermal energy, thereby reducing excessive vibration amplitudes and hard impacts.

[0095] In the current example, the first hydraulic damper 1002(A) may be connected to a first mooring line

1006(A), while the second hydraulic damper 1002(B) may be connected to a second mooring line 1006(B). The mooring lines 1006(A), 1006(B) extend downward and outward from their respective hydraulic dampers to provide lateral support and positioning control for the FRP 1000. In some aspects, the mooring lines 1006 may be configured with specific angles and tensions selected based at least in part on desired restraint characteristics and load distribution of the mooring system.

[0096] The first mooring line 1006(A) may terminate at a first anchor pile 1004(A), while the second mooring line 1006(B) may terminate at a second anchor pile 1004(B). The anchor piles 1004(A), 1004(B) may be driven or embedded into the ocean floor 112 to provide secure attachment points for the mooring system. In some implementations, the anchor piles may be positioned at predetermined distances and orientations from the monopile 108 to achieve desired mooring line geometries and load distribution patterns.

[0097] The fully restrained platform 1000 may also incorporate a tuned mass damper 1008 positioned between the hydraulic dampers 1002(A), 1002(B) to provide additional motion control capabilities. The tuned mass damper 1008 may include a mass element (e.g., fluid, spherical, hexagonal, triangular, or other geometric objects, and/or the like) that may be configured to move in reaction to environmental loads applied to the exterior of the FRP 1000, thereby reducing dynamic motions and improving stability.

[0098] In one specific example, the tuned mass damper 1008 may comprise a sloshing liquid tank (of for instance, water, oil, or other fluid) that utilizes the motion of liquid to create damping forces that oppose platform movements. In this example, the tuned mass damper 1008 may include a fill line 1010 that allows the fluid to move within a cavity of the tuned mass damper 1008. In some implementations, the fill line 1010 may be adjusted by adding and/or removing liquid from the tuned mass damper 1008, allowing operators to modify the damping characteristics based on operational requirements or environmental conditions discovered after installation. The fill line 1010 may also facilitate monitoring of the damper system and enable maintenance activities without requiring major disassembly of the platform components.

[0099] The combination of hydraulic dampers 1002(A), 1002(B), mooring lines 1006(A), 1006(B), anchor piles 1004(A), 1004(B), and tuned mass damper 1008 may work together to create a comprehensive motion control system for the fully restrained platform 1000. In some aspects, this integrated approach may provide enhanced stability compared to conventional fixed platforms, particularly in deeper water applications where environmental loads may be more severe. The damping systems may help extend the operational lifespan of the platform by reducing fatigue loads on structural components and mooring elements.

[0100] In some implementations, the hydraulic dam-

pers 1002(A), 1002(B) may be adjustable to accommodate varying environmental conditions or operational requirements. The damping characteristics may be modified by adjusting fluid pressures, orifice sizes, or other system parameters to optimize performance for specific sea states or platform configurations. The mooring lines 1006(A), 1006(B) may also be configured with different materials, diameters, or pretension levels to achieve desired restraint characteristics and load distribution patterns.

[0101] FIG. 11 illustrates a fully restrained platform 1100 that incorporates an expanded mooring configuration with additional damping elements to provide enhanced stability and motion control capabilities, according to some implementations. The fully restrained platform 1100 includes a deck or platform structure 104 positioned at the upper portion of the assembly and coupled to an interface piece 106 that connects to a monopile 108. The monopile 108 extends vertically from above the waterline 110, through the water column, and into the ocean floor 112 where it may be embedded to provide foundational support.

[0102] The fully restrained platform 1100 incorporates a multi-position mooring system that includes a first level or height of top mooring assemblies, such as the first hydraulic damper 1002(A) and second hydraulic damper 1002(B) described in relation to FIG. 10, along with additional lower level of top mooring assemblies, illustrated herein as additional third hydraulic damper or top mooring assembly 1102(A) and fourth hydraulic damper or top mooring assembly 1102(B). In some aspects, this expanded configuration may provide improved omnidirectional stability and enhanced resistance to environmental loads from multiple directions.

[0103] The third hydraulic damper or top mooring assembly 1102(A) may be connected to a third mooring line 1104(A), while the fourth hydraulic damper or top mooring assembly 1102(B) may be connected to a fourth mooring line 1104(B). In some implementations, the third and fourth mooring lines 1104(A), 1104(B) may extend downward and outward from their respective damping assemblies to provide additional lateral support and positioning control for the FRP 1100. The multilevel or height mooring arrangement may create a balanced load distribution system that enhances the platform's ability to resist environmental forces acting from various directions.

[0104] The third and fourth mooring lines 1104(A), 1104(B) may terminate at additional anchor piles embedded in the ocean floor 112, similar to the arrangement described for the first and second mooring lines 1006(A), 1006(B). In some cases, the anchor piles for the third and fourth mooring lines may be positioned at different radial distances or angular orientations from the monopile 108 compared to the first and second anchor piles, creating a more distributed anchoring pattern that may improve the overall stability characteristics of the mooring system.

[0105] The vertical separation between the upper level mooring assemblies 1002(A), 1002(B) and the lower

level mooring assemblies 1102(A), 1102(B) may be configured to optimize load distribution and reduce stress concentrations in the monopile structure. In some implementations, the vertical spacing may be selected based on the expected magnitude and direction of environmental loads, with closer spacing in areas experiencing higher bending moments and wider spacing where loads are more uniformly distributed. The multi-level arrangement may also provide redundancy in the mooring system, ensuring continued platform stability even if individual mooring components experience wear or require maintenance.

[0106] FIG. 12 illustrates a fully restrained platform 1200 that incorporates structural bracing elements to enhance the connection between the deck structure 104 and the monopile 108, according to some implementations. The fully restrained platform 1200 includes a deck or platform structure 104 positioned at the upper portion of the assembly and coupled to an interface piece 106 that connects to a monopile 108. The monopile 108 extends vertically from above the waterline 110, through the water column, and into the ocean floor 112 where the monopile 108 may be embedded to provide foundational support for the platform assembly.

[0107] The fully restrained platform 1200 incorporates a first brace 1204(A) and a second brace 1204(B) that extend between the deck or platform structure 104 and a support collar 1208 mounted on the monopile 108 as shown or, in some implementations, to the interface piece 106. In some aspects, the braces 1204(A), 1204(B) may provide additional structural stiffness and load transfer capabilities between the deck structure and the monopile foundation. The braces may be configured as diagonal members that help resist lateral forces and reduce deflections of the deck structure under environmental loading conditions.

[0108] The support collar 1208 may be positioned at a predetermined elevation on the monopile 108 to provide an attachment point for the braces 1204(A), 1204(B). In some implementations, the support collar 1208 may be configured as a ring-like structure that encircles the monopile 108 and provides multiple attachment points for structural bracing elements. The collar may be secured to the monopile through welding, bolted connections, or other mechanical fastening methods that ensure adequate load transfer between the components. In some implementations, the support collar 1208 may incorporate additional reinforcement techniques to enhance structural performance and connection integrity of the support collar 1208 with the monopile 108. The collar 1208 may include internal bracing elements or stiffeners that provide increased stiffness and load distribution capabilities within the collar structure itself, as discussed below with respect to FIG. 17. In some aspects, the support collar 1208 may utilize locking mechanisms and/or grouting techniques similar to those described in relation to FIGS. 6 and 7 to create a more robust connection with the monopile 108. Grouting ma-

terial may be injected into the annular space between the collar and a surface of the monopile 108 to eliminate voids and create a continuous load transfer path. The grouting may comprise cement-based materials, epoxy resins, or other cementitious compounds that provide high compressive strength and enhanced durability in marine environments.

[0109] The first brace 1204(A) may extend from a first attachment point on the deck or platform structure 104 to a corresponding attachment point on the support collar 1208, while the second brace 1204(B) may extend from a second attachment point on the deck structure to another location on the support collar. In some cases, the braces may be arranged in a symmetric pattern around the monopile 108 to provide balanced load distribution and enhanced resistance to environmental forces acting from multiple directions.

[0110] In some implementations, the braces 1204(A), 1204(B) may be configured with adjustable length or tension characteristics that allow for fine-tuning of the structural response during operation. The bracing system may also incorporate damping elements or flexible connections that help absorb dynamic loads while maintaining structural integrity. The support collar 1208 may include provisions for additional bracing elements or future modifications to accommodate changing operational requirements or environmental conditions.

[0111] In some cases, the FRP 1200 may also incorporate the mooring and damping systems described in relation to previous figures, including a first hydraulic damper 1002(A) and a second hydraulic damper 1002(B) connected to first mooring line 1006(A) and second mooring line 1006(B), respectively. The mooring lines may extend downward and outward from the hydraulic dampers to connect with first anchor pile 1004(A) and second anchor pile 1004(B) embedded in the ocean floor 112. The combination of structural bracing and mooring systems may work together to provide comprehensive stability and motion control for the platform assembly.

[0112] FIG. 13 illustrates a FRP 1300 configured to support a bridge structure 1302, demonstrating the versatility of the FRP system for marine infrastructure applications, according to some implementations. The FRP 1300 includes a deck or platform structure 104 positioned at the upper portion of the assembly and coupled to an interface piece 106 that connects to a monopile 108. The monopile 108 extends vertically from above the waterline 110, through the water column, and into the ocean floor 112 where it may be embedded to provide foundational support for the platform assembly.

[0113] The bridge structure 1302 may be mounted on or integrated with the deck or platform structure 104 to create a marine crossing or connection point between different locations. In some aspects, the bridge structure 1302 may extend horizontally from the deck structure 104 to span across waterways, connect to adjacent platforms, or provide access routes for marine operations.

The bridge structure 1302 may be configured to support various types of loads including pedestrian traffic, vehicle access, utility lines, or equipment transport depending on the specific application requirements.

[0114] The fully restrained platform 1300 incorporates a mooring system that includes a first hydraulic damper 1002(A) and a second hydraulic damper 1002(B) positioned to provide motion control capabilities for the platform assembly. The first hydraulic damper 1002(A) may be connected to a first mooring line 1006(A), while the second hydraulic damper 1002(B) may be connected to a second mooring line 1006(B). The mooring lines 1006(A), 1006(B) extend downward and outward from their respective hydraulic dampers to provide lateral support and positioning control for the FRP 1300.

[0115] The first mooring line 1006(A) may terminate at a first anchor pile 1004(A), while the second mooring line 1006(B) may terminate at a second anchor pile 1004(B). The anchor piles 1004(A), 1004(B) may be driven or embedded into the ocean floor 112 to provide secure attachment points for the mooring system. In some implementations, the positioning and orientation of the anchor piles may be configured to accommodate the additional loads and moments generated by the bridge structure 1302, ensuring adequate stability and load distribution for the combined platform and bridge assembly.

[0116] The hydraulic dampers 1002(A), 1002(B) may be particularly beneficial for bridge applications where dynamic motions could affect the structural integrity or operational performance of the spanning structure. In some aspects, the damping system may help reduce vibrations and oscillations that could be transmitted through the bridge structure 1302, improving the comfort and safety of users or equipment utilizing the bridge. The mooring configuration may also be adjusted to account for the directional loads and moments that may be imposed by the bridge structure 1302 on the overall platform assembly.

[0117] In some implementations, the bridge structure 1302 may incorporate additional support elements or connections that work in conjunction with the FRP 1300 to distribute loads effectively. The interface between the bridge structure 1302 and the deck or platform structure 104 may include flexible or rigid connections depending on the desired load transfer characteristics and operational requirements. The modular design of the FRP 1300 may allow for various bridge configurations to be accommodated without requiring significant modifications to the underlying monopile 108 or mooring system.

[0118] FIG. 14 illustrates a FRP 1400 that incorporates a truss structure 1402 as an alternative structural configuration for supporting offshore operations, according to some implementations. The FRP 1400 may be positioned in a marine environment with the truss structure 1402 extending between the waterline 110 and the ocean floor 112. In some aspects, the truss structure 1402 may provide an alternative to the monopile configuration de-

scribed in previous figures, offering different structural characteristics and load distribution patterns suitable for specific environmental conditions or operational requirements.

[0119] The truss structure 1402 may comprise a framework of interconnected structural members arranged in a geometric pattern that provides structural support while reducing the overall material requirements compared to solid structural elements. In some implementations, the truss structure 1402 may include diagonal bracing members, vertical supports, and horizontal elements that work together to transfer loads from the platform assembly to the ocean floor 112. The open framework design of the truss structure 1402 may also reduce hydrodynamic loading by allowing water flow to pass through the structure rather than creating solid resistance surfaces.

[0120] The fully restrained platform 1400 incorporates a mooring system that includes a first hydraulic damper 1002(A) and a second hydraulic damper 1002(B) positioned on opposite sides of the truss structure 1402 to provide motion control capabilities. The hydraulic dampers 1002(A), 1002(B) may be configured to reduce dynamic responses and vibrations of the platform assembly when subjected to environmental forces such as waves, currents, and wind loads. In some aspects, the hydraulic dampers may be particularly effective when used in conjunction with the truss structure 1402, as the open framework may reduce the environmental load experienced by the FRP 1400 at the waterline 110 where the environmental forces are often strongest.

[0121] As discussed above, the first hydraulic damper 1002(A) may be connected to a first mooring line 1006(A), while the second hydraulic damper 1002(B) may be connected to a second mooring line 1006(B). The mooring lines 1006(A), 1006(B) extend downward and outward from their respective hydraulic dampers to provide lateral support and positioning control for the FRP 1400. In some implementations, the mooring lines may be attached to the truss structure 1402 at strategic locations that optimize load distribution and minimize stress concentrations within the framework.

[0122] The first mooring line 1006(A) may terminate at a first anchor pile 1004(A), while the second mooring line 1006(B) may terminate at a second anchor pile 1004(B). The anchor piles 1004(A), 1004(B) may be driven or embedded into the ocean floor 112 to provide secure attachment points for the mooring system. In some cases, the anchor pile positioning may be configured to work effectively with the truss structure 1402 geometry, taking into account the distributed load paths and connection points available within the framework.

[0123] The truss structure 1402 may offer advantages in certain applications where reduced hydrodynamic loading is desired or where the structural requirements can be met with a more distributed load-bearing system. In some implementations, the truss structure 1402 may be configured with variable member sizes or arrangements to optimize performance for specific environmen-

tal conditions or operational loads. The framework design may also facilitate maintenance access and inspection activities compared to solid structural elements.

[0124] FIG. 15 illustrates a plan view of a FRP 1500 that incorporates a comprehensive multi-directional mooring system to provide enhanced omnidirectional stability and load distribution, according to some implementations. The fully restrained platform 1500 includes a central monopile 108 positioned at the center of the mooring arrangement, with multiple mooring lines extending radially outward in different directions to create a balanced anchoring system that may resist environmental forces from various orientations.

[0125] The mooring system includes six mooring lines arranged in a symmetric pattern around the monopile 108. A first mooring line 1502 extends from the monopile 108 in a first direction, while a second mooring line 1504 extends in a second direction that may be positioned at approximately 60 degrees from the first mooring line 1502. A third mooring line 1506 may be positioned at approximately 120 degrees from the first mooring line 1502, creating a triangular arrangement with the first and second mooring lines. The pattern continues with a fourth mooring line 1508 positioned opposite to the first mooring line 1502, a fifth mooring line 1510 positioned opposite to the second mooring line 1504, and a sixth mooring line 1512 positioned opposite to the third mooring line 1506.

[0126] In some implementations, the six-point mooring arrangement may provide superior stability characteristics compared to conventional two-point or four-point mooring systems by distributing environmental loads more evenly around the circumference of the monopile 108. The symmetric positioning of the mooring lines 1502, 1504, 1506, 1508, 1510, 1512 may help minimize torsional forces and reduce stress concentrations that might occur with asymmetric mooring configurations. The radial arrangement may also provide redundancy in the mooring system, ensuring continued platform stability even if individual mooring lines experience wear or require maintenance.

[0127] In some implementations, the number of mooring lines may be varied based on specific application requirements and environmental conditions. Alternative configurations may include five mooring lines arranged at 72-degree intervals around the monopile 108, providing a pentagonal mooring pattern that may offer enhanced stability characteristics for certain loading conditions. In some cases, seven mooring lines may be utilized, positioned at approximately 51.4-degree intervals to create a heptagonal arrangement that may provide increased redundancy and load distribution capabilities.

[0128] For applications requiring enhanced stability or operating in particularly harsh environmental conditions, the mooring system may incorporate ten or more mooring lines arranged around the circumference of the monopile 108. In some aspects, a ten-point mooring arrangement with lines positioned at 36-degree intervals, or more, may provide superior omnidirectional stability and load dis-

tribution compared to configurations with fewer mooring points. The increased number of mooring lines may also provide additional redundancy, allowing the platform to maintain stability even if multiple mooring lines require maintenance or experience operational issues.

[0129] In some cases, the selection of the number of mooring lines may be based on factors such as the magnitude of expected environmental loads, the size and weight of the payload, water depth, soil conditions at the anchor points, and operational requirements. Configurations with fewer mooring lines, such as three or four points, may be suitable for smaller platforms or applications in more benign environmental conditions, while configurations with eight, twelve, or more mooring points may be appropriate for larger platforms or installations in severe environmental conditions.

[0130] The multi-directional mooring configuration shown in FIG. 15 may be particularly beneficial for applications where the fully restrained platform 1500 may experience environmental loads from varying directions throughout different seasons or weather conditions. In some implementations, the six-point arrangement may provide enhanced resistance to rotating environmental forces such as those generated by tropical storms or changing current patterns. The mooring system may also be configured with different line tensions or damping characteristics for individual mooring lines to optimize performance for prevailing environmental conditions at the installation site.

[0131] In the illustrated example, each of the mooring lines 1502, 1504, 1506, 1508, 1510, 1512 may extend from the monopile 108 to corresponding anchor points embedded in the ocean floor at predetermined distances and orientations. In some aspects, the anchor points may be positioned at equal radial distances from the monopile 108 to create a uniform load distribution pattern, or they may be positioned at varying distances to accommodate specific site conditions or operational requirements. The mooring lines may incorporate hydraulic dampers or other motion control devices similar to those described in previous figures to provide dynamic response control and vibration reduction.

[0132] FIG. 16 illustrates a monopile 108 of a FRP 1600 that demonstrates the attachment configuration for top mooring assemblies, according to some implementations. The monopile 108 extends vertically and may be configured to support various types of mooring and damping systems at different elevations along its structure. In some aspects, the monopile 108 may include reinforced attachment points or mounting brackets that provide secure connection interfaces for mooring hardware and damping equipment.

[0133] The FRP 1600 incorporates a first top mooring assembly 1602(A) and a second top mooring assembly 1602(B) positioned at strategic locations on the monopile 108. In some implementations, the top mooring assemblies 1602(A), 1602(B) may be mounted at predetermined elevations that optimize load distribution and pro-

vide effective resistance to environmental forces acting on the platform structure. The positioning of these assemblies may be selected based on factors such as expected wave heights, current patterns, and the overall structural dynamics of the platform system.

[0134] The first top mooring assembly 1602(A) may be connected to a first mooring line 1604(A), while the second top mooring assembly 1602(B) may be connected to a second mooring line 1604(B). In some aspects, the mooring lines 1604(A), 1604(B) extend downward and outward from their respective top mooring assemblies at predetermined angles to provide lateral support and positioning control for the monopile 108. The angular orientation of the mooring lines may be configured to optimize the restraint characteristics and load distribution patterns based on the specific environmental conditions and operational requirements at the installation site.

[0135] In some implementations, the top mooring assemblies 1602(A), 1602(B) may incorporate various types of connection hardware such as shackles, clevis pins, or specialized marine connectors that provide reliable attachment points for the mooring lines 1604(A), 1604(B). The assemblies may also include provisions for adjustment or tensioning of the mooring lines to accommodate installation tolerances or operational requirements. In some cases, the top mooring assemblies may be configured with swivel connections or universal joints that allow for multi-directional movement while maintaining secure attachment to the mooring lines.

[0136] The mooring lines 1604(A), 1604(B) may comprise various materials such as steel cables, synthetic ropes, or chain segments depending on the specific load requirements and environmental conditions. In some aspects, the mooring lines may incorporate different sections with varying properties, such as chain segments near the anchor points for abrasion resistance and synthetic rope sections in the upper portions for reduced weight and improved fatigue characteristics. The selection of mooring line materials and configurations may be based on factors such as water depth, expected loads, corrosion resistance requirements, and maintenance considerations.

[0137] In some implementations, the first mooring line 1604(A) and second mooring line 1604(B) may extend to anchor points embedded in the ocean floor at predetermined distances and orientations from the monopile 108. The anchor points may comprise driven piles, drag anchors, or other anchoring systems suitable for the specific soil conditions and load requirements at the installation site. The positioning and capacity of the anchor points may be configured to provide adequate holding power while accommodating the directional loads transmitted through the mooring lines 1604(A), 1604(B).

[0138] The configuration shown in FIG. 16 may represent a portion of a larger mooring system that includes additional mooring lines and assemblies positioned around the circumference of the monopile 108. In some

aspects, the two-point arrangement illustrated may be part of a multi-point mooring system similar to those described in relation to previous figures, with additional mooring assemblies and lines providing comprehensive omnidirectional stability and load distribution capabilities for the fully restrained platform 1600.

[0139] In some implementations, the pair of top mooring assemblies 1602(A), 1602(B) and their associated mooring lines 1604(A), 1604(B) shown in FIG. 16 may represent a typical configuration that may be replicated for each of the mooring lines illustrated in the multi-directional mooring system of FIG. 15. In some aspects, each of the six mooring lines 1502, 1504, 1506, 1508, 1510, 1512 extending radially from the monopile 108 in FIG. 15 may incorporate similar top mooring assembly configurations to provide consistent attachment and damping characteristics around the circumference of the platform.

[0140] FIG. 17 illustrates a monopile 1700 that incorporates structural reinforcement elements to enhance the load-bearing capacity and structural integrity of the cylindrical shell, according to some implementations. The monopile 1700 may be configured with a comprehensive stiffening system that includes both longitudinal and circumferential reinforcement elements arranged in a systematic pattern to optimize structural performance under various loading conditions.

[0141] The monopile 1700 incorporates string stiffeners 1702 that extend longitudinally along the length of the cylindrical structure. In some aspects, the string stiffeners 1702 may be positioned at regular angular intervals around the circumference of the monopile 1700 to provide enhanced resistance to buckling and improve the overall structural stability of the shell. The string stiffeners 1702 may be welded or otherwise attached to the interior or exterior surface of the monopile shell. In some implementations, the string stiffeners 1702 may be positioned to align with or provide additional reinforcement at the coupling locations of the top mooring assemblies, where concentrated loads from the mooring lines are transferred to the monopile structure.

[0142] The monopile 1700 also includes ring stiffeners 1704 that are positioned at predetermined vertical intervals along the height of the structure. In some implementations, the ring stiffeners 1704 may be configured as circumferential reinforcement elements that help maintain the circular cross-sectional geometry of the monopile 1700 under various loading conditions. The ring stiffeners 1704 may help prevent local shell buckling and provide enhanced resistance to external pressure loads that may be encountered during installation or operation in marine environments. In some cases, the ring stiffeners 1704 may be strategically positioned at elevations corresponding to the attachment points of the top mooring assemblies to provide localized reinforcement where mooring loads are introduced into the monopile structure.

[0143] The monopile 1700 incorporates string stiffeners 1702 that extend longitudinally along the length of the

cylindrical structure. In some aspects, the string stiffeners 1702 may be positioned at regular angular intervals around the circumference of the monopile 1700 to provide enhanced resistance to buckling and improve the overall structural stability of the shell. The string stiffeners 1702 may comprise structural elements such as angles, T-sections, or flat bars that are welded or otherwise attached to the interior or exterior surface of the monopile shell to increase the section modulus and moment of inertia of the structure.

[0144] The monopile 1700 also includes ring stiffeners 1704 that are positioned at predetermined vertical intervals along the height of the structure. In some implementations, the ring stiffeners 1704 may be configured as circumferential reinforcement elements that help maintain the circular cross-sectional geometry of the monopile 1700 under various loading conditions. The ring stiffeners 1704 may help prevent local shell buckling and provide enhanced resistance to external pressure loads that may be encountered during installation or operation in marine environments.

[0145] In some aspects, the combination of string stiffeners 1702 and ring stiffeners 1704 may create a grid-like reinforcement pattern that distributes loads effectively throughout the monopile structure. The intersection points between the string stiffeners 1702 and ring stiffeners 1704 may provide enhanced structural continuity and load transfer capabilities, creating a robust framework that may resist various types of environmental and operational loads.

[0146] In some implementations, the stiffening system may provide enhanced fatigue resistance by reducing stress concentrations and improving load distribution throughout the monopile structure. The string stiffeners 1702 and ring stiffeners 1704 may help minimize local deformations and vibrations that could contribute to fatigue damage over the operational life of the platform. The reinforcement elements may also provide improved resistance to dynamic loading conditions such as those generated by wave action, wind forces, or other environmental forces on the platform.

[0147] The stiffened monopile configuration shown in FIG. 17 may be particularly beneficial for applications in deeper water where the monopile 1700 may experience higher environmental loads or where larger diameter structures are required to support substantial payloads. In some aspects, the stiffening system may allow for the use of thinner shell plates while maintaining adequate structural performance, potentially reducing material costs and fabrication complexity compared to unstiffened designs with thicker shell plates.

[0148] FIG. 18 illustrates an assembly 1800 for coupling the deck structure 104 to the monopile 108 that demonstrates a comprehensive structural framework for connecting a deck or platform structure 104 to a monopile 108, according to some implementations. The assembly 1800 may be configured to provide enhanced load distribution and structural stability through a

network of interconnected components that work together to transfer forces between the deck structure and the underlying monopile foundation.

[0149] The interface piece and monopile assembly 1800 incorporates interface receptacles 1804 positioned at strategic locations to accommodate mounting columns from the deck or platform structure 104. In the current example, the interface receptacles 1804 include a first interface receptacle 1804(A), a second interface receptacle 1804(B), a third interface receptacle 1804(C), and a fourth interface receptacle 1804(D) arranged in a geometric pattern that may provide balanced load distribution and enhanced structural stability. In some implementations, the assembly 1800 may incorporate different numbers of interface receptacles, such as three, five, six, or more receptacles, depending on the specific structural requirements and deck configuration. In some aspects, the interface receptacles 1804(A), 1804(B), 1804(C), 1804(D) may be configured with conical or cylindrical geometries that guide mounting columns into proper alignment during installation.

[0150] The assembly 1800 includes end brackets that provide additional structural support and connection points within the framework. In the current example, the end brackets comprise a first end bracket 1802(A), a second end bracket 1802(B), a third end bracket 1802(C), and a fourth end bracket 1802(D) positioned between the interface receptacles to create a distributed support system. In some implementations, the end brackets 1802(A), 1802(B), 1802(C), 1802(D) may be configured to provide intermediate load transfer points and enhance the overall stiffness of the interface assembly. In some cases, other numbers of end brackets may be used, with the number of end brackets 1802 corresponding to the number of receptacles 1804 on the interface piece to provide balanced structural support and load distribution.

[0151] The structural framework of the assembly 1800 incorporates multiple bracing elements that connect the interface receptacles to the end brackets. A first brace 1806(A) extends between the first interface receptacle 1804(A) and the first end bracket 1802(A), while a second brace 1806(B) connects the second interface receptacle 1804(B) to the second end bracket 1802(B). Similarly, a third brace 1806(C) links the third interface receptacle 1804(C) with the third end bracket 1802(C). The assembly also includes a connecting link 1806(D) that extends between the fourth interface receptacle 1804(D) and the fourth end bracket 1802(D).

[0152] In some aspects, the bracing elements may help transfer loads from the deck or platform structure 104 through the interface receptacles to the end brackets and ultimately to the monopile 108. In some implementations, the braces and connecting link may be designed with varying cross-sectional properties to improve structural performance based on expected load patterns and environmental conditions. In some examples, the geometric arrangement of the interface receptacles 1804(A),

1804(B), 1804(C), 1804(D) and end brackets 1802(A), 1802(B), 1802(C), 1802(D) may create a balanced structural system that distributes loads effectively around the circumference of the monopile 108. In some cases, the spacing and positioning of these components may be configured to accommodate various deck structure configurations while maintaining structural integrity and load transfer capabilities. The modular design of the assembly 1800 may allow for adaptation to different payload requirements or operational conditions without requiring significant modifications to the underlying monopile infrastructure.

[0153] FIG. 19 is a flow diagrams illustrating example processes associated with the system discussed herein. The processes are illustrated as a collection of blocks in a logical flow diagram, which represent a sequence of operations, some or all of which can be implemented in hardware, software, or a combination thereof. In the context of software, the blocks represent computer-executable instructions stored on one or more computer-readable media that, when executed by one or more processor(s), perform the recited operations. Generally, computer-executable instructions include routines, programs, objects, components, encryption, deciphering, compressing, recording, data structures and the like that perform particular functions or implement particular abstract data types.

[0154] The order in which the operations are described should not be construed as a limitation. Any number of the described blocks can be combined in any order and/or in parallel to implement the processes, or alternative processes, and not all of the blocks need be executed. For discussion purposes, the processes herein are described with reference to the frameworks, architectures and environments described in the examples herein, although the processes may be implemented in a wide variety of other frameworks, architectures or environments.

[0155] FIG. 19 illustrates a method 1900 for installing and deploying a fully restrained platform in a marine environment, according to some implementations. The method 1900 may be performed using specialized marine construction equipment and installation vessels to establish a stable offshore platform capable of supporting various payloads while minimizing motion in multiple degrees of freedom.

[0156] At 1902, the method 1900 begins with driving a monopile into the ocean floor. In some implementations, the monopile may be positioned at a predetermined location using dynamic positioning systems and driven into the seabed using pile driving hammers, vibratory drivers, or other installation equipment suitable for offshore operations. The driving process may be monitored to achieve specific penetration criteria such as minimum embedment depth, bearing capacity requirements, and lateral resistance specifications based on soil conditions and expected environmental loads.

[0157] At 1904, the method 1900 continues with driving

anchor piles into the ocean floor. The anchor piles may be positioned at predetermined distances and orientations from the monopile to accommodate the planned mooring line geometry and load distribution patterns. In some aspects, the anchor piles may be installed using similar driving techniques as the monopile, with positioning and capacity configured to provide adequate holding power for the anticipated loads from the mooring system.

[0158] At 1906, the method 1900 proceeds with mounting an interface piece atop the monopile. The interface piece may be positioned and aligned with the upper portion of the monopile using marine cranes or other lifting equipment. In some implementations, the interface piece may be configured to mate with the monopile through various coupling mechanisms, including external cap arrangements, internal insertion configurations, or other connection methods that provide secure load transfer between the components.

[0159] At 1908, the method 1900 includes securing the interface piece to the monopile. The securing process may involve various techniques such as tapered interference fits, angled alignment configurations, attaching locking mechanisms, grouting, or combinations thereof. In some cases, the securing process may include injecting grouting material into spaces between the interface piece and monopile to create a continuous load transfer path and eliminate voids in the connection interface. The locking mechanisms may comprise locking pins, hydraulic clamps, wedge-type connectors, cam-operated clamps, or spring-loaded retention devices that provide reliable mechanical connection between the interface piece and monopile.

[0160] At 1910, the method 1900 continues with installing a deck structure atop the interface piece. The deck structure may be positioned using marine cranes and aligned with receptacles or mounting points provided by the interface piece. In some implementations, the deck structure may include mounting columns that correspond to interface receptacles, allowing for guided installation and proper load distribution between the components.

[0161] At 1912, the method 1900 proceeds with securing the interface piece to the deck structure. The securing process may involve engaging mounting columns with interface receptacles, installing bracing elements, or implementing other connection mechanisms that provide structural continuity between the deck structure and the underlying platform foundation. In some aspects, the connection may be designed to accommodate various deck configurations while maintaining structural integrity and load transfer capabilities.

[0162] At 1914, the method 1900 includes securing the monopile to the anchor piles via one or more mooring lines. The mooring lines may be connected between top mooring assemblies mounted on the monopile and the previously installed anchor piles. In some implementations, the mooring system may incorporate hydraulic dampers, tuned mass dampers, or other motion control devices to reduce dynamic responses and improve plat-

form stability under environmental loading conditions.

[0163] At 1916, the method 1900 concludes with securing a payload atop the deck structure. The payload may comprise various types of equipment or facilities such as wind turbines, oil and gas extraction equipment, hydrogen production facilities, offshore charging stations, electrical substations, offshore datacenters, or other marine infrastructure. In some cases, the modular design of the platform may allow for different payload configurations to be accommodated without requiring modifications to the underlying structural components.

[0164] FIG. 20 further illustrates in diagram 2000 a relationship between the natural frequencies of exemplary FRP-monopiles implemented as described herein and wave frequencies. As illustrated in the diagram 2000, the systems and techniques described herein, including the use of high tension mooring lines and associated aspects described herein, may be used to implement an FRP structure with a wave frequency zone substantially below the natural frequencies corresponding to the 6 DOFs. As shown in this diagram, all of the 6 natural frequencies for surge, sway, heave, roll, pitch, and yaw are on the right side of the significant wave frequency (the peak in the diagram) where the wave energy is the largest. Thus, an FRP implemented according to the instant disclosure may experience minimal movement in both normal operating conditions and extreme (e.g., storm) conditions.

[0165] While the examples described herein may refer to FRP used as supporting structures for wind turbines, the disclosed FRP may be used to provide marine support for other objects, systems, and components, such as energy storage units, offshore substations, etc. Because the disclosed FRP-monopiles are not payload sensitive, FRP as described herein may be scaled up and/or down as needed to support objects having a wide range of mass.

[0166] As described throughout the instant disclosure, mooring lines may be used to provide further stability to an FRP. Mooring lines may be configured to maintain tension, in some examples, within a tension range. Over time, such mooring lines may loosen due to dynamic forces (e.g., wind, waves, currents, etc.). This loosening may result in mooring line tension falling outside of a design tension range, therefore reducing the ability of the loosened mooring lines to mitigate motion in the 6 DOFs. While re-tensioning systems and techniques have been successfully implemented for land-based applications and for floating marine platforms, these systems and techniques have not been successfully implemented for mooring lines used to stabilize fixed marine structures.

[0167] For example, the various systems and techniques available for re-tensioning in floating structures typically involve large increases or decreases in tension, preventing the fine tension adjustment often needed for FRP-monopile mooring lines. The various systems and techniques available for re-tensioning in land-based structures typically use less robust stabilizing compo-

nents due to land-based structures being subject to lower axial loads (e.g., lower levels of motion in the 6 DOFs). FRP-monopile structures 1210 require stabilizing systems and techniques that address the higher axial loads to which such structures are subject while providing finer tension adjustment. The FRP-monopile structure stabilizing systems and techniques described herein address these issues while providing safer, easier, and more cost-effective means of applying and adjusting tension in the environments in which such structures are typically located.

[0168] For example, in a FRP monopile design, all its motions (namely surge, sway, heave, roll, pitch, and yaw) are restrained by the monopile and the moorings. In general, an FRP monopile is a stiffness-controlled structure with its lateral stiffness, e.g., produced by a combination of the monopile and the moorings, can be on the order of 30,000 kN/m. The vertical stiffness is on the order of 5,000,000 kN/m. For supporting a turbine with a payload under 3,000 MT (a downward force of 29,420 kN), the vertical stiffness is significantly high. As a result, all of its six natural frequencies (corresponding to the 6 DOF motions) are above the significant wave frequency zone. Consequently, this structure has less movement in normal operations and even storm conditions.

[0169] Based on the foregoing, it should be appreciated that technologies for minimizing movement of a fixed marine structure that may support a wind turbine have been presented herein. The subject matter described above is provided by way of illustration only and should not be construed as limiting. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure. Various modifications and changes may be made to the subject matter described herein without following the examples and applications illustrated and described, and without departing from the true spirit and scope of the present invention, which is set forth in the following claims.

[0170] Although the discussion above sets forth example implementations of the described techniques, other architectures may be used to implement the described functionality and are intended to be within the scope of this disclosure. Furthermore, although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as exemplary forms of implementing the claims.

Example clauses

[0171]

A. A fully restrained platform for ocean deployment may comprise a monopile configured to be driven

into an ocean floor and extending vertically through a waterline, and an interface piece mounted atop the monopile, the interface piece including a first plurality of interface receptacles. The platform may include a deck structure coupled to the interface piece, the deck structure including a second plurality of mounting columns configured to align with and engage the interface receptacles of the interface piece, and a payload mounted on the deck structure.

B. The fully restrained platform of example A may include a configuration where the interface piece includes a truss portion and a cap portion, the cap portion to mate over a top portion of the monopile.

C. The fully restrained platform of example B may include a configuration where the top portion of the monopile is tapered to increase friction with regards to the cap of the interface piece when assembled.

D. The fully restrained platform of example A may include a configuration where the monopile has a top portion including a cavity, the interface piece includes a lower portion to mate within the cavity, and walls of the cavity are arranged at an angle and/or tapered to increase friction between the monopile and the interface piece when assembled.

E. The fully restrained platform of any of examples A-D may further comprise a tuned mass damper mounted on the monopile above the waterline.

F. The fully restrained platform of example E may include a configuration where the tuned mass damper comprises a sloshing tank partially filled with liquid, the liquid configured to move within the sloshing tank in response to environmental loads impacting the fully restrained platform.

G. The fully restrained platform of any of examples A-F may include a configuration where a number of the first plurality of interface receptacles of the interface piece is greater than or equal to a number of the second plurality of mounting columns of the deck structure.

H. The fully restrained platform of any of examples A-G may include a configuration where a number of the second plurality of mounting columns of the deck structure is greater than or equal to a number of the plurality of interface receptacles of the interface piece.

I. The fully restrained platform of any of examples A-H may include a configuration where the interface piece is secured to the monopile via grouting.

J. The fully restrained platform of any of examples A-I

may include a configuration where the interface piece is secured to the monopile via one or more locking mechanisms.

K. The fully restrained platform of any of examples A-J may include a configuration where the monopile includes at least one top mooring assembly incorporating a hydraulic damper, the at least one top mooring assembly coupled to an anchor pile via a mooring line.

L. A fully restrained platform for ocean deployment may comprise a monopile driven into an seabed floor and extending vertically upward past a waterline, an interface piece including a cap mounted over a top portion of the monopile, the interface piece including a first plurality of interface receptacles, and a deck structure including a second plurality of mounting columns coupled to corresponding one of the first plurality of the interface receptacles of the interface piece.

M. The fully restrained platform of example L may include a configuration where the monopile includes an open truss structure that extends from below the waterline to above the waterline.

N. The fully restrained platform of examples L or M may further comprise a support collar mounted around the monopile and one or more braces extending between the deck structure and the support collar to provide additional structural stiffness and load transfer capabilities between the deck structure and the monopile.

O. The fully restrained platform of any of examples L-N may further comprise a payload mounted on the deck structure.

P. The fully restrained platform of example O may include a configuration where the payload comprises one or more of a wind turbine, oil and gas extraction equipment, offshore charging stations, electrical substations, offshore datacenters, bridge structures, offshore substations, weather monitoring stations, or research facilities.

Q. The fully restrained platform of any of examples L-P may include a configuration where the monopile includes a moonpool.

R. The fully restrained platform of any of examples L-Q may include a configuration where at least a portion of a wall of the monopile is reinforced with at least one of string stiffeners or ring stiffeners.

S. A method of installing a fully restrained platform in a marine environment may comprise driving a mono-

pile into an ocean floor, mounting an interface piece atop the monopile, the interface piece including a plurality of interface receptacles, installing a deck structure atop the interface piece via mating a plurality of mounting columns of the deck structure and the plurality of interface receptacles of the interface piece, and securing a payload atop the deck structure.

T. The method of example S may further comprise driving anchor piles into the ocean floor at predetermined distances from the monopile, securing the monopile to the anchor piles via one or more mooring lines, securing the interface piece to the monopile, and securing the deck structure to the interface piece.

[0172] While the example clauses described above are described with respect to one particular implementation, it should be understood that, in the context of this document, the content of the example clauses can also be implemented via a method, device, system, a computer-readable medium, and/or another implementation. Additionally, any of examples may be implemented alone or in combination with any other one or more of the other examples.

Claims

1. A fully restrained platform (100) for ocean deployment comprising:

a monopile (108) configured to be driven into an ocean floor (112) and extending vertically through a waterline (110);
an interface piece (106) mounted atop the monopile (108), the interface piece including a first plurality of interface receptacles (204);
a deck structure (104) coupled to the interface piece (106), the deck structure (104) including a second plurality of mounting columns (206) configured to align with and engage the interface receptacles (204) of the interface piece (106); and
a payload (102) mounted on the deck structure (104).

2. The fully restrained platform of claim 1, wherein the interface piece (106) includes a truss portion (306) and a cap portion (308), the cap portion (308) to mate over a top portion of the monopile (108).

3. The fully restrained platform of claim 2, wherein the top portion of the monopile (108) is tapered to increase friction with regards to the cap (308) of the interface piece (106) when assembled.

4. The fully restrained platform of any of claims 1-3, wherein:

the monopile (108) has a top portion including a cavity;
the interface piece (106) includes a lower portion to mate within the cavity; and
walls of the cavity are arranged at an angle and/or tapered to increase friction between the monopile (108) and the interface piece (106) when assembled.

5. The fully restrained platform of any of claims 1-4, wherein a number of the first plurality of interface receptacles (204) of the interface piece (106) is greater than or equal to a number of the second plurality of mounting columns (206) of the deck structure (104).

6. The fully restrained platform of any of claims 1-5, wherein a number of the second plurality of mounting columns (206) of the deck structure (104) is greater than or equal to a number of the plurality of interface receptacles (204) of the interface piece (106).

7. The fully restrained platform of any of claims 1-6, wherein the interface piece (106) is secured to the monopile (108) via grouting (702).

8. The fully restrained platform of any of claims 1-7, wherein the interface piece (106) is secured to the monopile (108) via one or more locking mechanisms (602).

9. The fully restrained platform of any of claims 1-8, wherein the monopile (108) includes at least one top mooring assembly (1002; 1102) incorporating a hydraulic damper (1002; 1102), the at least one top mooring assembly (1002; 1102) coupled to an anchor pile (1004) via a mooring line (1006; 1104).

10. A fully restrained platform (100) for ocean deployment comprising:

a monopile (108) driven into a seabed floor (112) and extending vertically upward past a waterline (110);
an interface piece (106) including a cap (308) mounted over a top portion of the monopile (108), the interface piece (106) including a first plurality of interface receptacles (204); and
a deck structure (104) including a second plurality of mounting columns (206) coupled to corresponding one of the first plurality of the interface receptacles (204) of the interface piece (106).

11. The fully restrained platform of claim 10, wherein the

monopile (108) includes an open truss structure (1402) that extends from below the waterline (110) to above the waterline (110).

12. The fully restrained platform of claims 10 or 11, further comprising:

a support collar (1208) mounted around the monopile (108); and
one or more braces (1204) extending between the deck structure (140) and the support collar (1208) to provide additional structural stiffness and load transfer capabilities between the deck structure (104) and the monopile (108).

13. The fully restrained platform of any of claims 10-12, further comprising a payload (102; 1302) mounted on the deck structure (104).

14. The fully restrained platform of any of claims 10-13, wherein the monopile (108) includes a moonpool (210).

15. The fully restrained platform of any of claims 10-14, wherein at least a portion of a wall of the monopile (108) is reinforced with at least one of string stiffeners (1702) or ring stiffeners (1704).

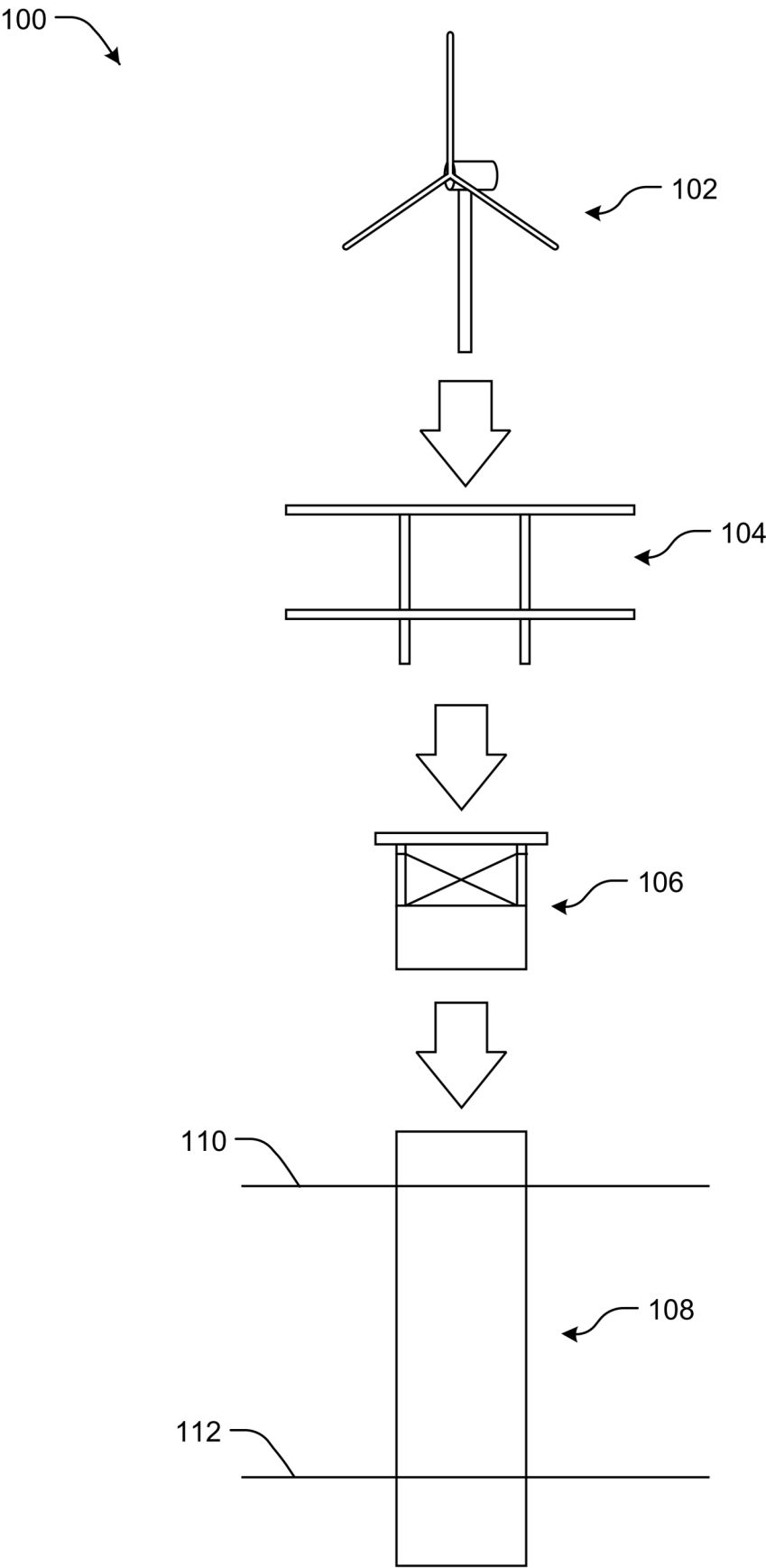


Fig. 1

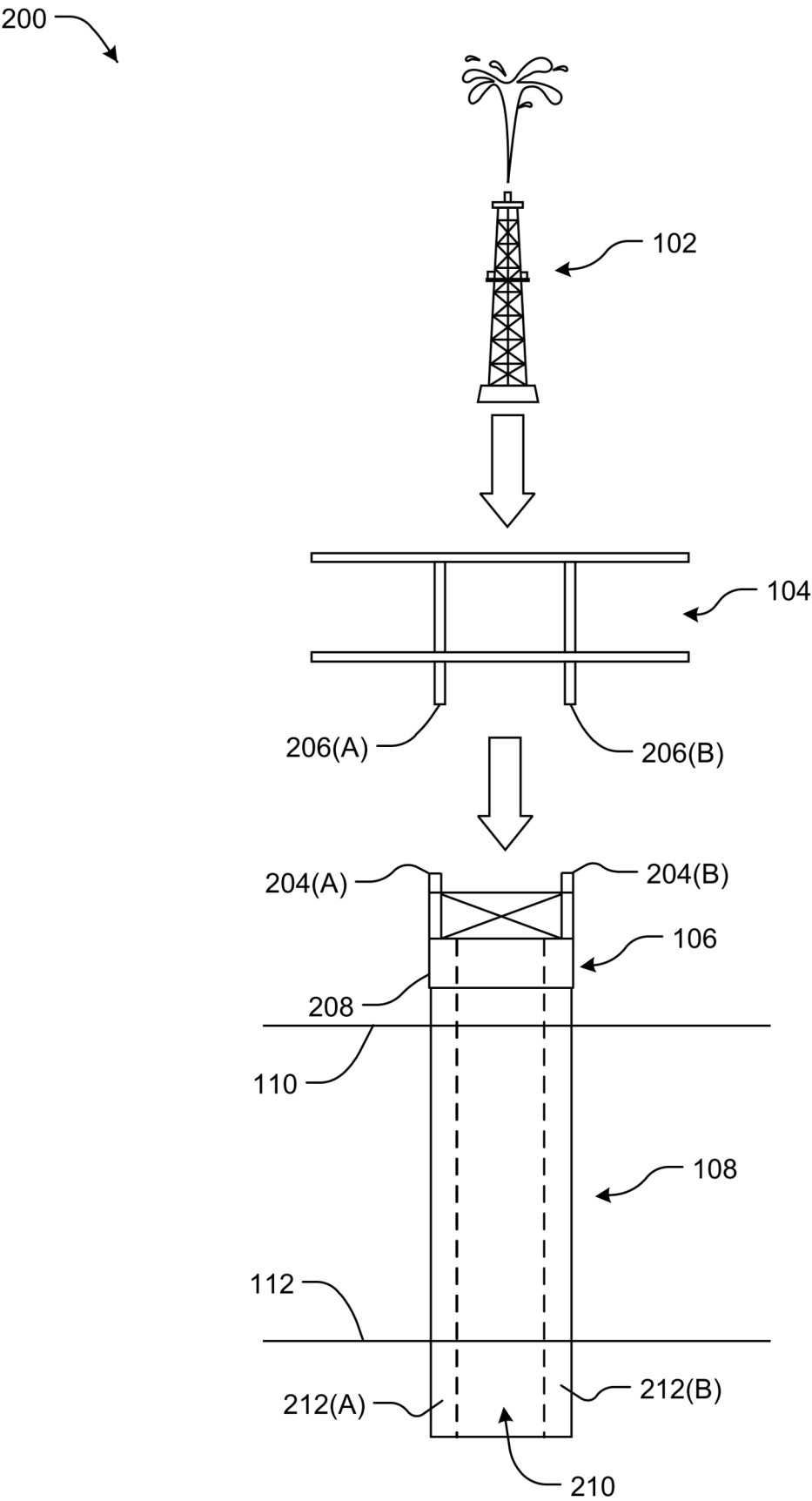


Fig. 2

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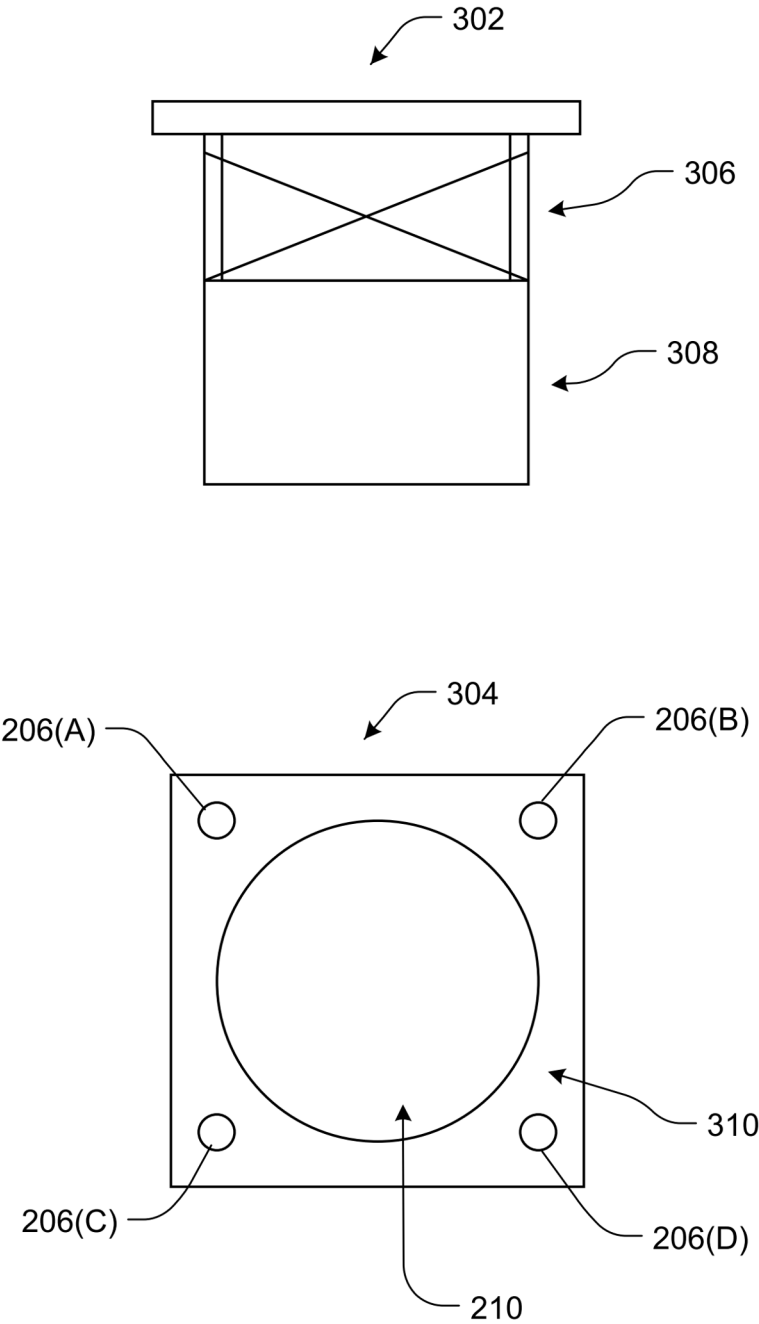


Fig. 3

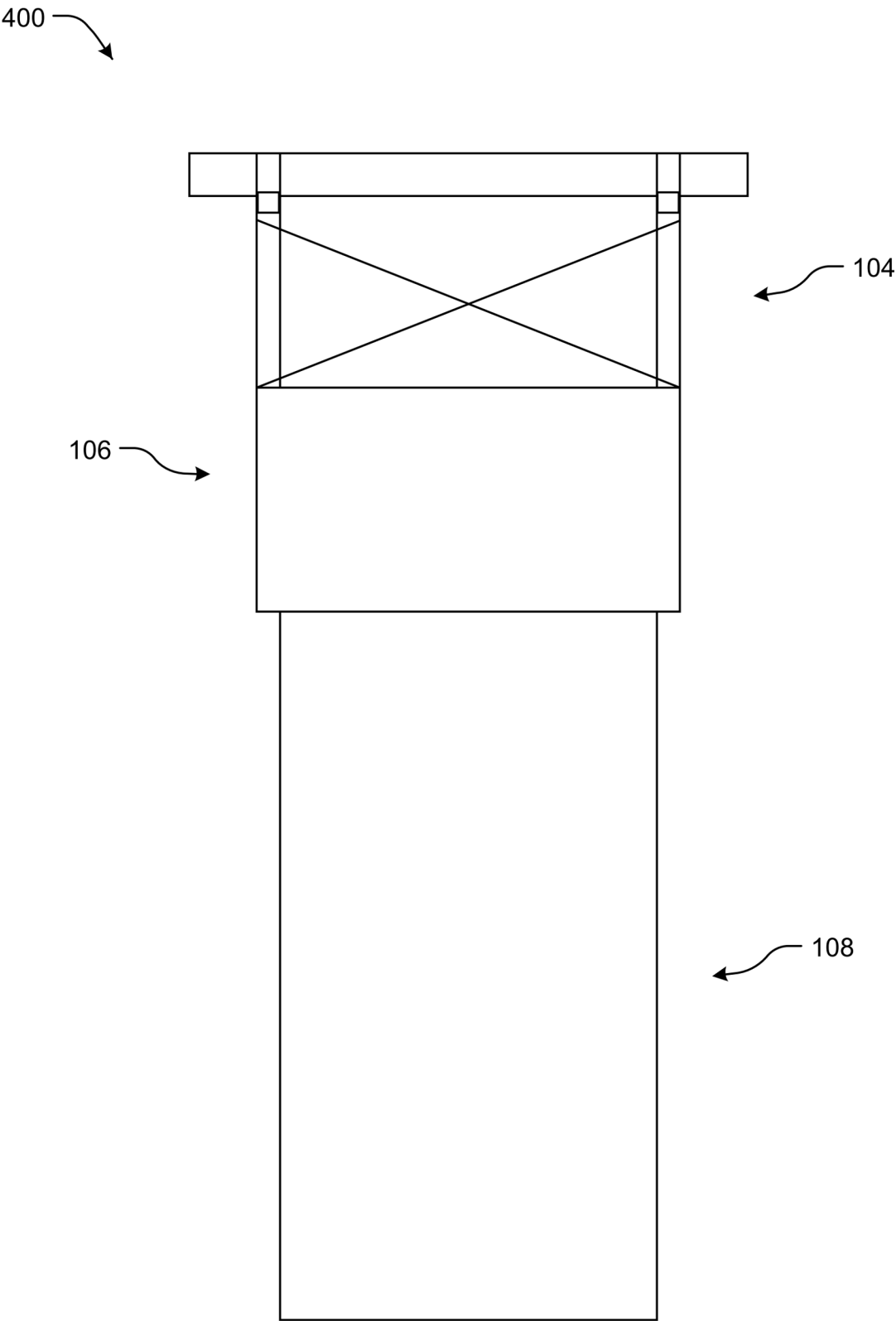


Fig. 4

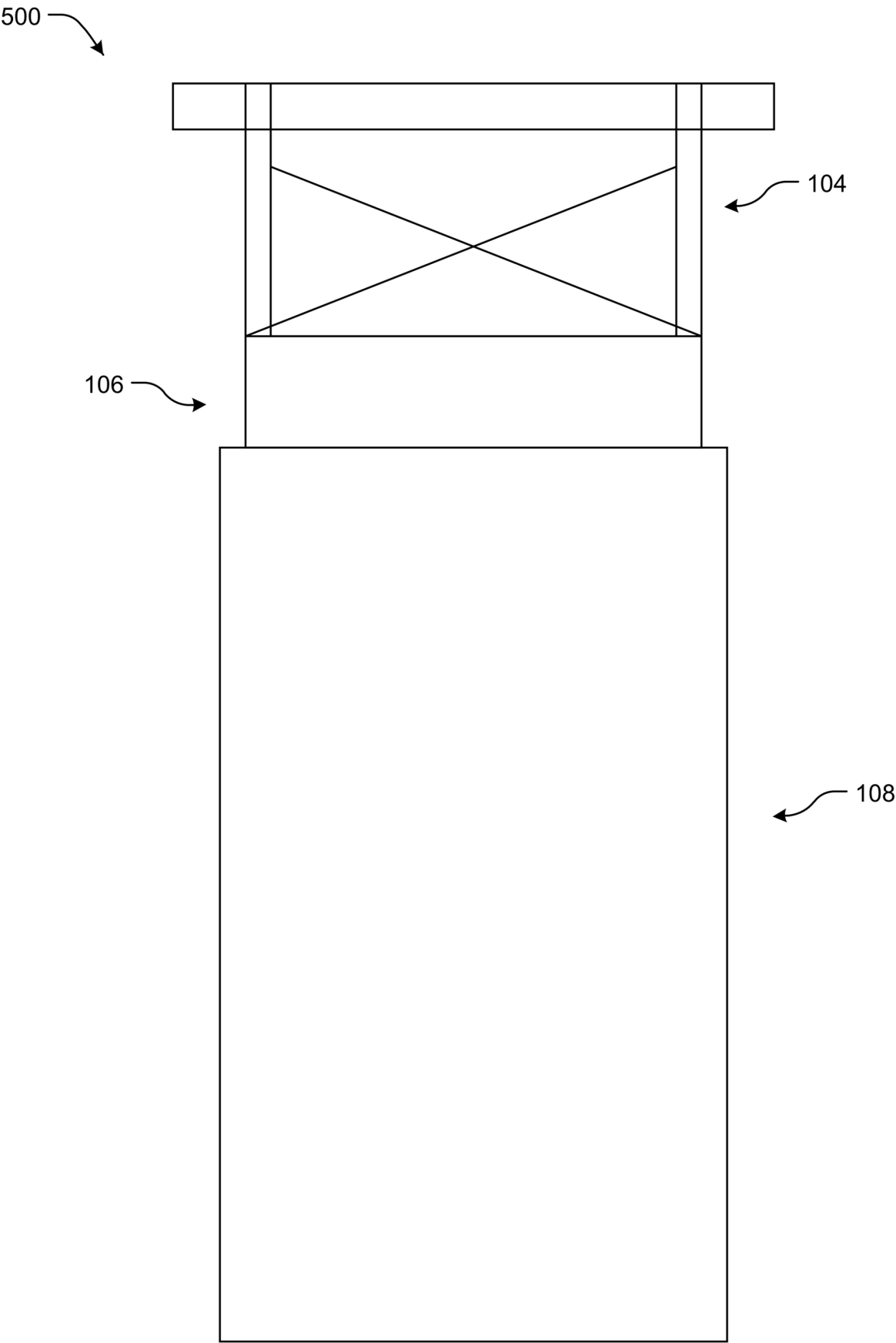


Fig. 5

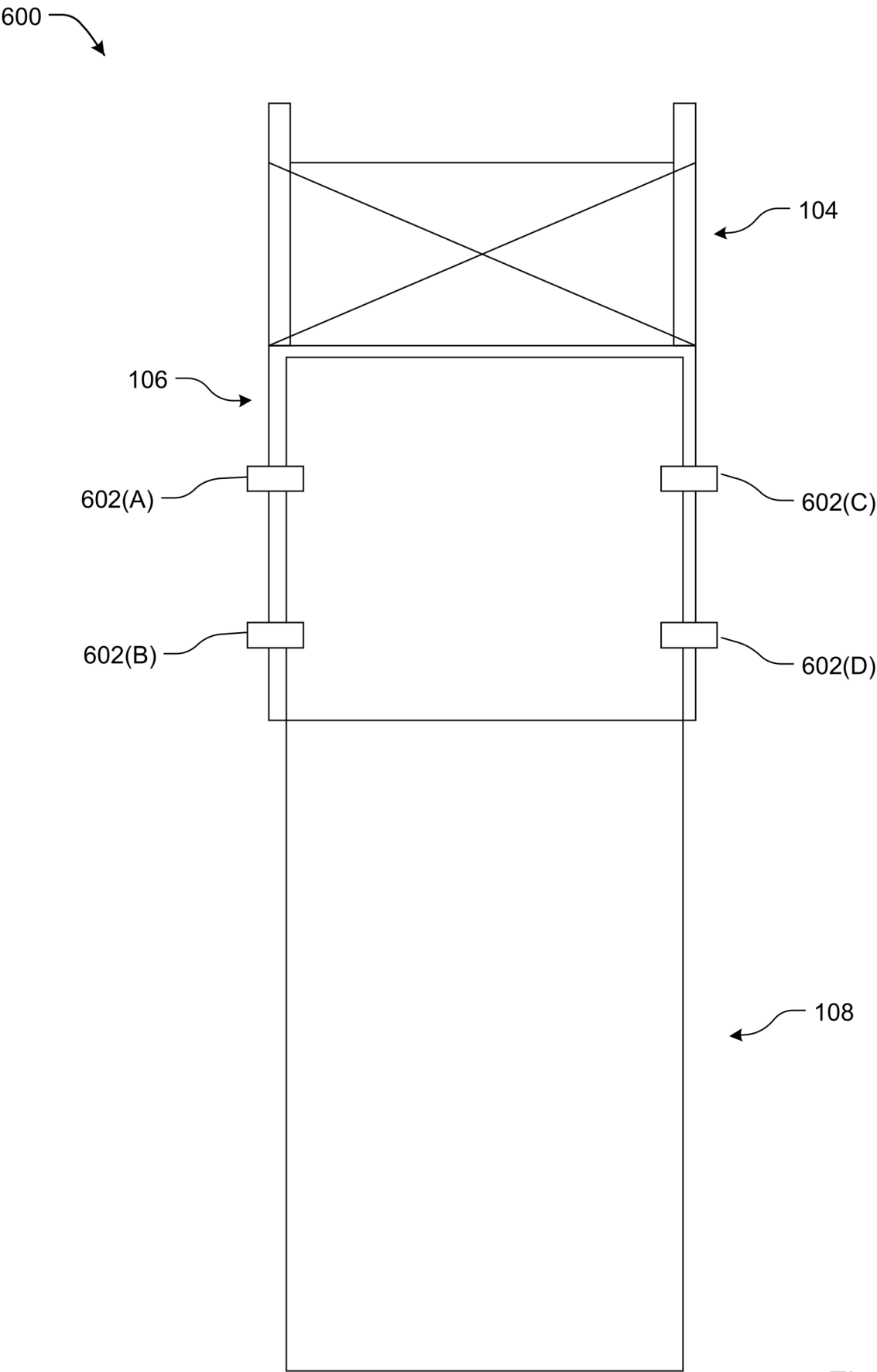


Fig. 6

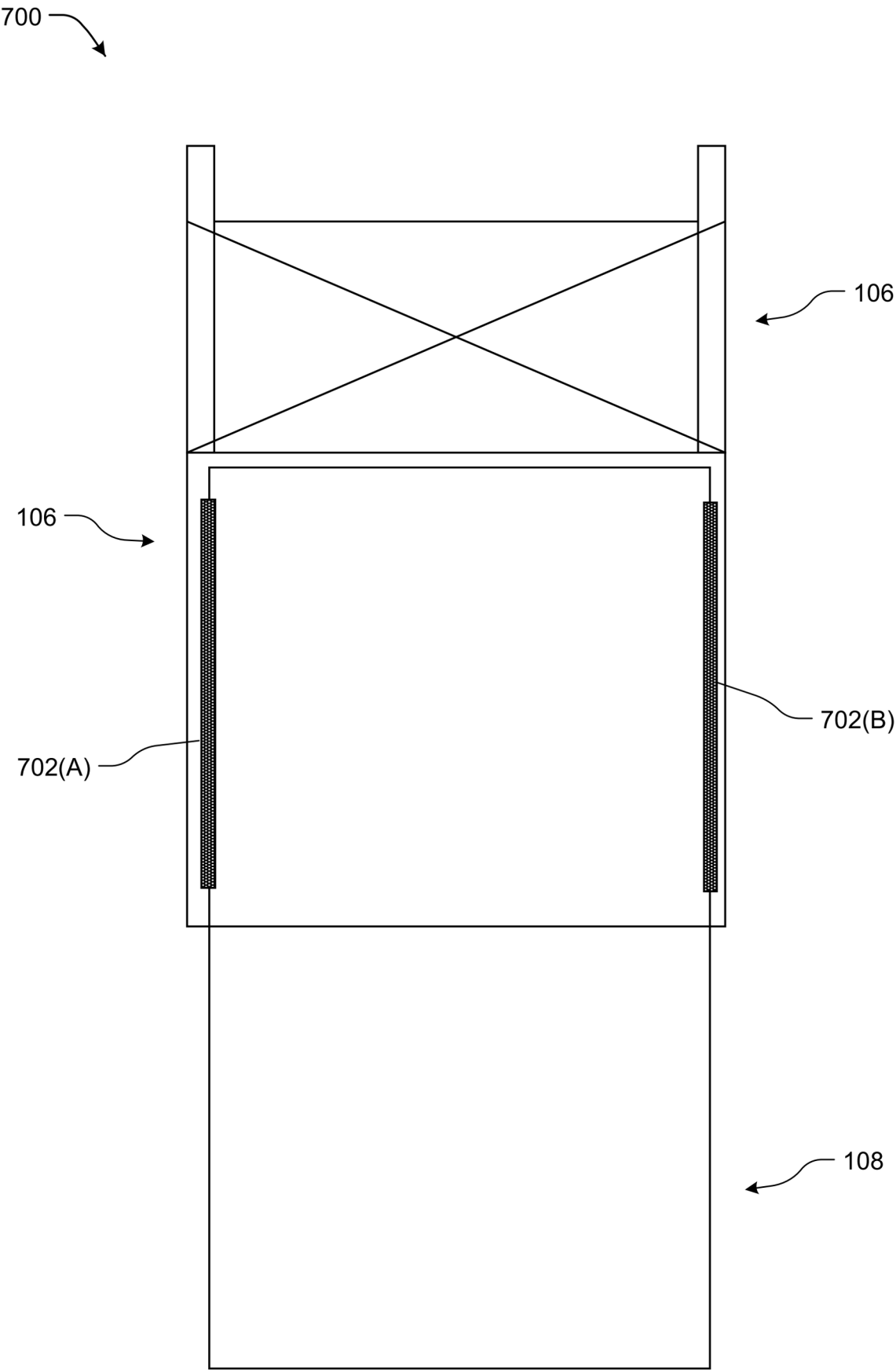


Fig. 7

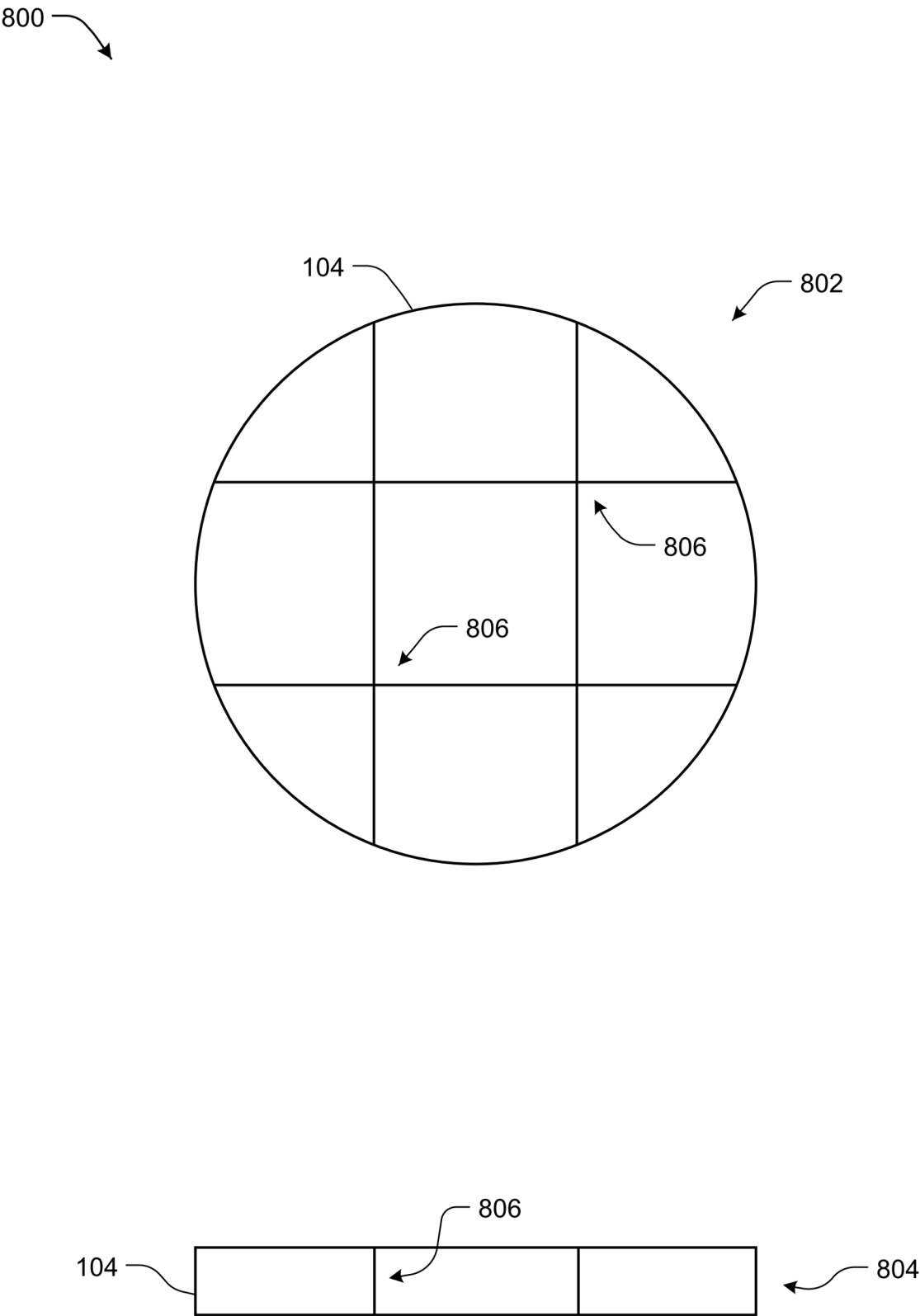


Fig. 8

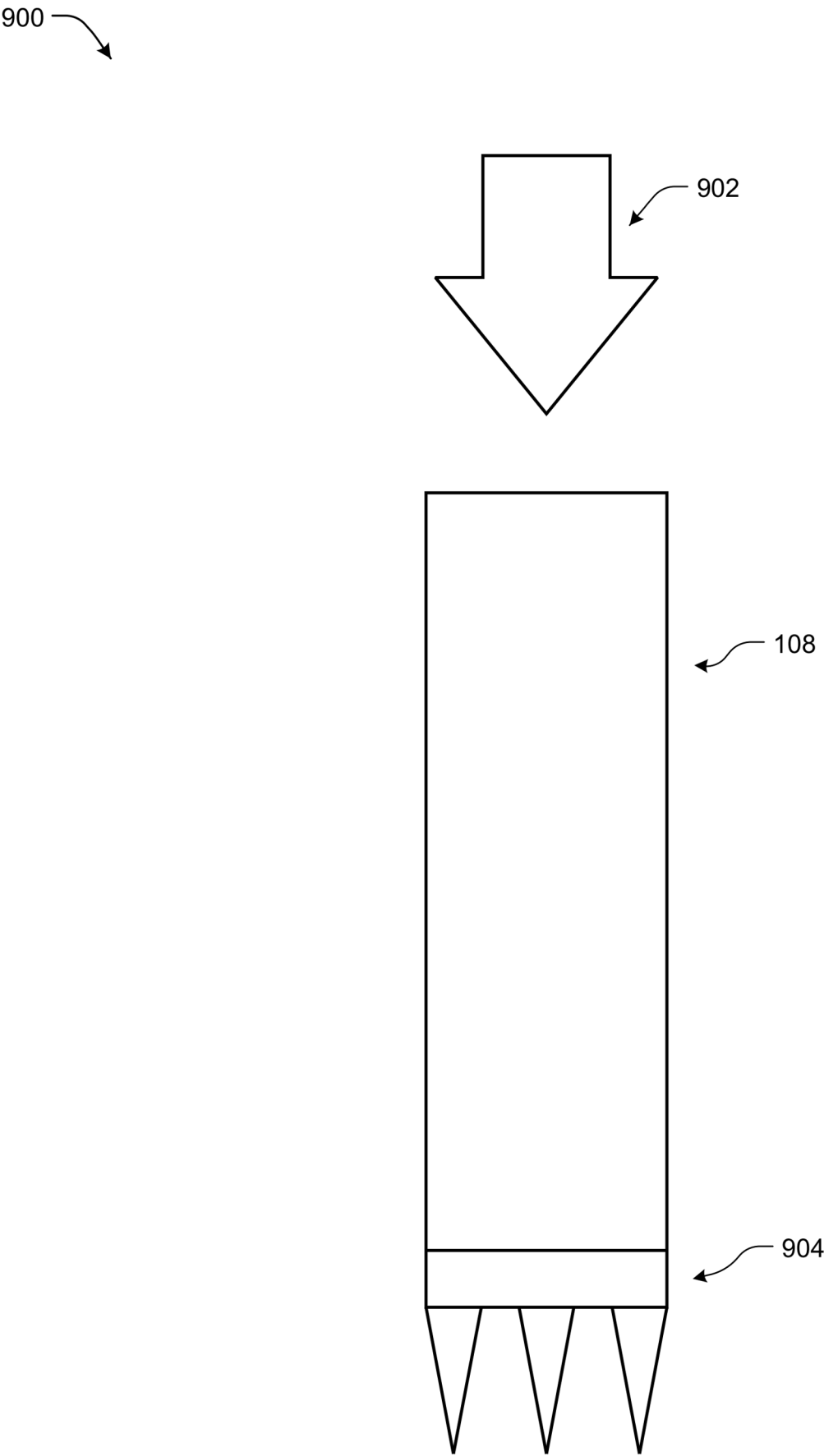


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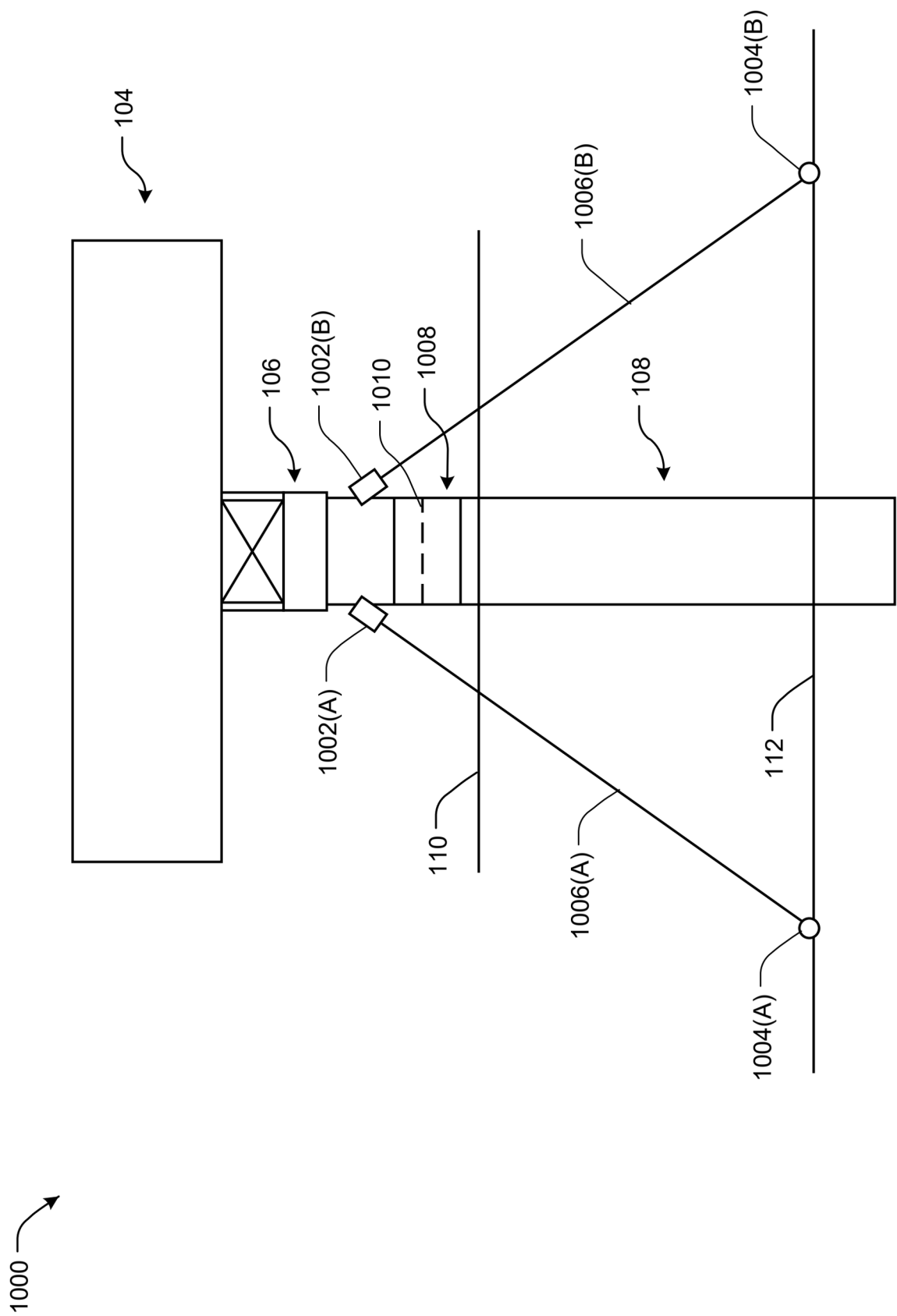


Fig. 10

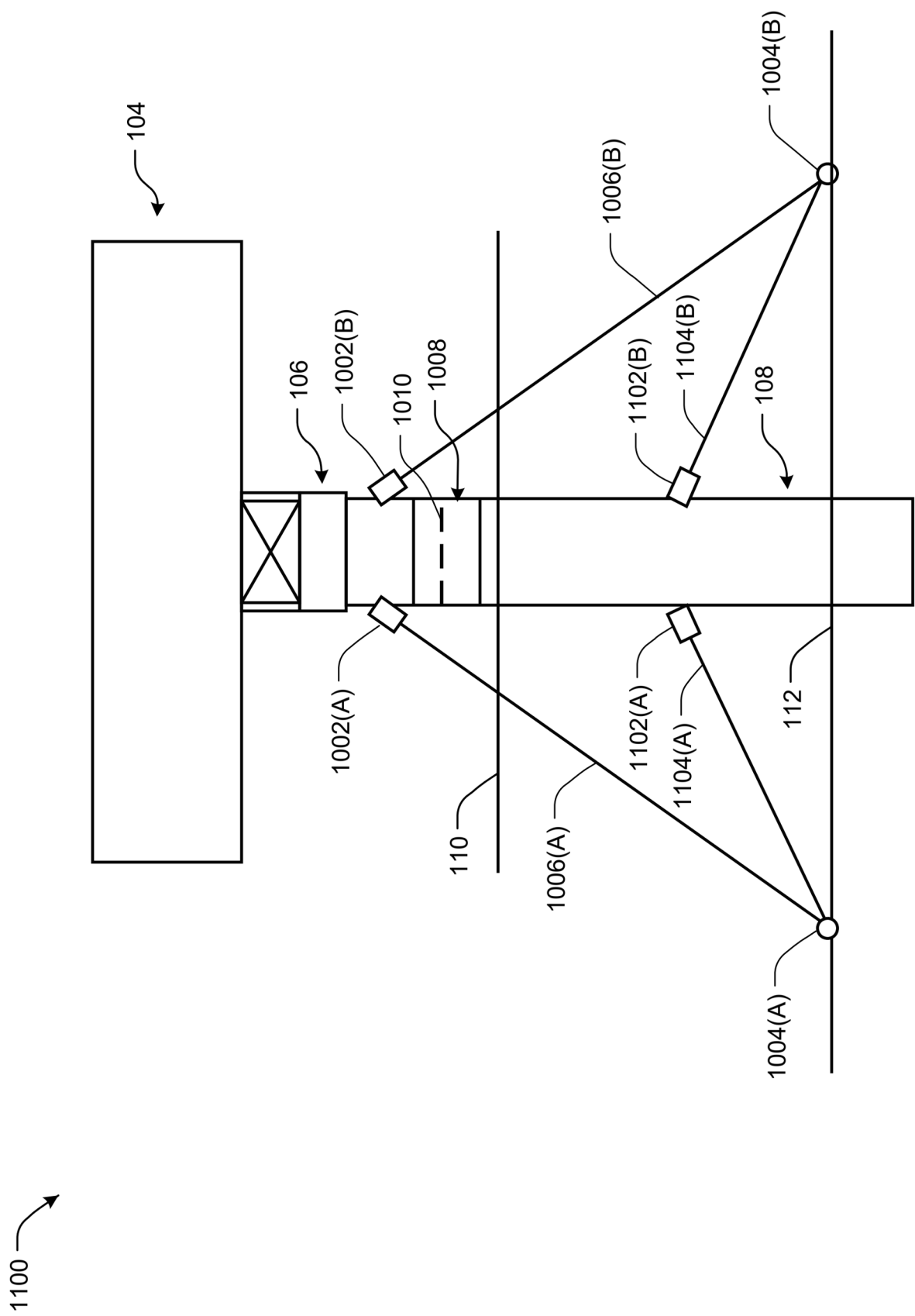


Fig. 11

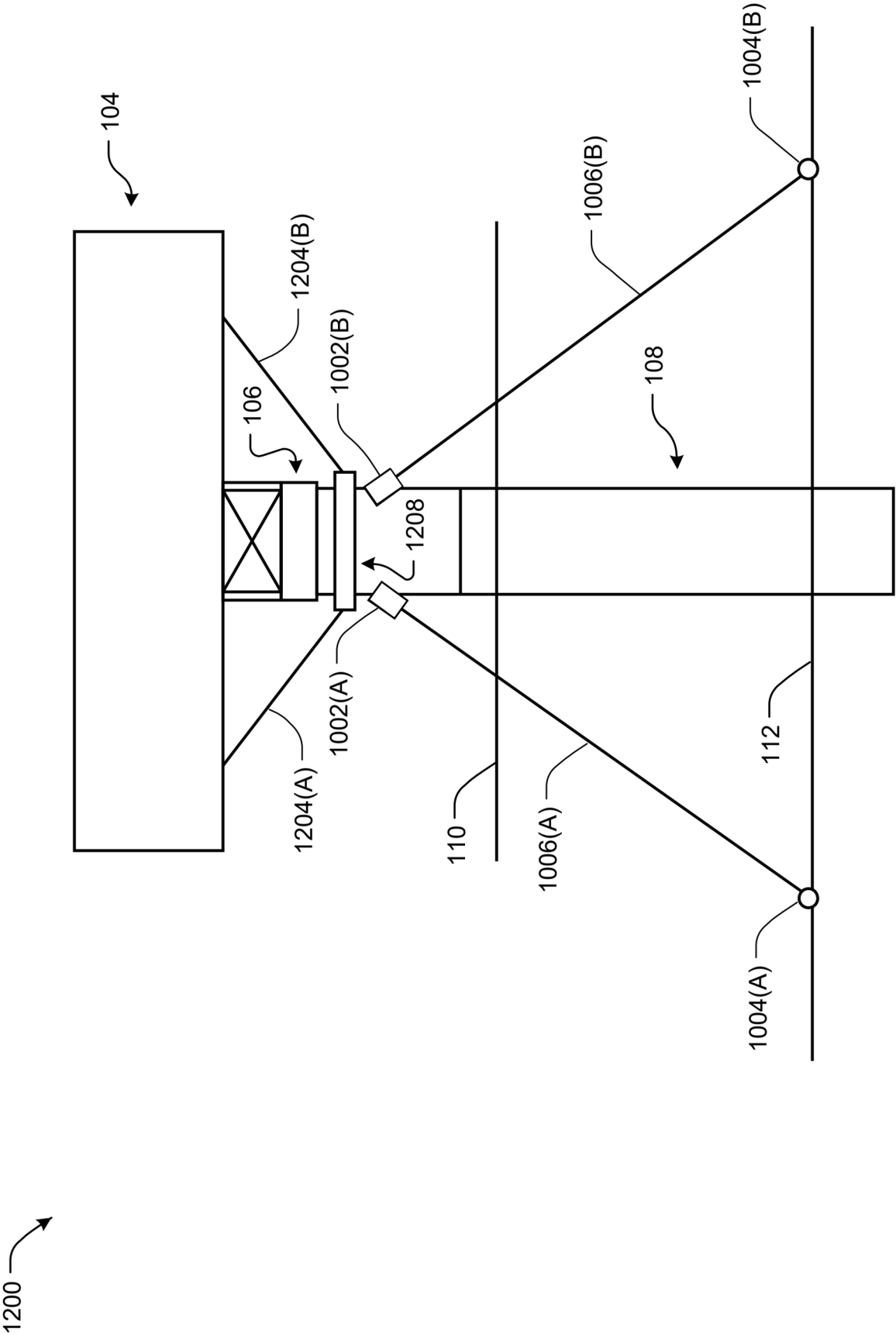


Fig. 12

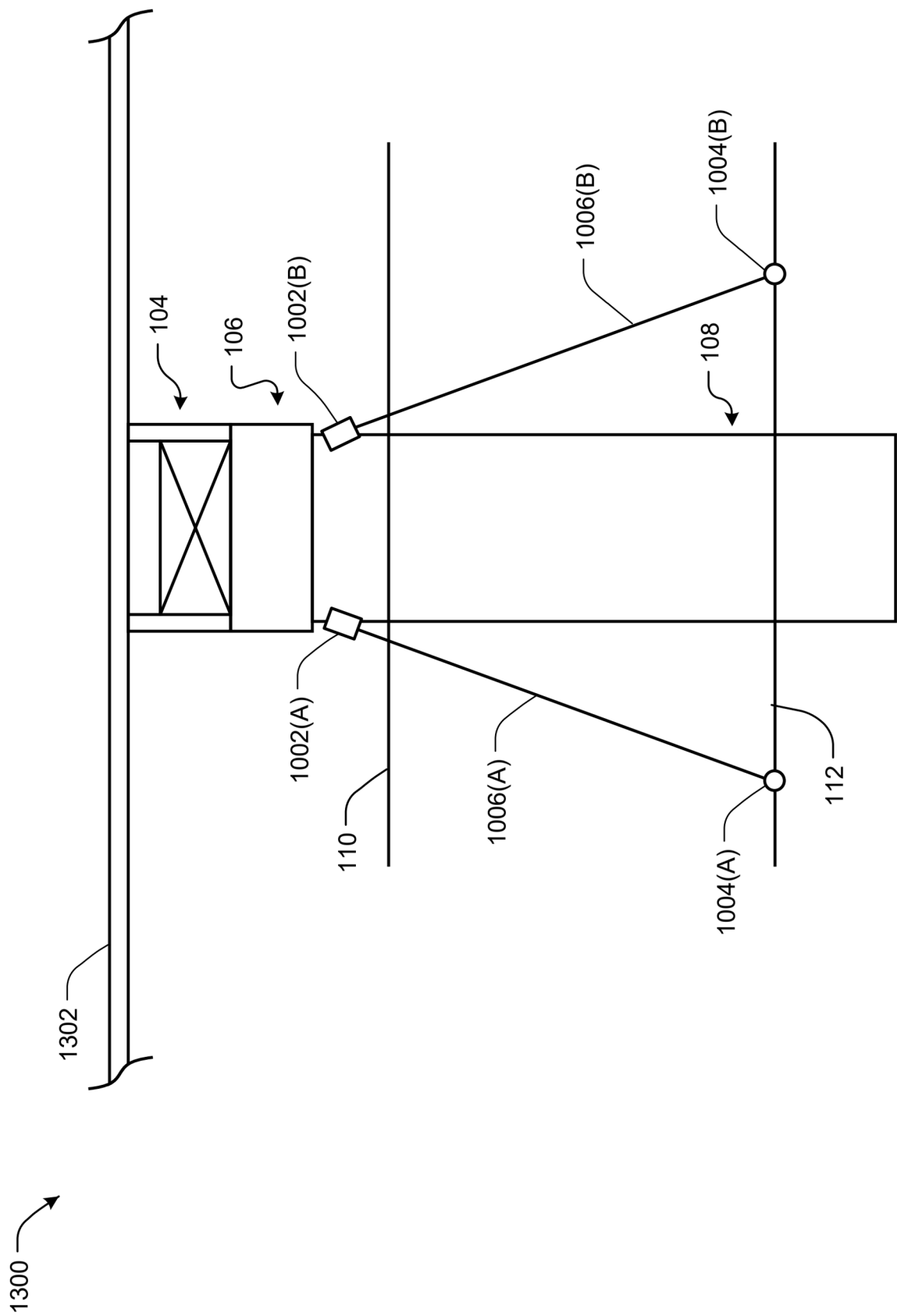


Fig. 13

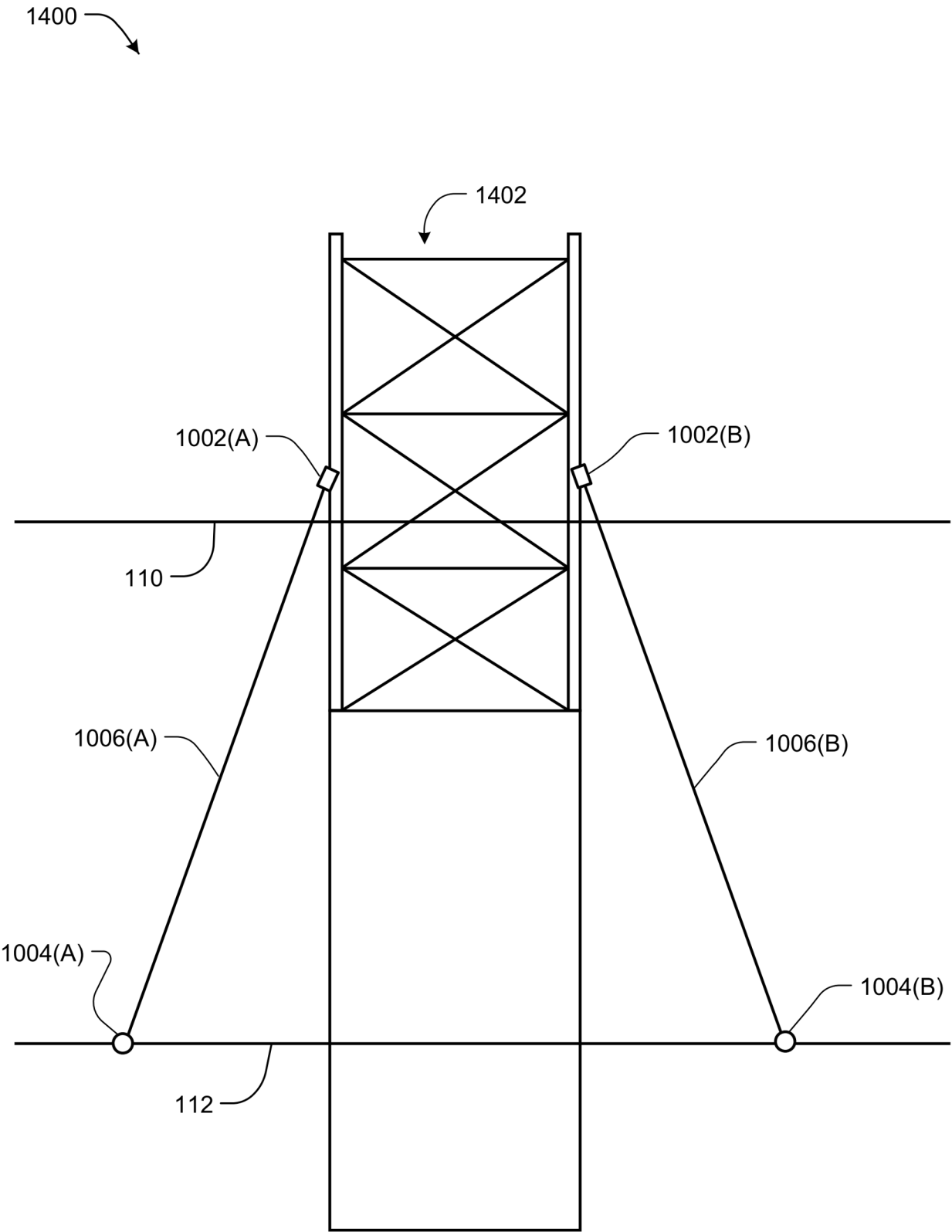


Fig. 14

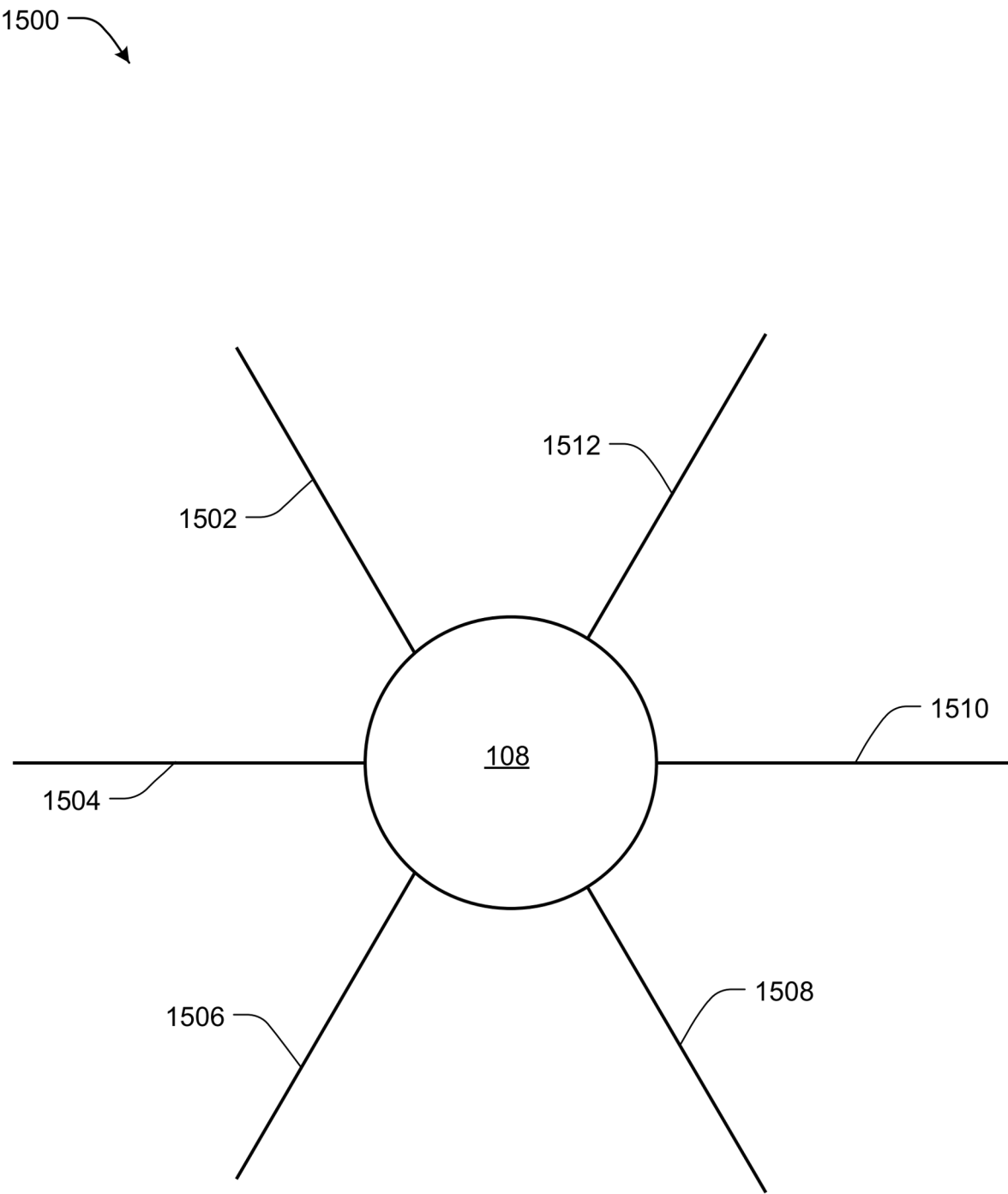


Fig. 15

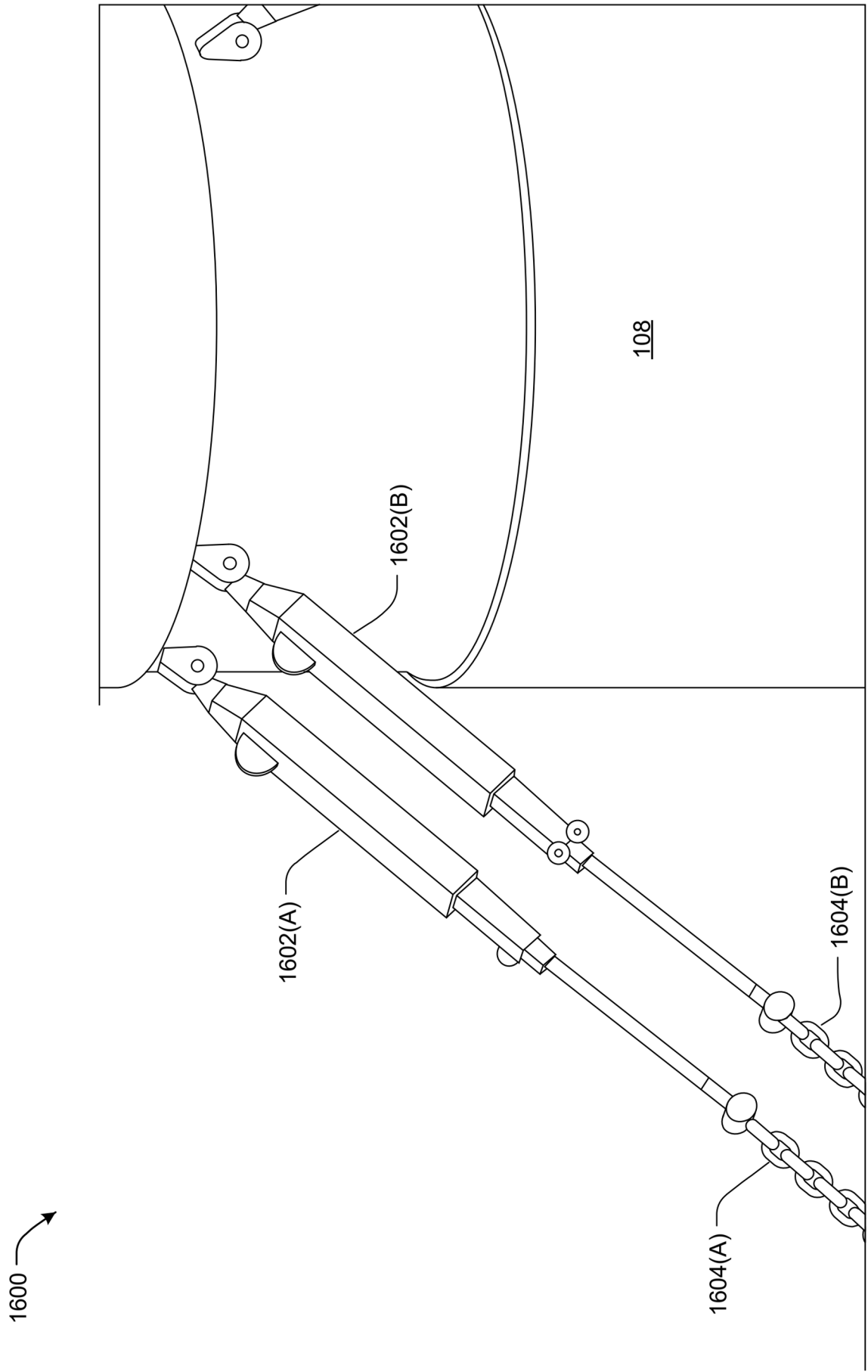


Fig. 16

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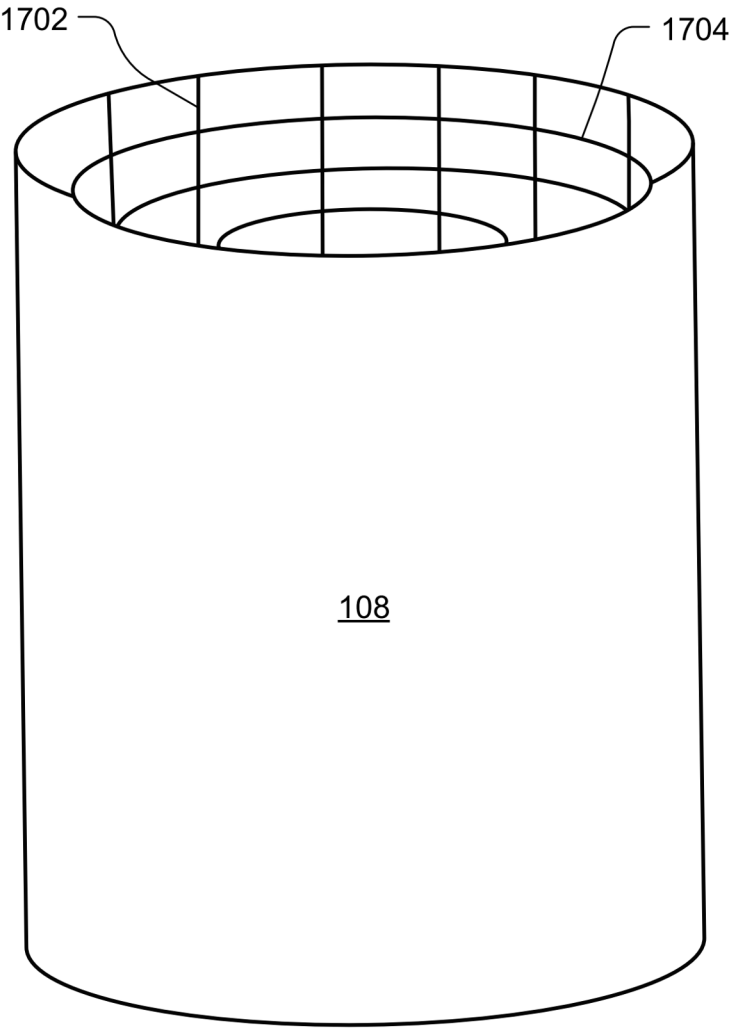


Fig. 17

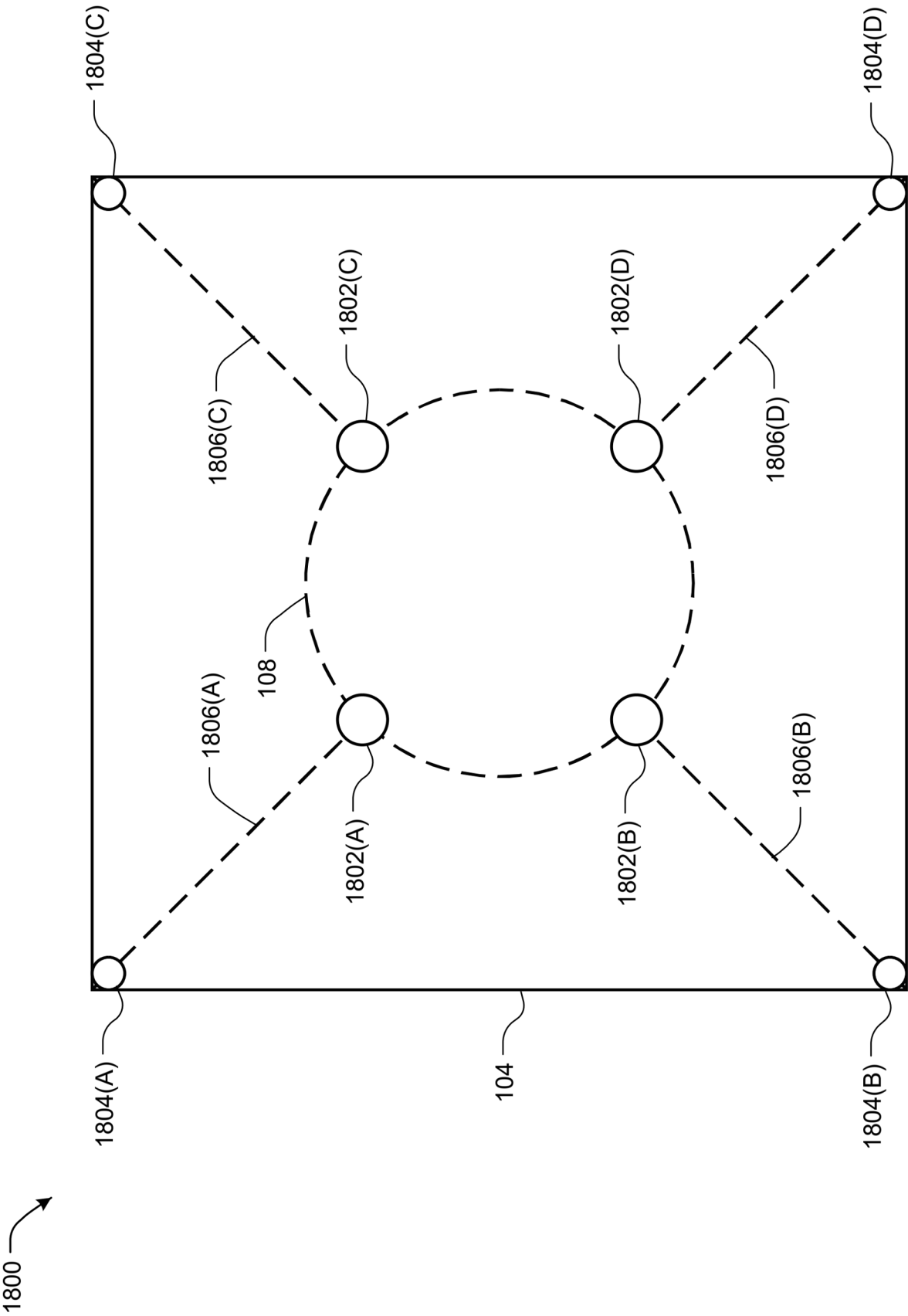
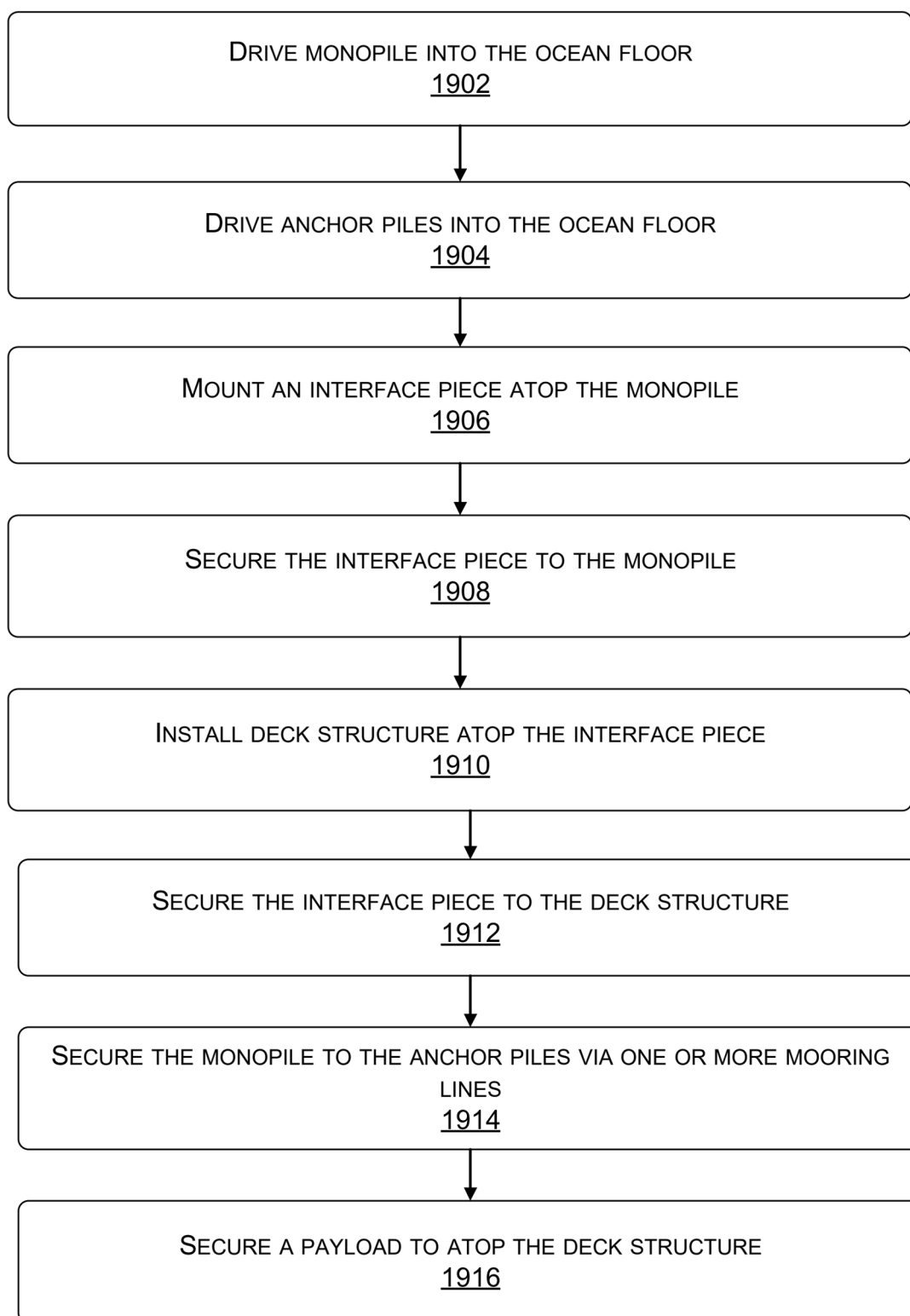


Fig. 18

1900 *Fig. 19*

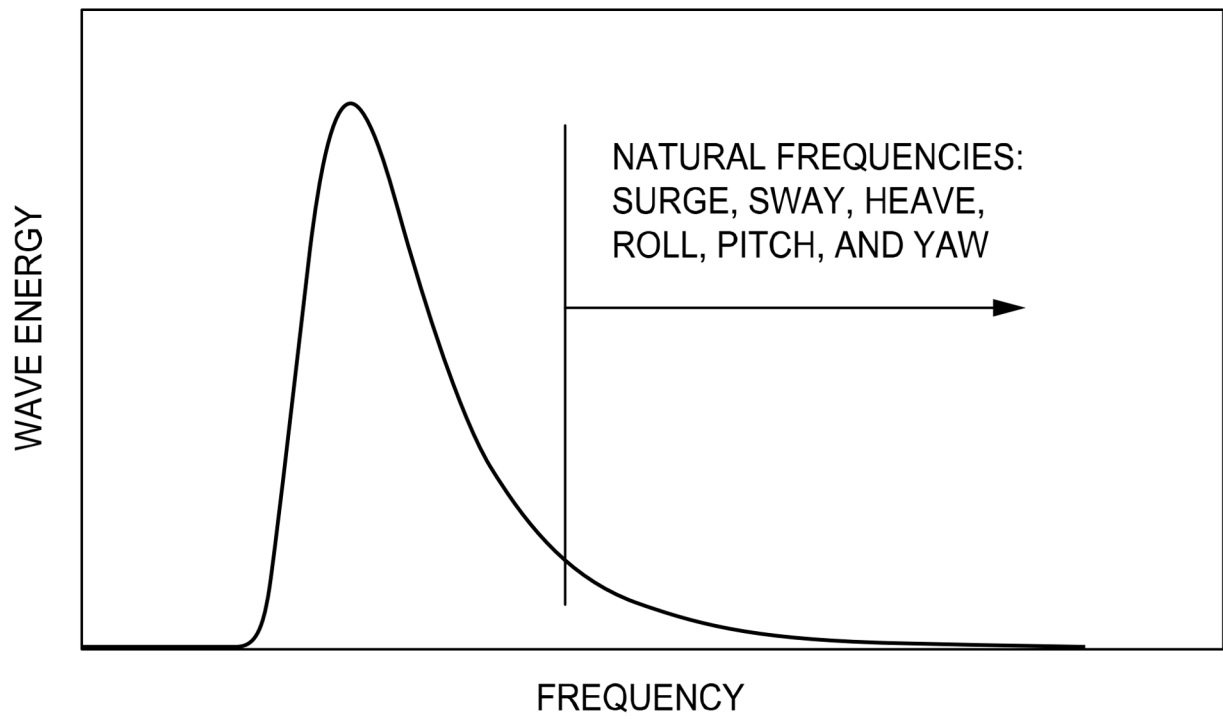
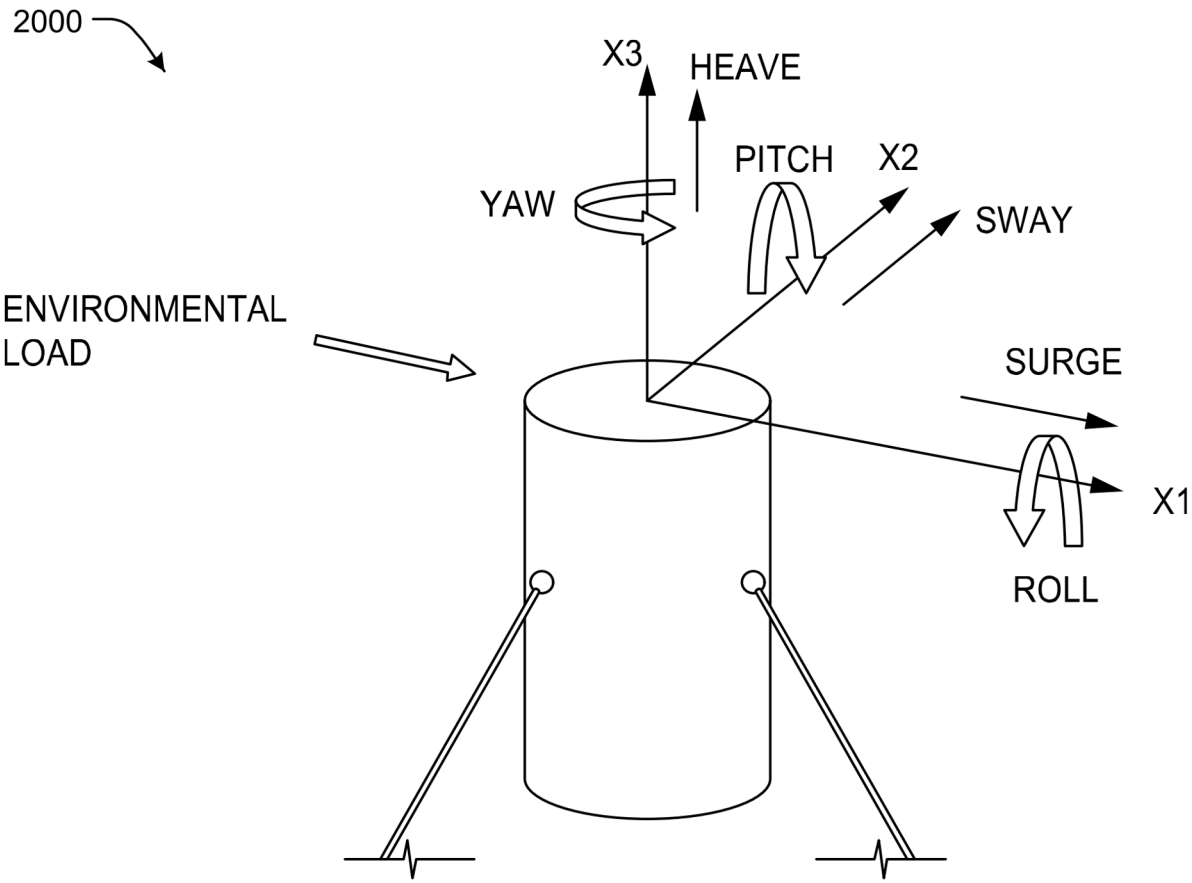


Fig. 20

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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