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(54) **PYROTECHNIC PRESSURE ACCUMULATOR**

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(57) **ABSTRACT**

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A pyrotechnic pressure accumulator includes an elongated body extending from a first end of a pyrotechnic section to a discharge end of a hydraulic section. A propellant charge located in a gas chamber of the pyrotechnic section, a piston movably disposed the hydraulic section, and a fluid disposed in a hydraulic chamber between the piston and the discharge end, wherein the fluid is exhausted under pressure through a discharge port in response to ignition of the propellant charge.

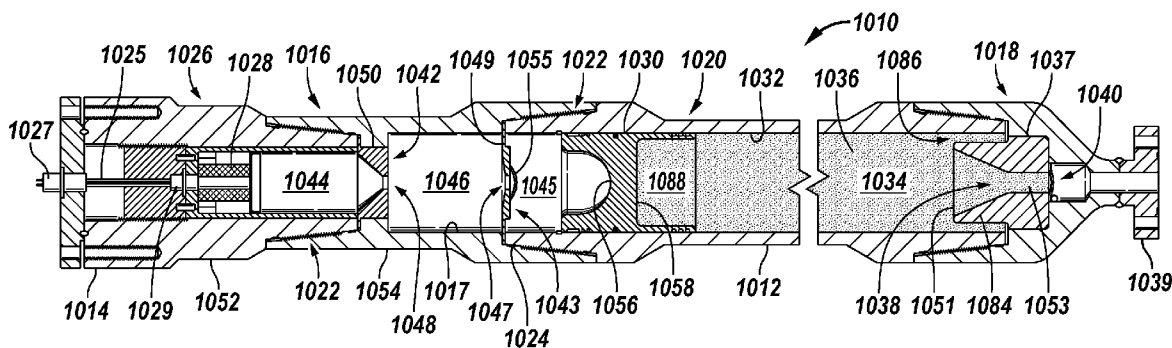


FIG. 1

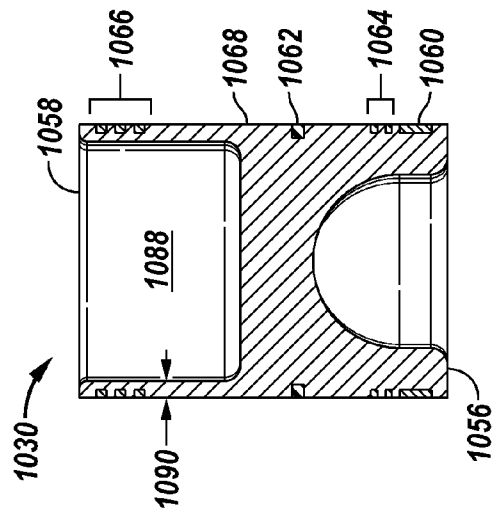
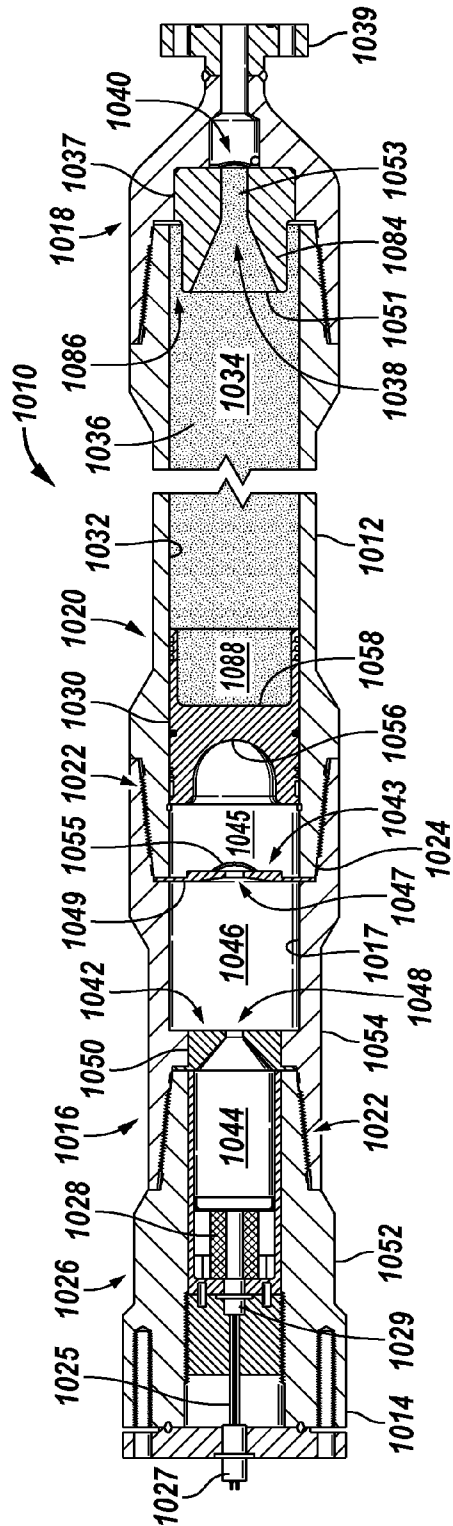


FIG. 2

FIG. 3

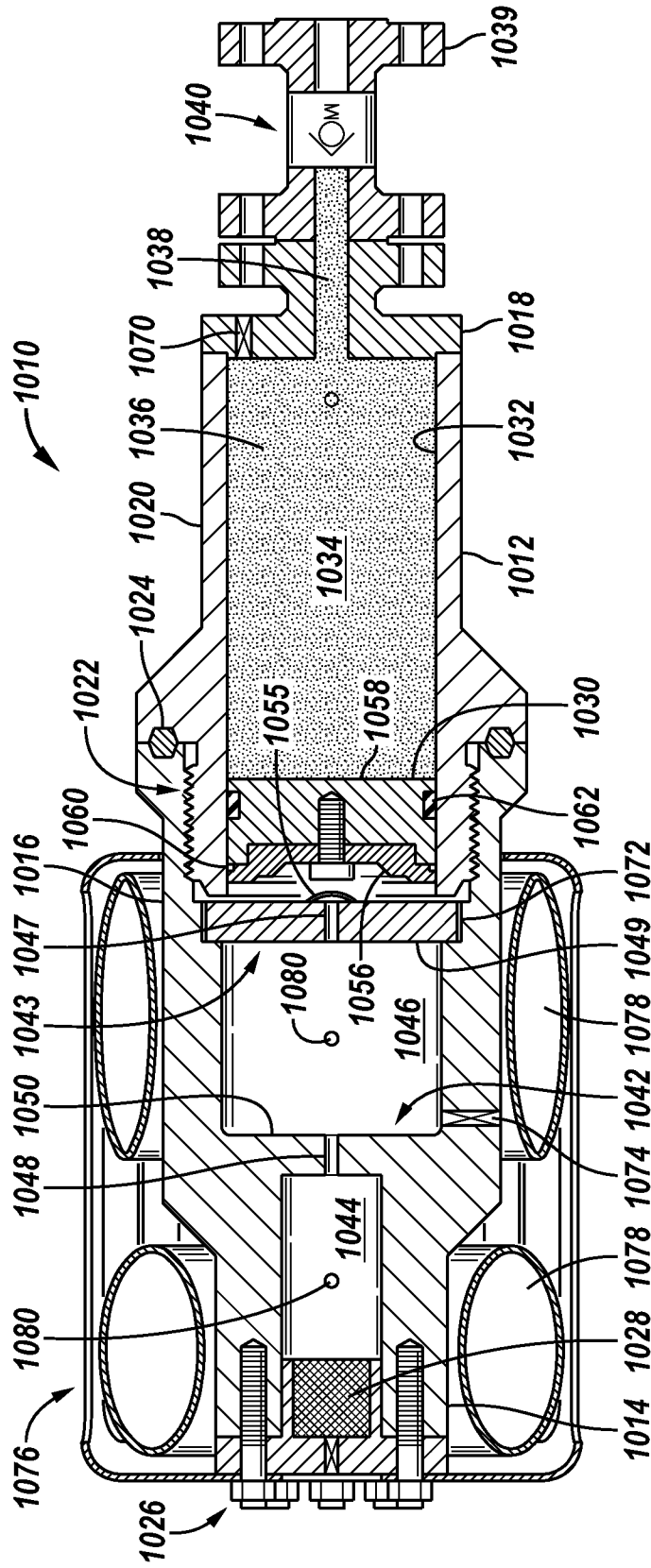


FIG. 4

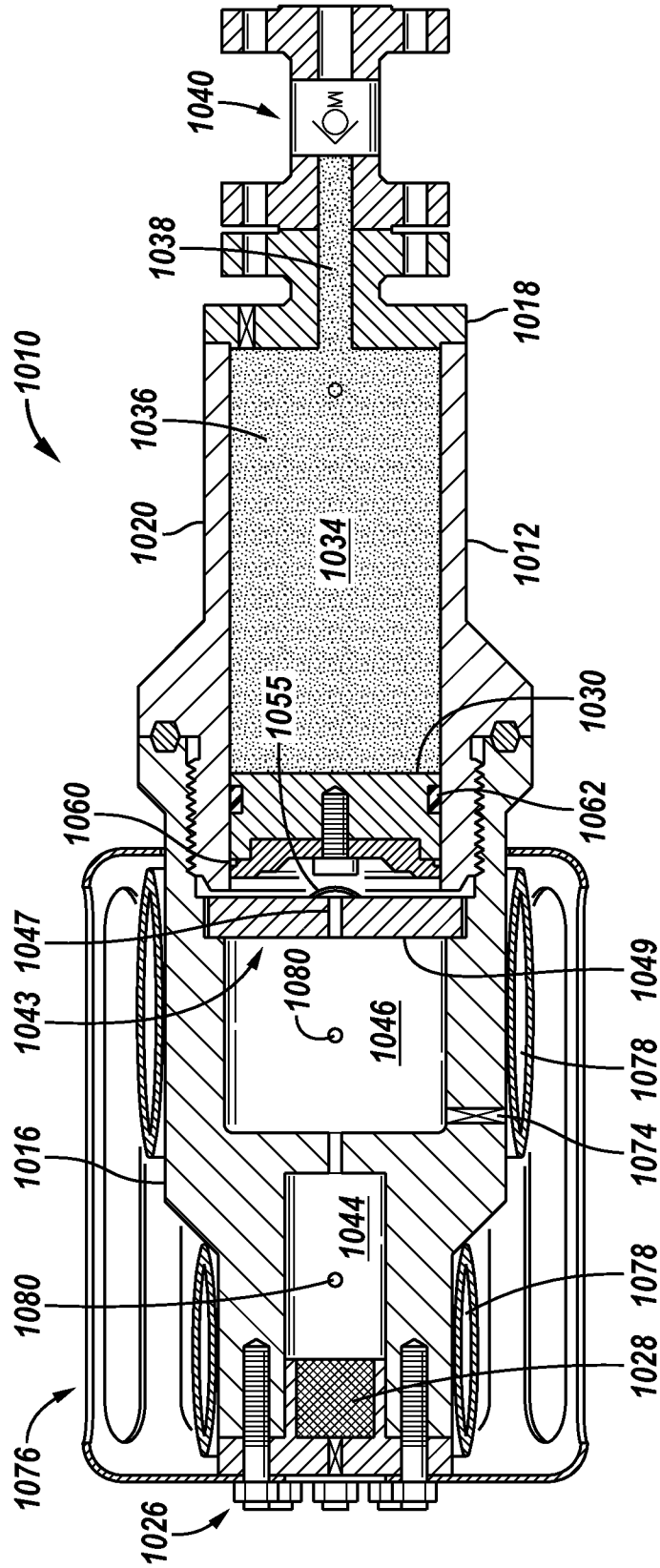


FIG. 5

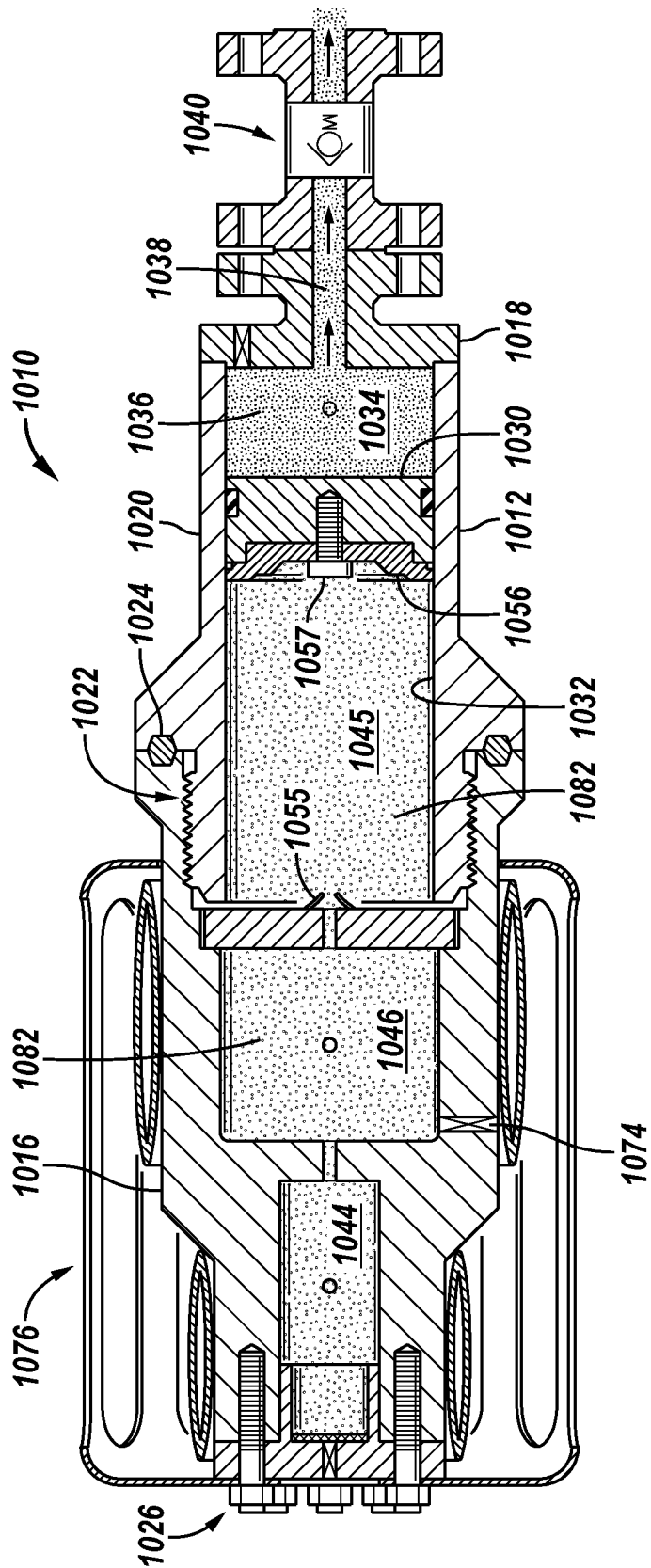


FIG. 6

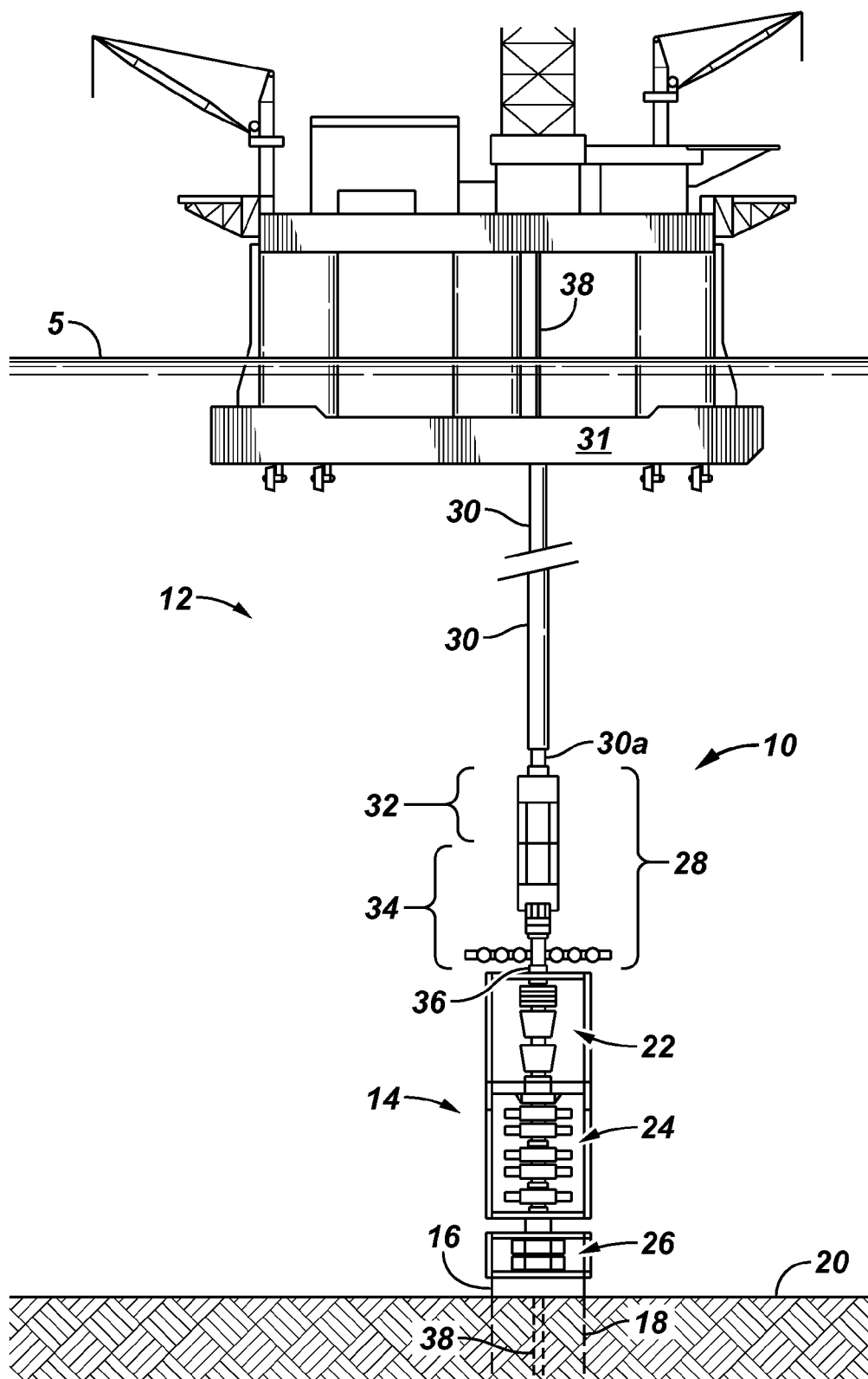


FIG. 7

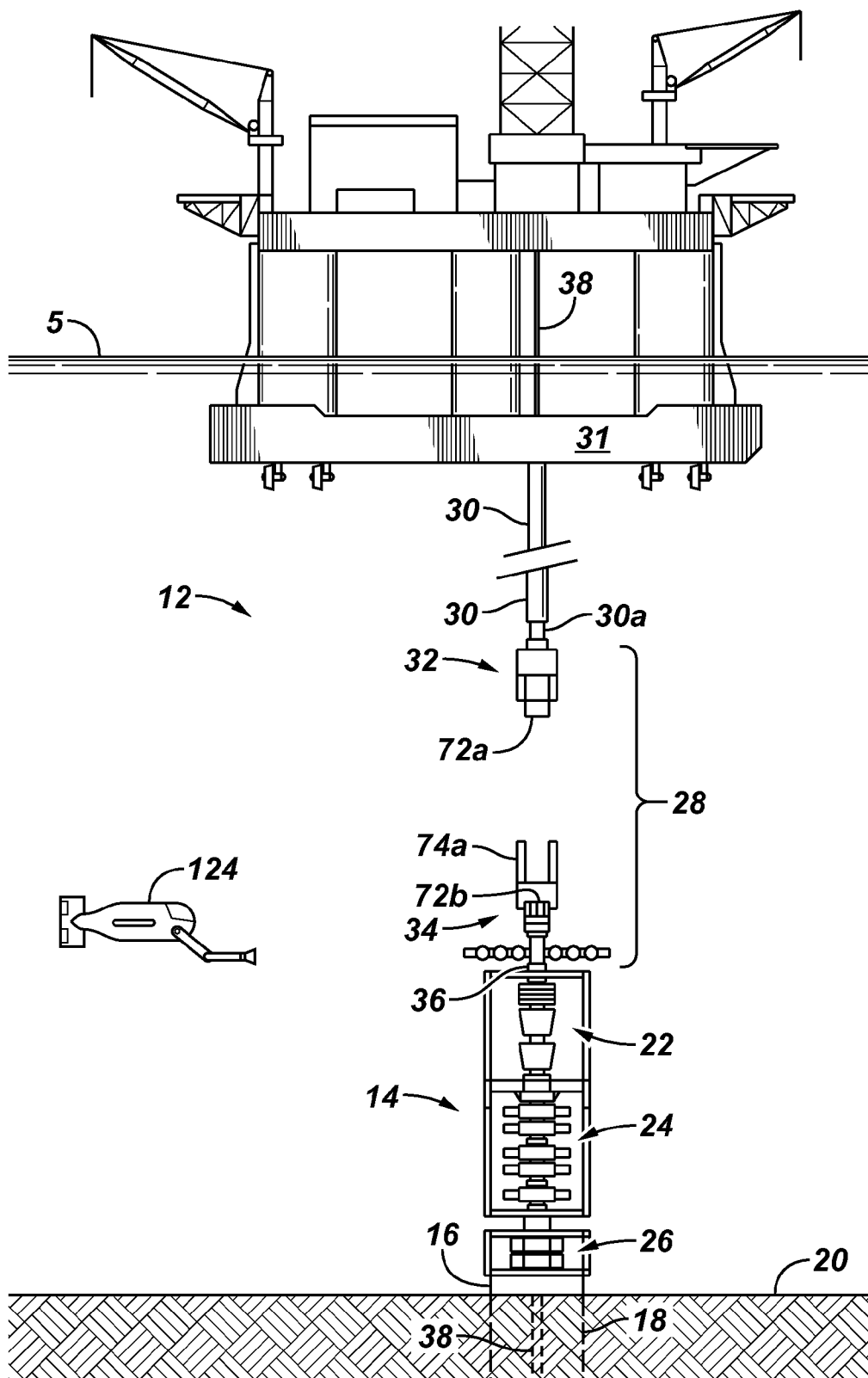


FIG. 8

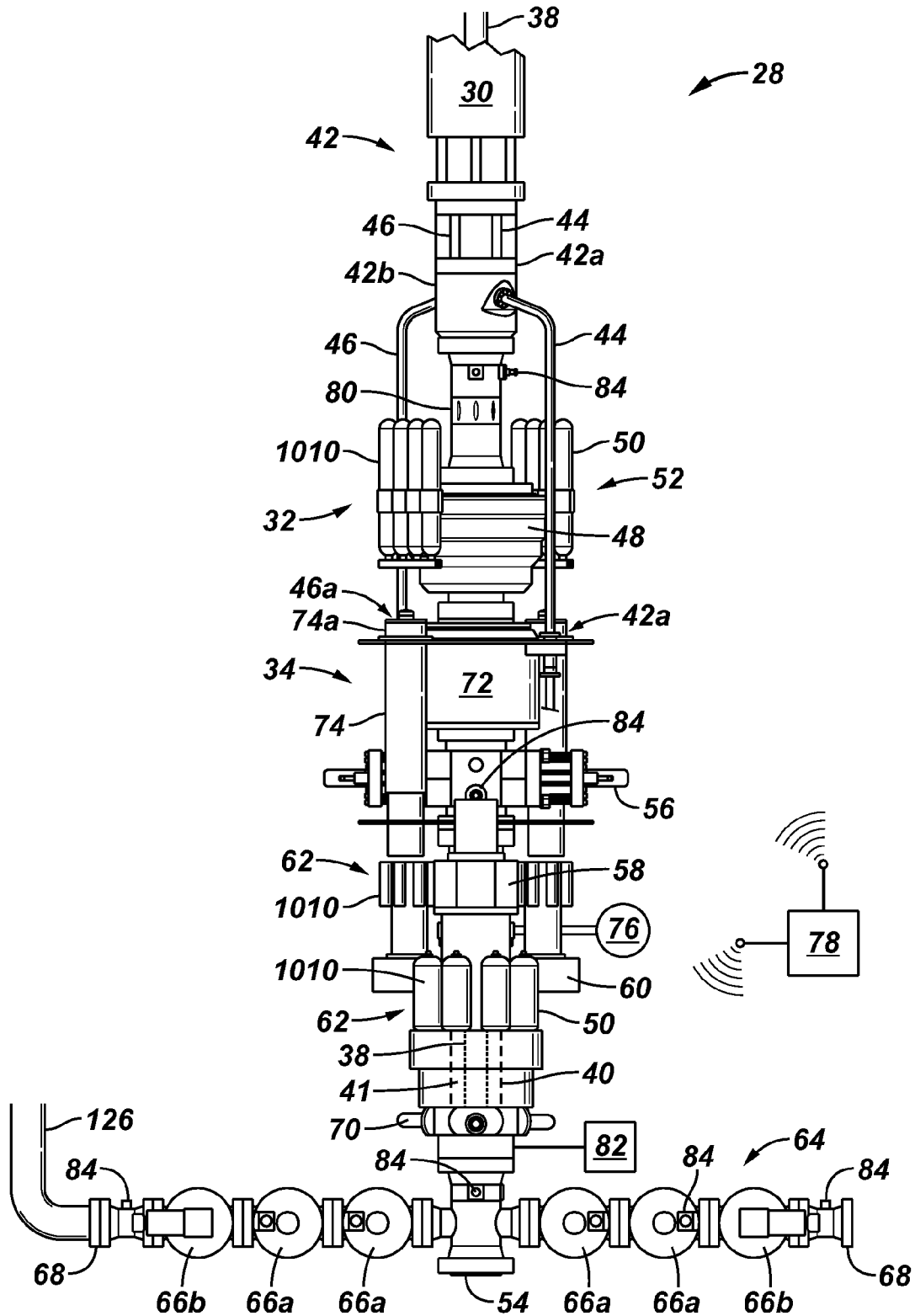
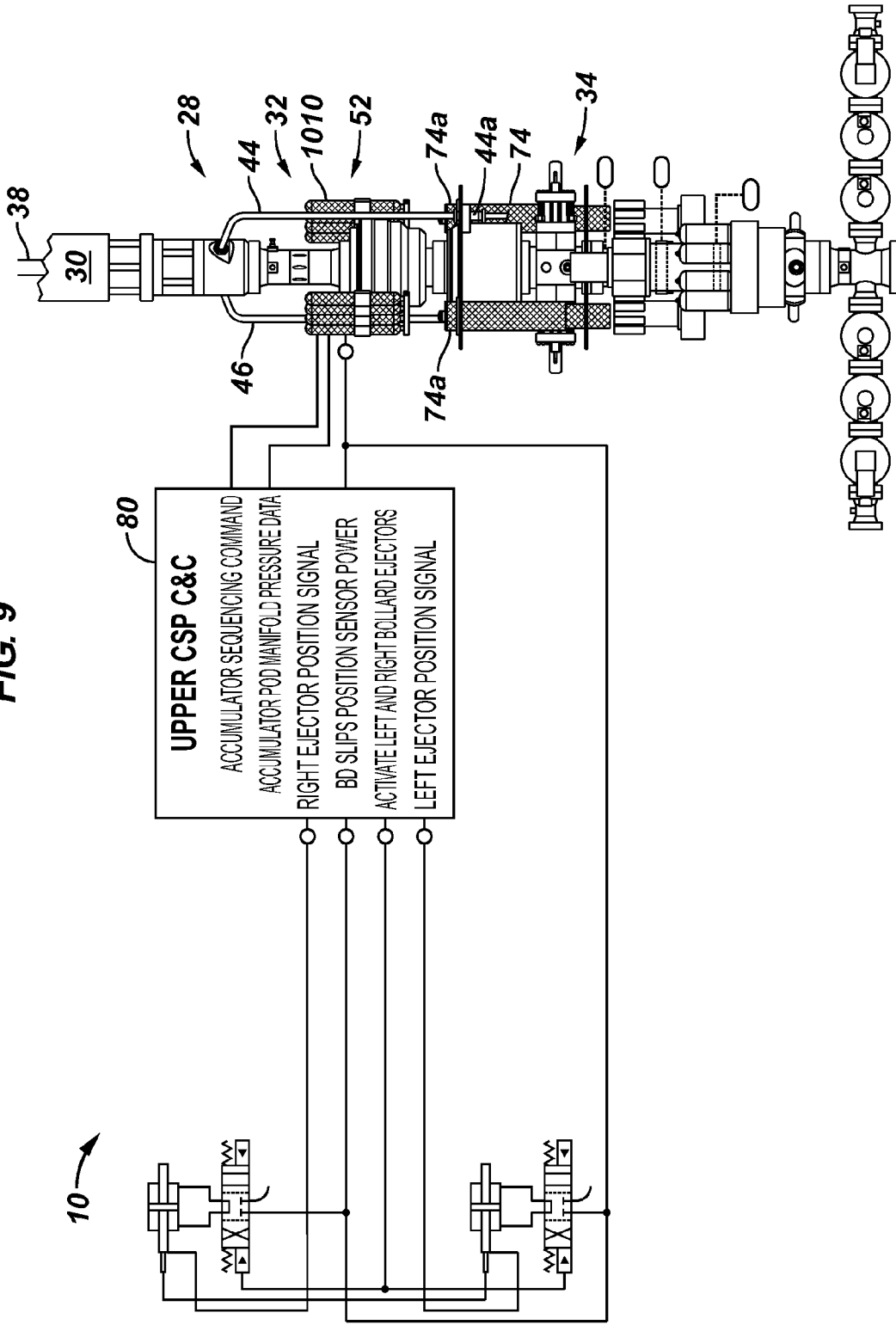


FIG. 9



PYROTECHNIC PRESSURE ACCUMULATOR

BACKGROUND

[0001] This section provides background information to facilitate a better understanding of the various aspects of the disclosure. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art.

[0002] Pre-charged hydraulic accumulators are utilized in many different industrial applications to provide a source of hydraulic pressure and operating fluid to actuate devices such as valves. It is common for installed hydraulic accumulators to be connected to or connectable to a source of hydraulic pressure to recharge the hydraulic accumulator due to leakage and/or uses.

SUMMARY

[0003] According to one or more aspects, a pyrotechnic pressure accumulator includes an elongated body extending from a first end of a pyrotechnic section to a discharge end of a hydraulic section. A propellant charge located in a gas chamber of the pyrotechnic section, a piston movably disposed in the hydraulic section, and a fluid disposed in a hydraulic chamber between the piston and the discharge end, wherein the fluid is exhausted under pressure through a discharge port in response to ignition of the propellant charge. According to an embodiment, the piston has a pyrotechnic end oriented toward the propellant charge and having a ballistic seal and a hydraulic end oriented toward the discharge end and having a hydraulic seal. The pyrotechnic pressure accumulator can include a pressure control device located between the propellant charge and the piston, wherein the pressure control device comprises an orifice formed through a barrier.

[0004] A pyrotechnic pressure accumulator according to one or more aspects includes an elongated body extending from a first end of a pyrotechnic section to a discharge end of a hydraulic section. A breech chamber located in the pyrotechnic section between the first end and a breech barrier having a breech orifice, and a propellant charge located in the breech chamber. A snubbing chamber formed in the pyrotechnic section between the breech barrier and a snubbing barrier having a snubbing orifice. A piston movably disposed in the hydraulic section and a fluid disposed in a hydraulic chamber between the piston and the discharge end, wherein the fluid is exhausted under pressure through a discharge port in response to ignition of the propellant charge

[0005] A method according to one or more aspects includes activating a pyrotechnic pressure accumulator to supply a hydraulic pressure to device in a subsea well system, the pyrotechnic pressure accumulator according to one or more embodiments having an elongated body extending from a first end of a pyrotechnic section to a discharge end of a hydraulic section, a propellant charge located in a gas chamber of the pyrotechnic section, a piston movably disposed in the hydraulic section, and a fluid disposed in a hydraulic chamber between the piston and the discharge end. Igniting the propellant charge and pressurizing the fluid and discharging the pressurized fluid through a discharge port to the device in response to igniting the propellant charge.

[0006] The foregoing has outlined some of the features and technical advantages in order that the detailed description of the pyrotechnic pressure accumulator that follows may be

better understood. Additional features and advantages of the pyrotechnic pressure accumulator will be described herein-after which form the subject of the claims of the invention. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of various features may be arbitrarily increased or reduced for clarity of discussion.

[0008] FIG. 1 is a schematic view of a pyrotechnic pressure accumulator according to one or more aspects of the disclosure.

[0009] FIG. 2 is a schematic illustration of a piston according to one or more aspects of the disclosure.

[0010] FIG. 3 is schematic illustration of a pyrotechnic pressure accumulator depicted in a first position prior to being activated.

[0011] FIG. 4 is a schematic illustration of a pyrotechnic pressure accumulator prior to being activated and depicted in a second position having higher external environmental pressure than the first position of FIG. 3.

[0012] FIG. 5 is schematic illustration of a pyrotechnic pressure accumulator after being activated according to one or more aspects of the disclosure.

[0013] FIGS. 6 and 7 illustrated a subsea well system and subsea well safety system in which a pyrotechnic pressure accumulator according to one or more aspects of the disclosure can be utilized.

[0014] FIG. 8 illustrates a subsea well safety system utilizing a pyrotechnic pressure accumulator according to one or more aspects of the disclosure.

[0015] FIG. 9 is a schematic diagram illustrating operation of a pyrotechnic pressure accumulator in accordance with one or more aspects of the disclosure.

DETAILED DESCRIPTION

[0016] It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. Specific examples of components and arrangements are described below to simplify the disclosure. These are, of course, merely examples and are not intended to be limiting. In addition, the disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0017] A pyrotechnic pressure device is disclosed that provides a useable storage of hydraulic fluid that can pressurized for use on demand. The pyrotechnic pressure device, referred to herein as an accumulator, can be utilized to establish the necessary hydraulic power to drive and operate hydraulic and mechanical devices and systems and it may be utilized in conjunction with or in place of pre-charged hydraulic accumulators. Example of utilization of the pyrotechnic pressure accumulator are described with reference to subsea well systems, in particular safety systems; however, use of the pyrotechnic pressure accumulator is not limited to subsea systems

and environments. For example, and without limitation, hydraulic accumulators are utilized to operate valves, bollards, pipe rams, and pipe shears. According to embodiments disclosed herein, the pyrotechnic pressure accumulator can be located subsea and remain in place without requiring hydraulic pressure recharging. In addition, when located for example subsea the pyrotechnic hydraulic accumulator does not require charging by high pressure hydraulic systems located at the surface.

[0018] FIG. 1 is a sectional view of an example of a pyrotechnic pressure device, generally denoted by the numeral 1010, according to one or more embodiments. As will be understood by those skilled in the art with benefit of this disclosure, pyrotechnic pressure device 1010, also referred to as a pyrotechnic pressure accumulator, may be utilized in many different applications to provide hydraulic pressure at a desired operating or working pressure to a connected device.

[0019] In the example of FIG. 1, pyrotechnic pressure accumulator 1010 comprises an elongated body 1012 extending substantially from a first end 1014 of pyrotechnic section 1016 to a discharge end 1018 of a hydraulic section 1020. As will be understood by those skilled in the art with benefit of this disclosure, body 1012 may be constructed of one or more sections (e.g., tubular sections). In the depicted embodiment, pyrotechnic section 1016 and hydraulic section 1020 are connected at a threaded joint 1022 (e.g., double threaded) having a seal 1024. In the depicted embodiment, threaded joint 1022 provided a high pressure seal (e.g., hydraulic seal and/or gas seal).

[0020] A pressure generator 1026 (i.e., gas generator), comprising a pyrotechnic (e.g., propellant) charge 1028, is connected at first end 1014 and disposed in the gas chamber 1017 (i.e., expansion chamber) of pyrotechnic section 1016. In the depicted embodiment, pressure generator 1026 comprises an initiator (e.g., ignitor) 1029 connected to pyrotechnic charge 1028 and extending via electrical conductor 1025 to an electrical connector 1027. In this example, electrical connector 1027 is wet-mate connector for connecting to an electrical source for example in a sub-sea, high pressure environment.

[0021] A piston 1030 is moveably disposed within a bore 1032 of the hydraulic section 1020 of body 1012. A hydraulic fluid chamber 1034 is formed between piston 1030 and discharge end 1018. Hydraulic chamber 1034 is filled with a fluid 1036, e.g., non-compressible fluid, e.g., oil, water, or gas. Fluid 1036 is generally described herein as a liquid or hydraulic fluid, however, it is understood that a gas can be utilized for some embodiments. Hydraulic chamber 1034 can be filled with fluid 1036 for example through a port. Fluid 1036 is not pre-charged and stored in hydraulic chamber 1034 at the operating pressure.

[0022] A discharge port 1038 is in communication with discharge end 1018 to communicate the pressurized fluid 1036 to a connected operational device (e.g., valve, rams, bollards, etc.). In the depicted embodiment, discharge port 1038 is formed by a member 1037, referred to herein as cap 1037, connected at discharge end 1018 for example by a bolted flange connection. A flow control device 1040 is located in the fluid flow path of discharge port 1038. In this example, flow control device 1040 is a one-way valve (i.e., check valve) permitting fluid 1036 to be discharged from fluid hydraulic chamber 1034 and blocking backflow of fluid into hydraulic chamber 1034. A connector 1039 (e.g., flange) is depicted at discharge end 1018 to connect hydraulic chamber

1034 to an operational device for example through an accumulator manifold. According to embodiments, pyrotechnic pressure accumulator 1010 is adapted to be connected to a subsea system for example by a remote operated vehicle.

[0023] Upon ignition of pyrotechnic charge 1028, high pressure gas expands in gas chamber 1017 and urges piston 1030 toward discharge end 1018 thereby pressurizing fluid 1036 and exhausting the pressurized fluid 1036 through discharge end 1018 and flow control device 1040 to operate the connected operational device.

[0024] Piston 1030, referred to also as a hybrid piston, is adapted to operate in a pyrotechnic environment and in a hydraulic environment. A non-limiting example of piston 1030 is described with reference to FIGS. 1 and 2. Piston 1030, depicted in FIGS. 1 and 2, includes a pyrotechnic end, or end section, 1056 and a hydraulic end, or end section 1058. Pyrotechnic end 1056 faces pyrotechnic charge 1028 and hydraulic end 1058 faces discharge end 1018. Piston 1030 may be constructed of a unitary body or may be constructed in sections (see, e.g., FIGS. 3-5) of the same or different material. In this embodiment, piston 1030 comprises a ballistic seal (i.e., obturator seal) 1060, a hydraulic seal 1062, and a first and a second piston ring set 1064, 1066. According to an embodiment, ballistic seal 1060 is located on outer surface 1068 of pyrotechnic end 1056 of piston 1030. Ballistic seal 1060 may provide centralizing support for piston 1030 in bore 1032 and provide a gas seal to limit gas blow by (e.g., depressurization). First piston ring set 1064 is located adjacent to ballistic seal 1060 and is separated from the terminal end of pyrotechnic end 1056 by ballistic seal 1060. Second piston ring set 1066 is located proximate the terminal end of hydraulic end section 1058. A hydraulic seal 1062 is located between first piston ring set 1064 and second piston ring set 1066 in this non-limiting example of piston 1030.

[0025] According to some embodiments, one or more pressure control devices 1042 are positioned in gas chamber 1017 for example to dampen the pressure pulse and/or to control the pressure (i.e., operating or working pressure) at which fluid 1036 is exhausted from discharge port 1038. In the embodiment depicted in FIG. 1, gas chamber 1017 of pyrotechnic section 1016 includes two pressure control devices 1042, 1043 dividing gas chamber 1017 into three chambers 1044, 1046 and 1045. First chamber 1044, referred to also as breech chamber 1044, is located between first end 1014 (e.g., the connected gas generator 1026) and first pressure control device 1042 and a snubbing chamber 1046 is formed between pressure control devices 1042, 1043. Additional snubbing chambers can be provided when desired.

[0026] First pressure control device 1042 comprises an orifice 1048 formed through a barrier 1050 (e.g., orifice plate). Barrier 1050 may be constructed of a unitary portion of the body of pyrotechnic section 1016 or it may be a separate member connected with pyrotechnic section. Second pressure control device 1043 comprises an orifice 1047 formed through a barrier 1049. Barrier 1049 may be a continuous or unitary portion of the body of pyrotechnic section 1016 or may be a separate member connected within the pyrotechnic section. The size of orifices 1048, 1047 can be sized to provide the desired working pressure of the discharged hydraulic fluid 1036.

[0027] For example, in FIG. 1 pyrotechnic section 1016 includes two interconnected tubular sections or subs. In this embodiment, the first tubular sub 1052 (e.g., breech sub), includes first end 1014 and breech chamber 1044. The second

tubular sub **1054**, also referred to as snubbing sub **1054**, forms snubbing chamber **1046** between the first pressure control device **1042**, i.e., breech orifice, and the second pressure control device **1043**, i.e., snubbing orifice. For example, piston **1030** and snubbing pressure control device **1043** may be inserted at the threaded joint **1022** between hydraulic section **1020** and snubbing sub **1054** as depicted in FIG. 1, formed by a portion of body **1012**, and or secured for example by soldering or welding as depicted in FIGS. 3-5 (e.g., connector **1072**, FIG. 3). The breech pressure control device **1042** can be inserted at the threaded joint **1022** between breech sub **1052** and snubbing sub **1054**. In the FIG. 1 embodiment, barrier **1050** and/or barrier **1049** may be retained between the threaded connection **1022** of adjacent tubular sections of body **1012** and/or secured for example by welding or soldering (e.g., connector **1072** depicted in FIG. 3).

[0028] In the embodiment of FIG. 1, a rupture device **1055** closes an orifice **1048**, **1047** of at least one of pressure control devices **1042**, **1043**. In the depicted example, rupture device **1055** closes orifice **1047** of second pressure control device **1043**, adjacent to hydraulic section **1020**, until a predetermined pressure differential across rupture device **1055** is achieved by the ignition of pyrotechnic charge **1028**. Rupture device **1055** provides a seal across orifice **1047** prior to connecting pyrotechnic section **1016** with hydraulic section **1020** and during pyrotechnic pressure accumulator **1010** inactivity, for example to prevent fluid **1036** leakage to seep into pyrotechnic section **1016**.

[0029] According to some embodiments, a pressure compensation device (see, e.g., FIGS. 3-5) may be connected for example with gas chamber **1017** of pyrotechnic section **1016**. When being located subsea, the pressure compensation device substantially equalizes the pressure in gas chamber **1017** with the environmental hydrostatic pressure.

[0030] According to one or more embodiments, pyrotechnic pressure accumulator **1010** may provide a hydraulic cushion to mitigate impact of piston **1030** at discharge end **1018**, for example against cap **1037**. In the example depicted in FIG. 1, the cross-sectional area of discharge port **1038** decreases from an inlet end **1051** to the outlet end **1053**. The tapered discharge port **1038** may act to reduce the flow rate of fluid **1036** through discharge port **1038** as piston **1030** approaches discharge end **1018** and providing a fluid buffer that reduces the impact force of piston **1030** against cap **1037**.

[0031] A hydraulic cushion at the end of the stroke of piston **1030** may be provided for example, by a mating arrangement of piston **1030** and discharge end **1018** (e.g., cap **1037**). For example, as illustrated in FIG. 1 and with additional reference to FIG. 2, end cap **1037** includes a sleeve section **1084** disposed inside of bore **1032** of hydraulic section **1020**. Sleeve section **1084** has a smaller outside diameter than the inside diameter of bore **1032** providing an annular gap **1086**. Piston **1030** has a cooperative hydraulic end **1058** that forms a cavity **1088** having an annular sidewall **1090** (e.g., skirt). Annular sidewall **1090** is sized to fit in annular gap **1086** disposed inlet end **1051** and sleeve **1084** in cavity **1088**. Hydraulic fluid **1036** disposed in gap **1086** will cushion the impact of piston **1030** against end cap **1037**. It is to be noted that discharge port **1038** does not have to be tapered to provide a hydraulic cushion.

[0032] In some embodiments (e.g., see FIGS. 3-5), hydraulic chamber **1034** may be filled with a volume of fluid **1036** in excess of the volume required for the particular installation of accumulator **1010**. The excess volume of fluid **1036** can pro-

vide a cushion separating piston **1030** from discharge end **1018** at the end of the stroke of piston **1030**.

[0033] FIG. 3 is a sectional view of a pyrotechnic pressure accumulator **1010** according to one or more embodiments illustrated in a first position for example prior to being deployed at a depth subsea. Pyrotechnic pressure accumulator **1010** comprises an elongated body **1012** extending from a first end **1014** of a pyrotechnic section **1016** to discharge end **1018** of a hydraulic section **1020**. In the depicted example pyrotechnic section **1016** and hydraulic section **1020** are connected at a threaded joint **1022** having at least one seal **1024**.

[0034] Hydraulic section **1020** comprises a bore **1032** in which a piston **1030** (i.e., hybrid piston) is movably disposed. Piston **1030** comprises a pyrotechnic end section **1056** having a ballistic seal **1060** and hydraulic end section **1058** having a hydraulic seal **1062**. In the depicted embodiment, piston **1030** is a two-piece construction. Pyrotechnic end section **1056** and hydraulic end section **1058** are depicted coupled together by a connector, generally denoted by the numeral **1057** in FIG. 5. Connector **1057** is depicted as a bolt, e.g., threaded bolt, although other attaching devices and mechanism (e.g., adhesives may be utilized). Hydraulic chamber **1034** is formed between piston **1030** and discharge end **1018**. A flow control device **1040** is disposed with discharge port **1038** of discharge end **1018** substantially restricting fluid flow to one-direction from hydraulic chamber **1034** through discharge port **1038**.

[0035] Hydraulic chamber **1034** may be filled with hydraulic fluid **1036** for example through discharge port **1038**. Port **1070** (e.g., valve) is utilized to relieve pressure from hydraulic chamber **1034** during fill operations or to drain fluid **1036** for example if an un-actuated pyrotechnic pressure accumulator **1010** is removed from a system.

[0036] In the depicted embodiment, pyrotechnic section **1016** includes a breech chamber **1044** and a snubbing chamber **1046**. Gas generator **1026** is illustrated connected, for example by bolted interface, to first end **1014** disposing pyrotechnic charge **1028** into breech chamber **1044**. Breech chamber **1044** and snubbing chamber **1046** are separated by pressure control device **1042** which is illustrated as an orifice **1048** formed through breech barrier **1050**. In this non-limiting example, breech barrier **1050** is formed by a portion of body **1012** forming pyrotechnic section **1016**. Breech orifice **1048** can be sized for the desired operating pressure of pyrotechnic pressure accumulator **1010**.

[0037] Snubbing chamber **1046** is formed in pyrotechnic section **1016** between barrier **1050** and a snubbing barrier **1049** of second pressure control device **1043**. Pressure control device **1043** has a snubbing orifice **1047** formed through snubbing barrier **1049**. In the illustrated embodiment, snubbing barrier **1049** may be secured in place by a connector **1072**. In this example, connector **1072** is a solder or weld to secure barrier **1049** (i.e., plate) in place and provide additional sealing along the periphery of barrier **1049**. Snubbing orifice **1047** may be sized for the fluid capacity and operating pressure of the particular pyrotechnic pressure accumulator **1010** for example to dampen the pyrotechnic charge pressure pulse. A rupture device **1055** is depicted disposed with the orifice **1047** to seal the orifice and therefore gas chambers **1044**, **1046** during inactivity of the deployed pyrotechnic pressure accumulator **1010**. Rupture device **1055** can provide a clear opening during activation of pyrotechnic pressure accumulator **1010** and burning of charge **1028**.

[0038] A vent **1074**, i.e., valve, is illustrated in communication with gas chamber **1017** to relieve pressure from the gas

chambers prior to disassembly after pyrotechnic pressure accumulator **1010** has been operated.

[0039] FIGS. **3** to **5** illustrate a pressure compensation device **1076** in operational connection with the gas chambers, breech chamber **1044** and snubbing chamber **1046**, to increase the pressure in the gas chambers in response to deploying pyrotechnic pressure accumulator **1010** subsea. In the depicted embodiment, pressure compensator **1076** includes one or more devices **1078** (e.g. bladders) containing a gas (e.g., nitrogen). Bladders **1078** are in fluid connection with gas chambers **1017** (e.g., chambers **1044**, **1046**, etc.) for example through ports **1080**.

[0040] Refer now to FIG. **4**, wherein pyrotechnic pressure accumulator **1010** is depicted deployed subsea (see, e.g., FIGS. **6-8**) prior to being activated. In response to the hydrostatic pressure at the subsea depth of pyrotechnic pressure accumulator bladders **1078** have deflated thereby pressurizing breech chamber **1044** and snubbing chamber **1046**.

[0041] FIG. **5** illustrates an embodiment of pyrotechnic pressure accumulator **1010** after being activated. With reference to FIGS. **4** and **5**, pyrotechnic pressure accumulator **1010** is activated by igniting pyrotechnic charge **1028**. The ignition generates gas **1082** which expands in breech chamber **1044** and snubbing chamber **1046**. The pressure in the gas chambers ruptures rupture device **1055** and the expanding gas acts on pyrotechnic side **1056** of piston **1030**. Piston **1030** is moved toward discharge end **1018** in response to the pressure of gas **1082** thereby discharging pressurized fluid **1036** through discharge port **1038** and flow control device **1040**. In FIG. **5**, piston **1030** is illustrated spaced a distance apart from discharge end **1018**. In accordance to one or more embodiments, at least a portion of the volume of fluid **1036** remaining in hydraulic fluid chamber **1034** is excess volume supplied to provide a space (i.e., cushion) between piston **1030** and discharge end **1018** at the end of the stroke of piston **1030**.

[0042] Pyrotechnic pressure accumulator **1010** can be utilized in many applications wherein an immediate and reliable source of pressurized fluid is required. Pyrotechnic pressure accumulator **1010** provides a sealed system that is resistant to corrosion and that can be constructed of material for installation in hostile environments. Additionally, pyrotechnic pressure accumulator **1010** can provide a desired operating pressure level without regard to the ambient environmental pressure.

[0043] A method of operation and is now described with reference to FIGS. **6-9** which illustrate a subsea well system in which one or more pyrotechnic pressure accumulators are utilized. An example of a subsea well system is described in U.S. patent application publication No. 2012/0048566, which is incorporated by reference herein.

[0044] FIG. **6** is a schematic illustration of a subsea well safing system, generally denoted by the numeral **10**, being utilized in a subsea well drilling system **12**. In the depicted embodiment drilling system **12** includes a BOP stack **14** which is landed on a subsea wellhead **16** of a well **18** (i.e., wellbore) penetrating seafloor **20**. BOP stack **14** conventionally includes a lower marine riser package ("LMRP") **22** and blowout preventers ("BOP") **24**. The depicted BOP stack **14** also includes subsea test valves ("SSTV") **26**. As will be understood by those skilled in the art with benefit of this disclosure, BOP stack **14** is not limited to the devices depicted.

[0045] Subsea well safing system **10** comprises safing package, or assembly, referred to herein as a catastrophic

safing package ("CSP") **28** that is landed on BOP system **14** and operationally connects a riser **30** extending from platform **31** (e.g., vessel, rig, ship, etc.) to BOP stack **14** and thus well **18**. CSP **28** comprises an upper CSP **32** and a lower CSP **34** that are adapted to separate from one another in response to initiation of a safing sequence thereby disconnecting riser **30** from the BOP stack **14** and well **18**, for example as illustrated in FIG. **7**. The safing sequence is initiated in response to parameters indicating the occurrence of a failure in well **18** with the potential of leading to a blowout of the well. Subsea well safing system **10** may automatically initiate the safing sequence in response to the correspondence of monitored parameters to selected safing triggers. According to one or more embodiments, CSP **28** includes one or more pyrotechnic pressure accumulators **1010** (see, e.g., FIGS. **8** and **9**) to provide hydraulic pressure on demand to operate one or more of the well system devices (e.g., valves, connectors, ejector bollards, rams, and shears).

[0046] Wellhead **16** is a termination of the wellbore at the seafloor and generally has the necessary components (e.g., connectors, locks, etc.) to connect components such as BOPs **24**, valves (e.g., test valves, production trees, etc.) to the wellbore. The wellhead also incorporates the necessary components for hanging casing, production tubing, and subsurface flow-control and production devices in the wellbore.

[0047] LMRP **22** and BOP stack **24** are coupled together by a connector that is engaged with a corresponding mandrel on the upper end of BOP stack **24**. LMRP **22** typically provides the interface (i.e., connection) of the BOPs **24** and the bottom end **30a** of marine riser **30** via a riser connector **36** (i.e., riser adapter). Riser connector **36** may further comprise one or more ports for connecting fluid (i.e., hydraulic) and electrical conductors, i.e., communication umbilical, which may extend along (exterior or interior) riser **30** from the drilling platform located at surface **5** to subsea drilling system **12**. For example, it is common for a well control choke line **44** and a kill line **46** to extend from the surface for connection to BOP stack **14**.

[0048] Riser **30** is a tubular string that extends from the drilling platform **31** down to well **18**. The riser is in effect an extension of the wellbore extending through the water column to drilling vessel **31**. The riser diameter is large enough to allow for drillpipe, casing strings, logging tools and the like to pass through. For example, in FIGS. **6** and **7**, a tubular **38** (e.g., drillpipe) is illustrated deployed from drilling platform **31** into riser **30**. Drilling mud and drill cuttings can be returned to surface **5** through riser **30**. Communication umbilical (e.g., hydraulic, electric, optic, etc.) can be deployed exterior to or through riser **30** to CSP **28** and BOP stack **14**. A remote operated vehicle ("ROV") **124** is depicted in FIG. **7** and may be utilized for various tasks including installing and removing pyrotechnic pressure accumulators **1010**.

[0049] Refer now to FIG. **8** which illustrates a subsea well safing package **28** according to one or more embodiments in isolation. CSP **28** depicted in FIG. **8** is further described with reference to FIGS. **6** and **7**. In the depicted embodiment, CSP **28** comprises upper CSP **32** and lower CSP **34**. Upper CSP **32** comprises a riser connector **42** which may include a riser flange connection **42a**, and a riser adapter **42b** which may provide for connection of communication umbilicals and extension of the communication umbilicals to various CSP **28** devices and/or BOP stack **14** devices. For example, a choke line **44** and a kill line **46** are depicted extending from the

surface with riser **30** and extending through riser adapter **42b** for connection to the choke and kill lines of BOP stack **14**. CSP **28** comprises a choke stab **44a** and a kill line stab **46a** for interconnecting the upper portion of choke line **44** and kill line **46** with the lower portion of choke line **44** and kill line **46**. Stabs **44a**, **46a** can provide for disconnecting from the stab and kill lines during safing operations; and during subsequent recovery and reentry operations reconnecting to the choke and kill lines via stabs **44a**, **46a**. CSP **28** comprises an internal longitudinal bore **40**, depicted in FIG. **8** by the dashed line through lower CSP **34**, for passing tubular **38**. Annulus **41** is formed between the outside diameter of tubular **38** and the diameter of bore **40**.

[0050] Upper CSP **32** further comprises slips **48** (i.e., safety slips) adapted to close on tubular **38**. Slips **48** are actuated in the depicted embodiment by hydraulic pressure from a hydraulic accumulator **50** and/or a pyrotechnic pressure accumulator **1010**. In the depicted embodiment, CSP **28** comprises a plurality of hydraulic accumulators **50** and pyrotechnic pressure accumulators **1010** which may be interconnected in pods, such as upper hydraulic accumulator pod **52**. A pyrotechnic pressure accumulator **1010** located in the upper hydraulic accumulator pod **52** is hydraulically connected to one or more devices, such as slips **48**.

[0051] Lower CSP **34** comprises a connector **54** to connect to BOP stack **14**, for example, via riser connector **36**, rams **56** (e.g., blind rams), high energy shears **58**, lower slips **60** (e.g., bi-directional slips), and a vent system **64** (e.g., valve manifold). Vent system **64** comprises one or more valves **66**. In this embodiment, vent system **64** comprise vent valves (e.g., ball valves) **66a**, choke valves **66b**, and one or more connection mandrels **68**. Valves **66b** can be utilized to control fluid flow through connection mandrels **68**. For example, a recovery riser **126** is depicted connected to one of mandrels **68** for flowing effluent from the well and/or circulating a kill fluid (e.g., drilling mud) into the well.

[0052] In the depicted embodiment, lower CPS **34** further comprises a deflector device **70** (e.g., impingement device, shutter ram) disposed above vent system **64** and below lower slips **60**, shears **58**, and blind rams **56**. Lower CSP **34** includes a plurality of hydraulic accumulators **50** and pyrotechnic pressure accumulators **1010** arranged and connected in one or more lower hydraulic pods **62** for operations of various devices of CSP **28**.

[0053] Upper CSP **32** and lower CSP **34** are detachably connected to one another by a connector **72**. An ejector device **74** (e.g., ejector bollards) is operationally connected between upper CSP **32** and lower CSP **34** to separate upper CSP **32** and riser **30** from lower CSP **34** and BOP stack **14** after connector **72** has been actuated to the unlocked position. Ejector device **74** can be actuated by operation of pyrotechnic pressure accumulator **1010**.

[0054] CSP **28** includes a plurality of sensors **84** which can sense various parameters, such as and without limitation, temperature, pressure, strain (tensile, compression, torque), vibration, and fluid flow rate. Sensors **84** further includes, without limitation, erosion sensors, position sensors, and accelerometers and the like. Sensors **84** can be in communication with one or more control and monitoring systems, for example forming a limit state sensor package.

[0055] According to one or more embodiments of the invention, CSP **28** comprises a control system **78** which may be located subsea, for example at CSP **28** or at a remote location such as at the surface. Control system **78** may com-

prise one or more controllers which are located at different locations. For example, in at least one embodiment, control system **78** comprise an upper controller **80** (e.g., upper command and control data bus) and a lower controller **82** (e.g., lower command and controller bus). Control system **78** may be connected via conductors (e.g., wire, cable, optic fibers, hydraulic lines) and/or wirelessly (e.g., acoustic transmission) to various subsea devices (e.g., pyrotechnic pressure accumulators **1010**) and to surface (i.e., drilling platform **31**) control systems.

[0056] FIG. **9** is a schematic diagram of sequence step, according to one or more embodiments of subsea well safing system **10** illustrating operation of ejector devices **74** (i.e., ejector bollards) to physically separate upper CSP **32** and riser **30** from lower CSP **34** as depicted in FIG. **7**. For example, ejector devices **74** may include piston rods **74a** which extend to push the upper CSP **32** away from lower CSP **34** in the depicted embodiment. FIG. **7** illustrates piston rod **74a** in an extended position. In the embodiment of FIG. **9**, actuation of ejector devices **74** is provided by upper controller **80** sending a signal activating a pyrotechnic pressure accumulator **1010** located for example in upper accumulator pod **52** to direct the operating pressure to ejector devices **74**.

[0057] Referring also to FIGS. **1-5**, an electronic signal is transmitted from controller **80** and received at gas generator **1026**. The firing signal may be an electrical pulse and/or coded signal. In response to receipt of the firing signal, ignitor **1029** ignites pyrotechnic charge **1028** thereby generating gas **1082** (FIG. **5**) that drives piston **1030** toward discharge end **1018** thereby pressurizing fluid **1036** and discharging the pressurized fluid **1036** through discharge port **1038** to ejector device **74**. Similarly, pyrotechnic accumulators **1010** can be activated to supply on demand hydraulic pressure to other devices such as, and without limitation to, valves, slips, rams, shears and locks.

[0058] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the disclosure. Those skilled in the art should appreciate that they may readily use the disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the disclosure. The scope of the invention should be determined only by the language of the claims that follow. The term “comprising” within the claims is intended to mean “including at least” such that the recited listing of elements in a claim are an open group. The terms “a,” “an” and other singular terms are intended to include the plural forms thereof unless specifically excluded.

What is claimed is:

1. A pyrotechnic pressure accumulator, comprising:
 - an elongated body extending from a first end of a pyrotechnic section to a discharge end of a hydraulic section;
 - a propellant charge located in a gas chamber of the pyrotechnic section;
 - a piston movably disposed the hydraulic section; and
 - a fluid disposed in a hydraulic chamber between the piston and the discharge end, wherein the fluid is exhausted under pressure through a discharge port in response to ignition of the propellant charge.

- 2. The device of claim 1, wherein the piston comprises: a pyrotechnic end oriented toward the propellant charge and having a ballistic seal; and a hydraulic end oriented toward the discharge end and having a hydraulic seal.
- 3. The device of claim 1, comprising a pressure control device located between the propellant charge and the piston, wherein the pressure control device comprises an orifice formed through a barrier.
- 4. The device of claim 3, wherein the barrier is connected in the elongated body by a solder or weld.
- 5. The device of claim 1, comprising: a pressure control device located between the propellant charge and the piston, wherein the pressure control device comprises an orifice formed through a barrier; and a rupture device sealing the orifice prior to ignition of the propellant charge.
- 6. The device of claim 5, wherein the piston comprises: a pyrotechnic end oriented toward the propellant charge and having a ballistic seal; and a hydraulic end oriented toward the discharge end and having a hydraulic seal.
- 7. The device of claim 1, wherein: the discharge port is disposed through a member located in the hydraulic section, whereby an annular gap is formed about the member; and the piston comprises: a hydraulic end oriented toward the discharge end, the hydraulic end having an annular skirt sized to fit into the annular gap.
- 8. The device of claim 7, comprising: a pressure control device located between the propellant charge and the piston, wherein the pressure control device comprises an orifice formed through a barrier; and a rupture device sealing the orifice prior to ignition of the propellant charge.
- 9. The device of claim 1, wherein the cross-section area of the discharge port decrease from an inlet end to an outlet end.
- 10. A pyrotechnic pressure accumulator, comprising: an elongated body extending from a first end of a pyrotechnic section to a discharge end of a hydraulic section; a breech chamber located in the pyrotechnic section between the first end and a breech barrier having a breech orifice; a propellant charge located in the breech chamber; a snubbing chamber formed in the pyrotechnic section between the breech barrier and a snubbing barrier having a snubbing orifice; a piston movably disposed the hydraulic section; a fluid disposed in a hydraulic chamber between the piston and the discharge end, wherein the fluid is exhausted

- under pressure through a discharge port in response to ignition of the propellant charge
- 11. The device of claim 10, wherein the pyrotechnic section is connected to the hydraulic section at a threaded joint.
- 12. The device of claim 10, wherein the breech barrier is a continuous portion of the pyrotechnic section of the elongated body.
- 13. The device of claim 10, wherein the snubbing barrier is connected in pyrotechnic section by a solder or weld.
- 14. The device of claim 10, comprising a pressure compensation device in hydraulic communication with the breech chamber.
- 15. The device of claim 10, comprising a rupture device sealing the snubbing orifice prior to ignition of the propellant charge.
- 16. The device of claim 10, wherein the piston comprises: a pyrotechnic end oriented toward the propellant charge and having a ballistic seal; and a hydraulic end oriented toward the discharge end and having a hydraulic seal.
- 17. The device of claim 16, further comprising: a pressure compensation device in hydraulic communication with the breech chamber; and a rupture device sealing the snubbing orifice prior to ignition of the propellant charge.
- 18. A method, comprising: activating a pyrotechnic pressure accumulator to supply a hydraulic pressure to device in a subsea well system, the pyrotechnic pressure accumulator comprising: an elongated body extending from a first end of a pyrotechnic section to a discharge end of a hydraulic section; a propellant charge located in a gas chamber of the pyrotechnic section; a piston movably disposed the hydraulic section; and a fluid disposed in a hydraulic chamber between the piston and the discharge end; igniting the propellant charge; and pressurizing the fluid and discharging the pressurized fluid through a discharge port to the device in response to igniting the propellant charge.
- 19. The method of claim 18, wherein the piston comprises: a pyrotechnic end oriented toward the propellant charge and having a ballistic seal; and a hydraulic end oriented toward the discharge end and having a hydraulic seal.
- 20. The method of claim 18, wherein the gas chamber comprises: a breech chamber located between the first end and a breech barrier having a breech orifice; and a snubbing chamber located between the breech barrier and a snubbing barrier having a snubbing orifice.

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