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(54) SHAPED CHARGE PERFORATION GUN WITH PHASING ALIGNMENT AND RELATED EQUIPMENT AND METHODS

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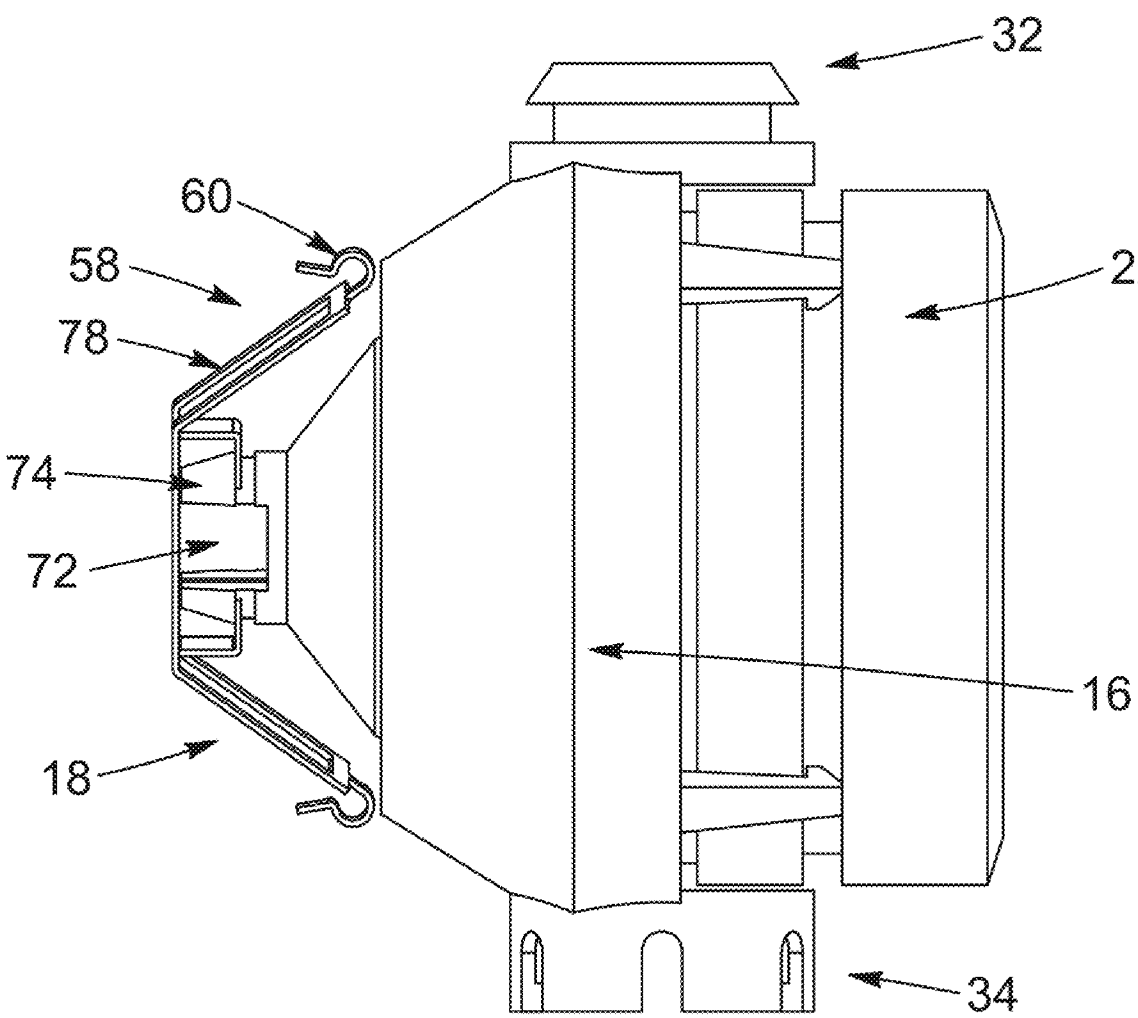
(57) ABSTRACT

In a perforating gun, shaped charges can be configured to be rotatable with respect to each other and can be secured in a predetermined phasing by an alignment rod that can be helical with a pitch that defines the phasing. The shaped charges can be supported by holders, which can be directly connected to each other to be infinitely rotatable and can also be attached to and/or retained by the alignment rod via alignment connectors. The alignment connectors can also be configured to hold detonation and signal cords. This shaped charge alignment approach can facilitate manufacturing and assembly, for instance since a single design of holders and other components of the assembly can be used with various different alignment rods to provide the desired phasing based on well design criteria.



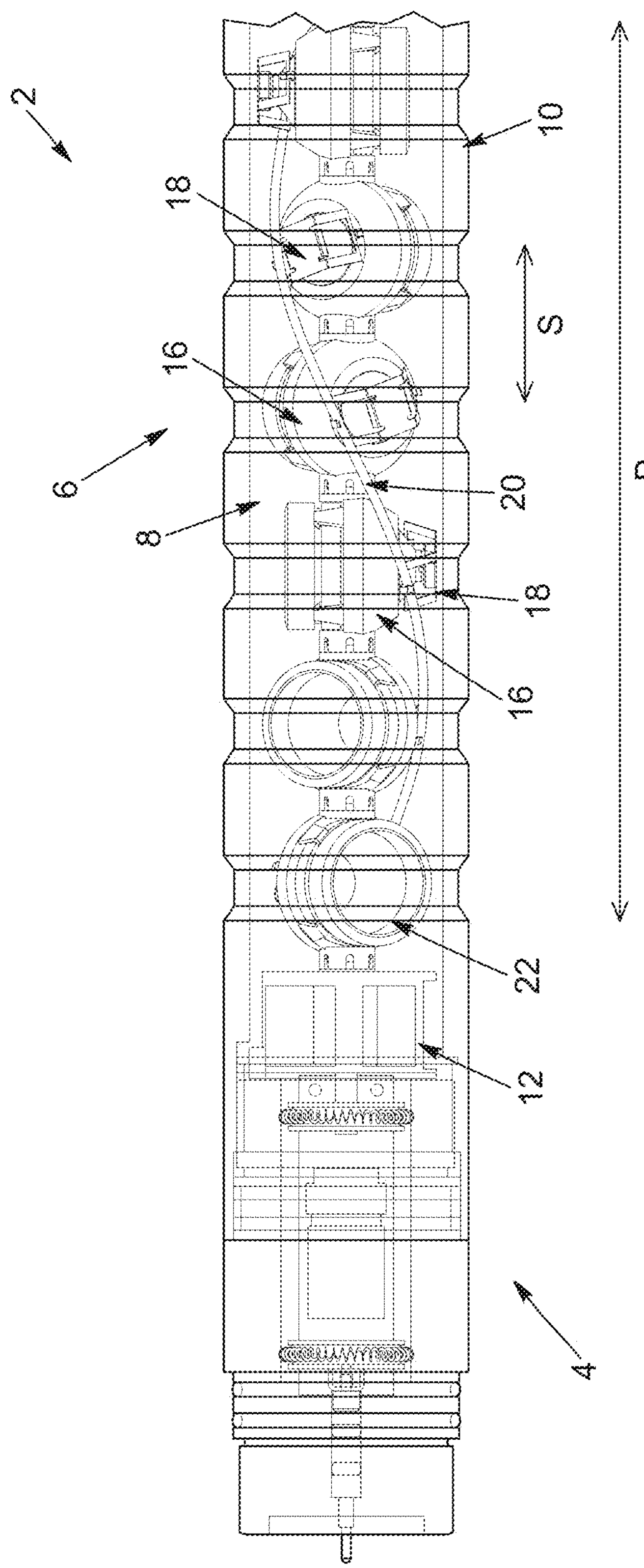


FIG. 1

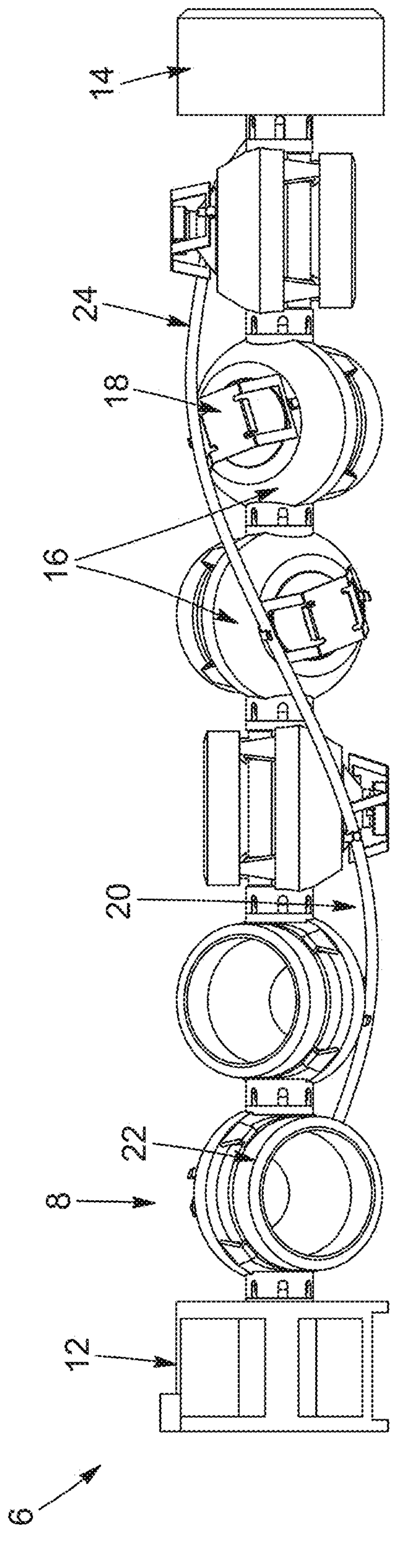


FIG. 2

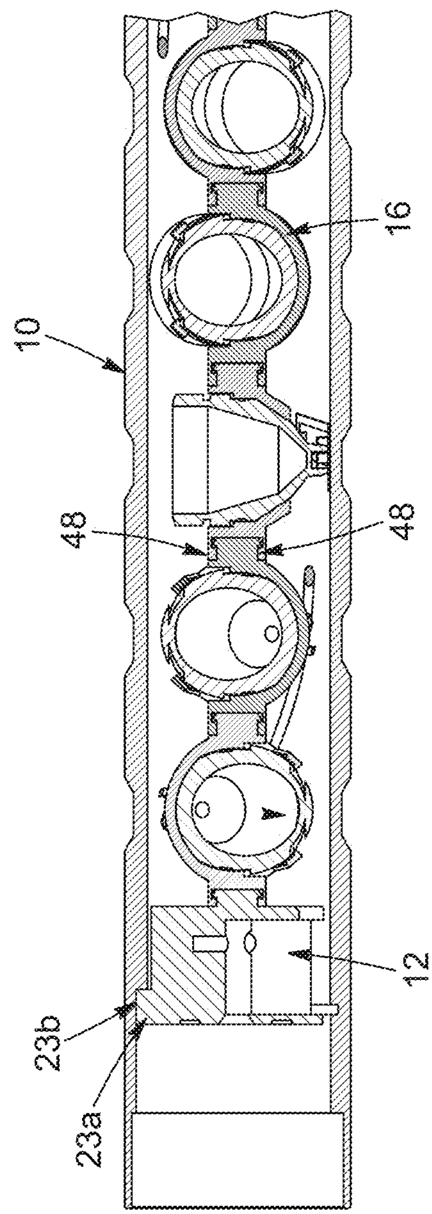


FIG. 3

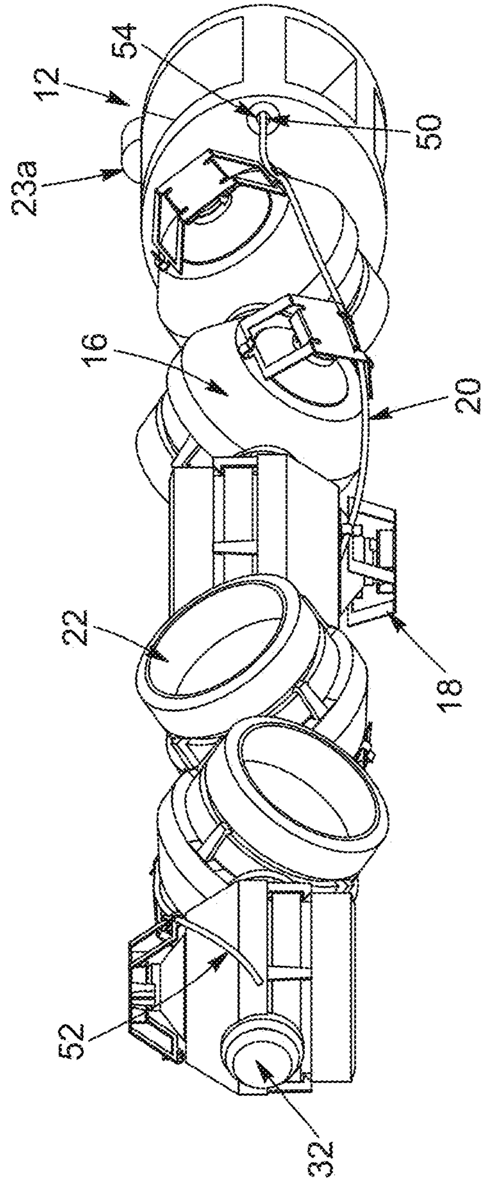


FIG. 4

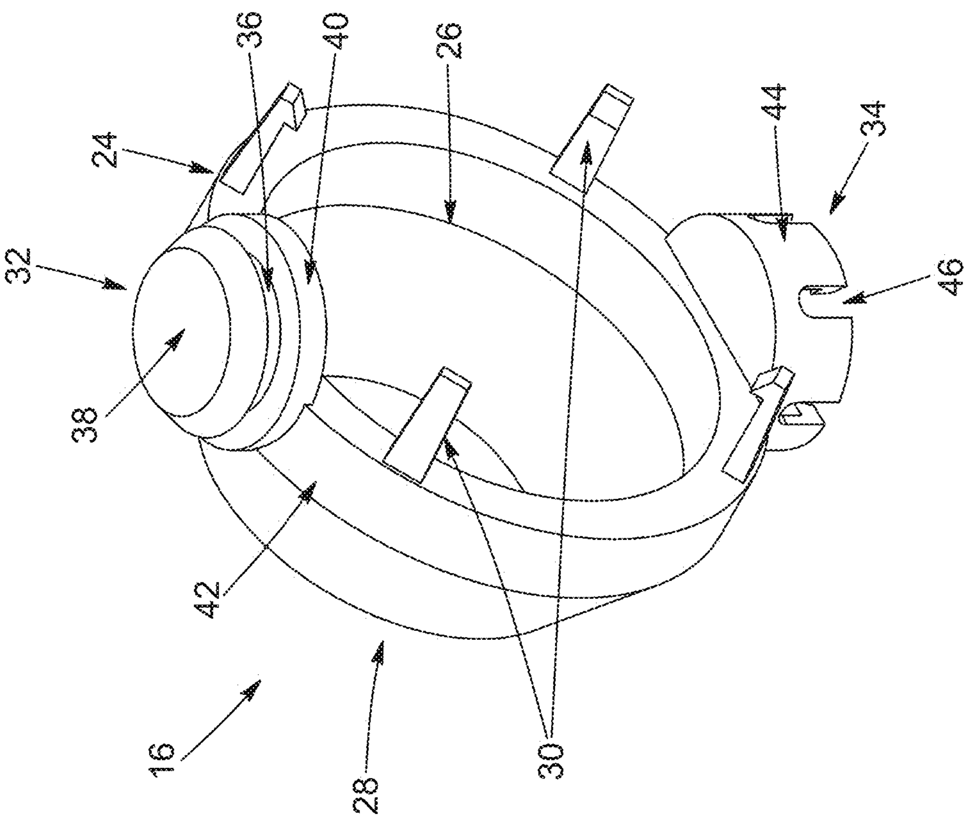


FIG. 5

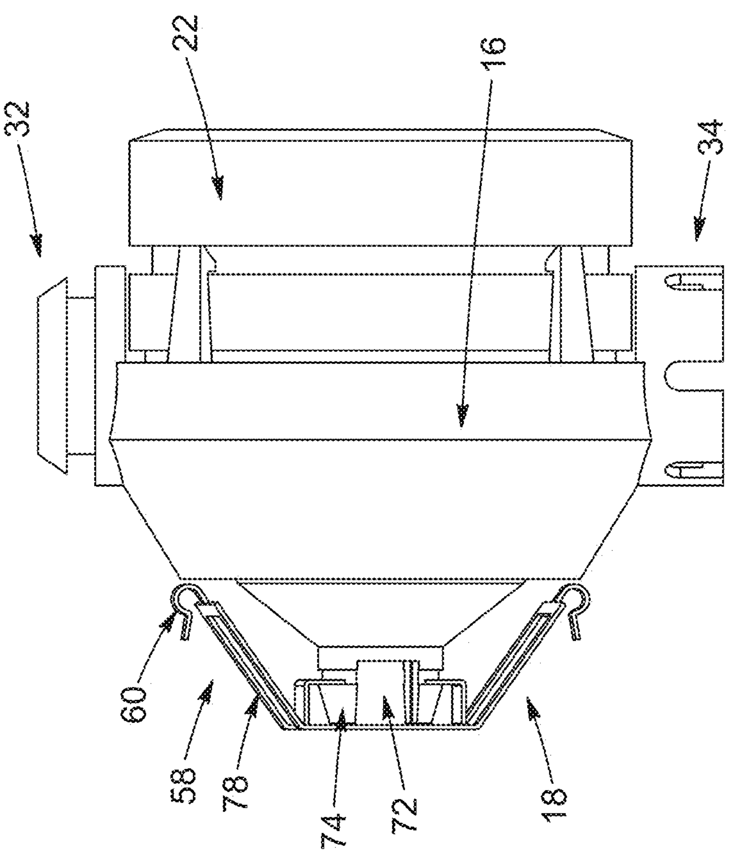


FIG. 6

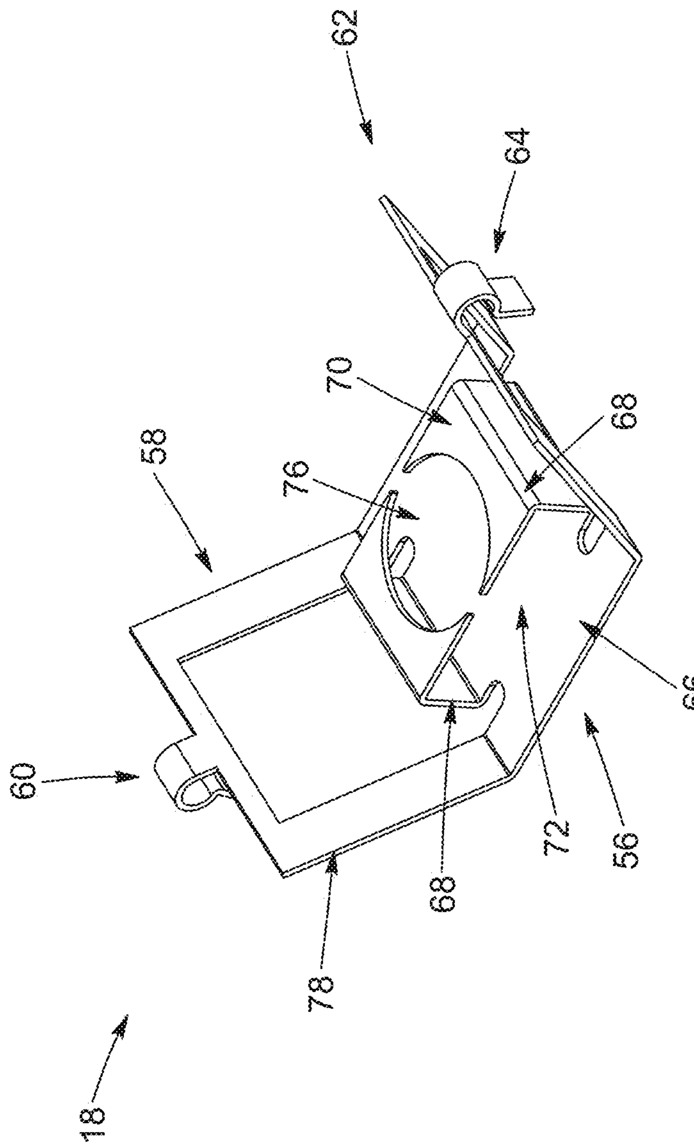
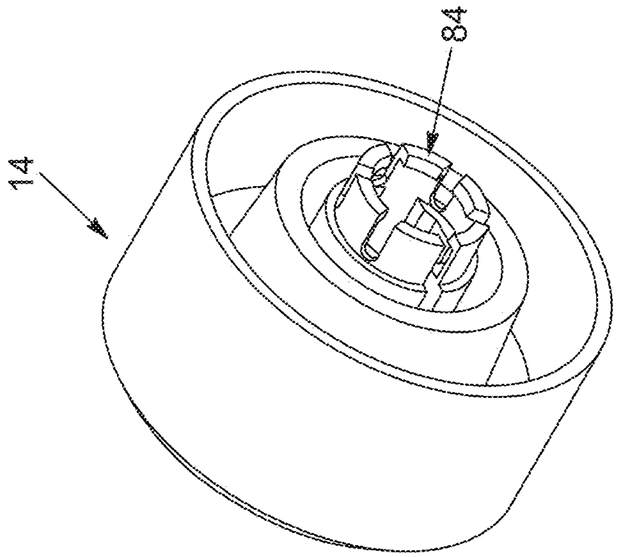


FIG. 7



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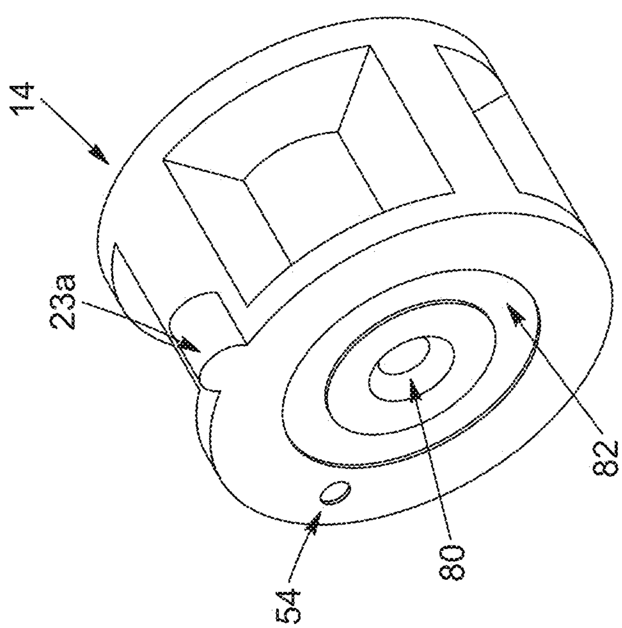

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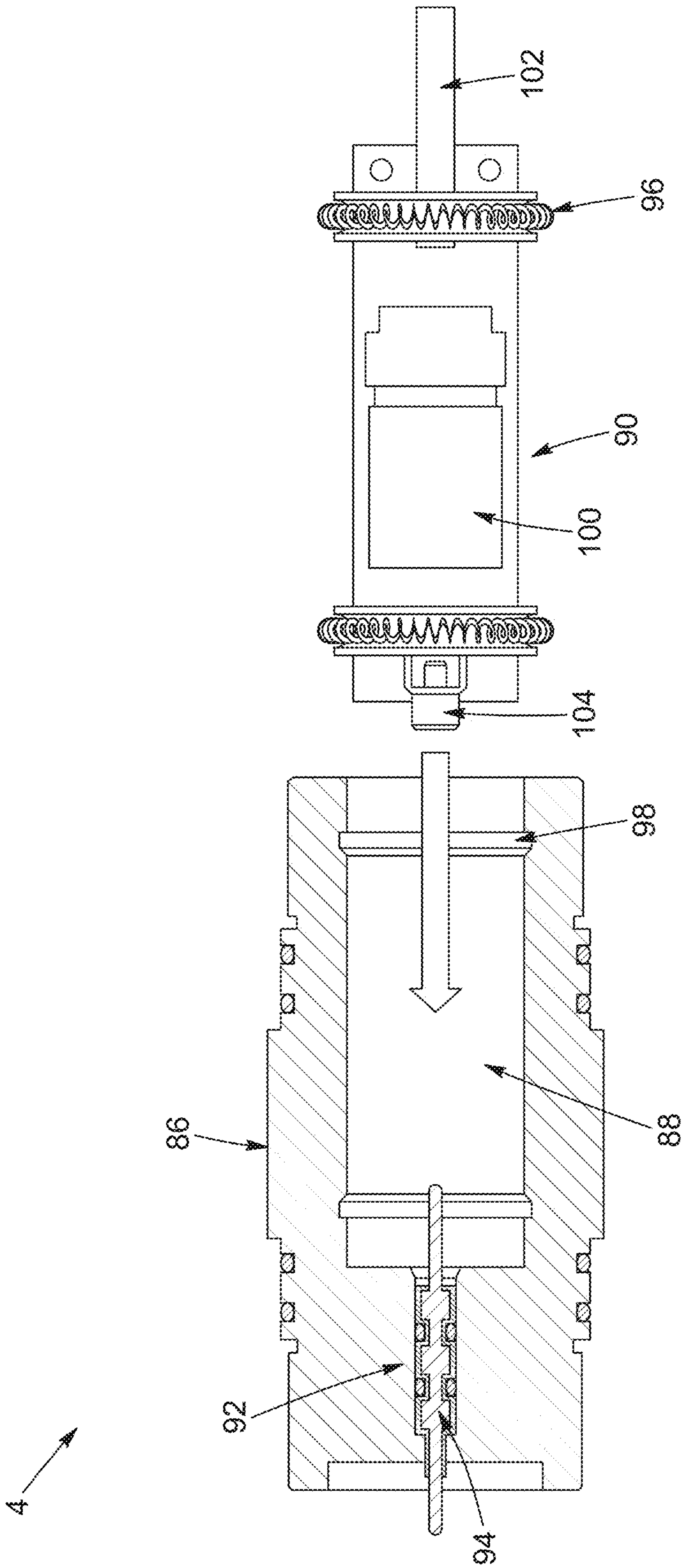


FIG. 10

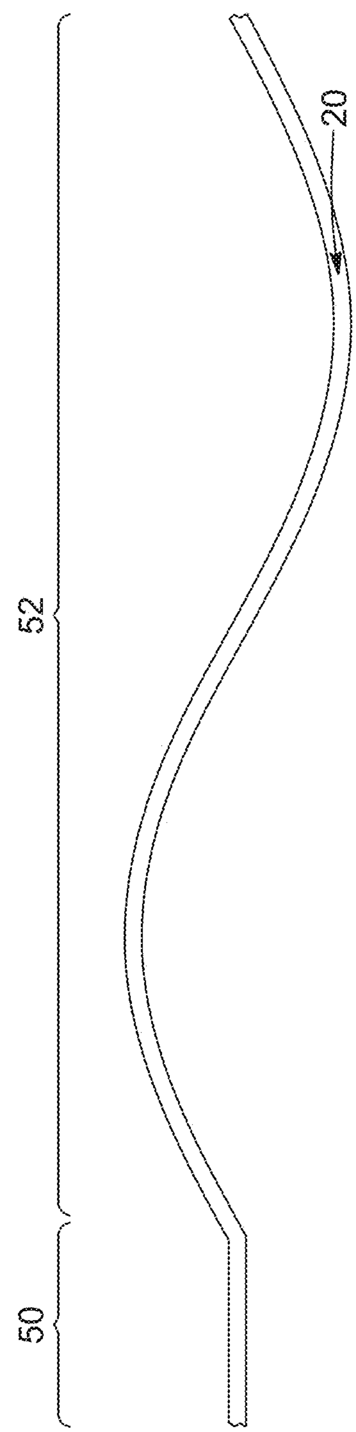


FIG. 11

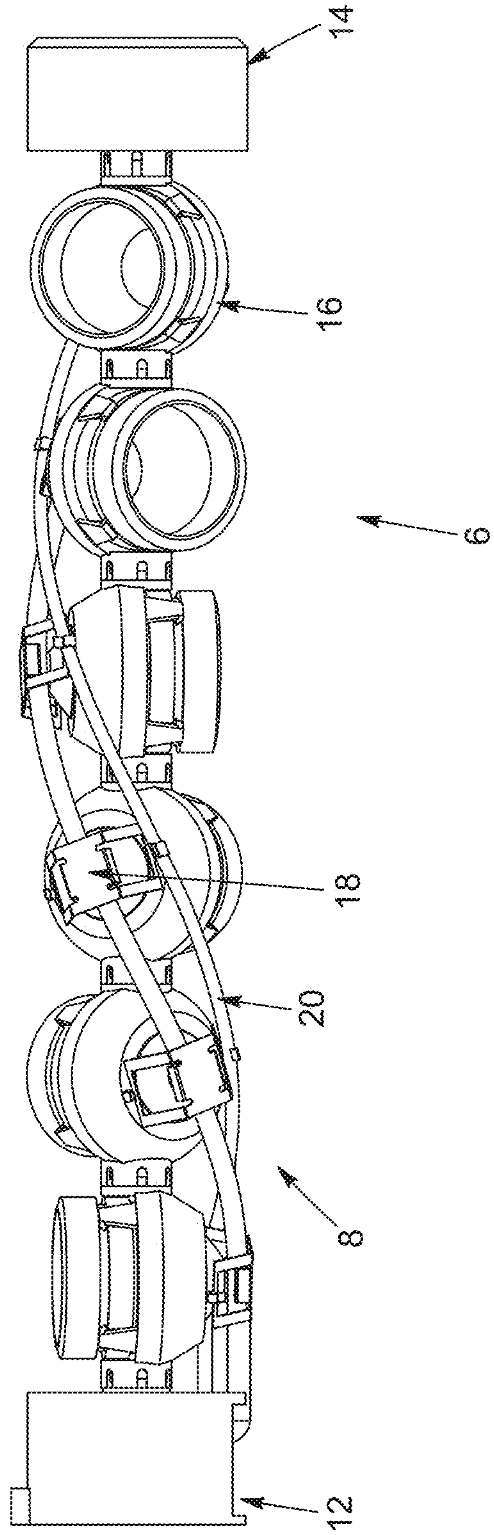
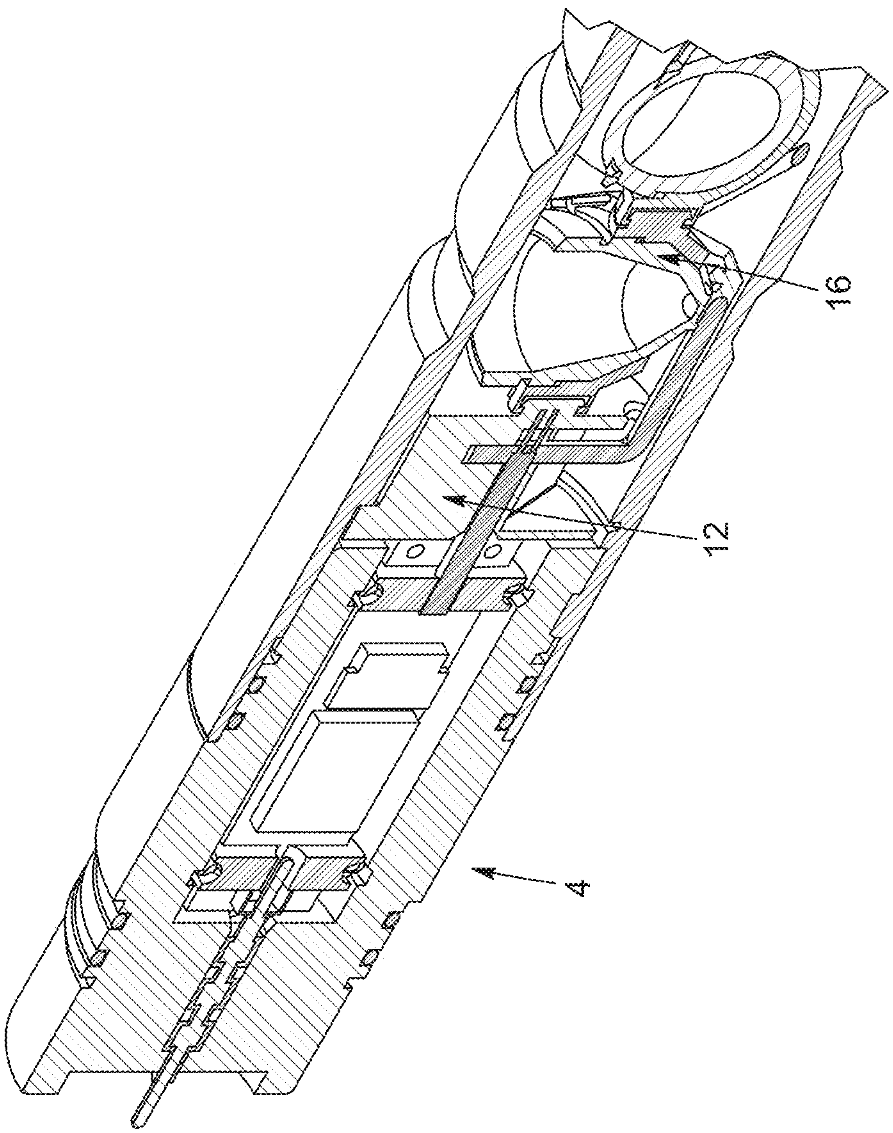


FIG. 12



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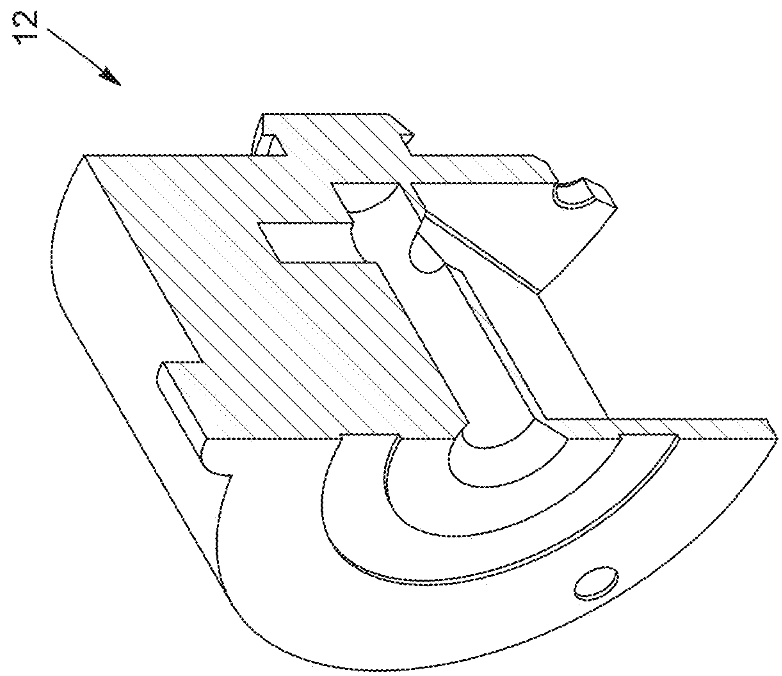


FIG. 15

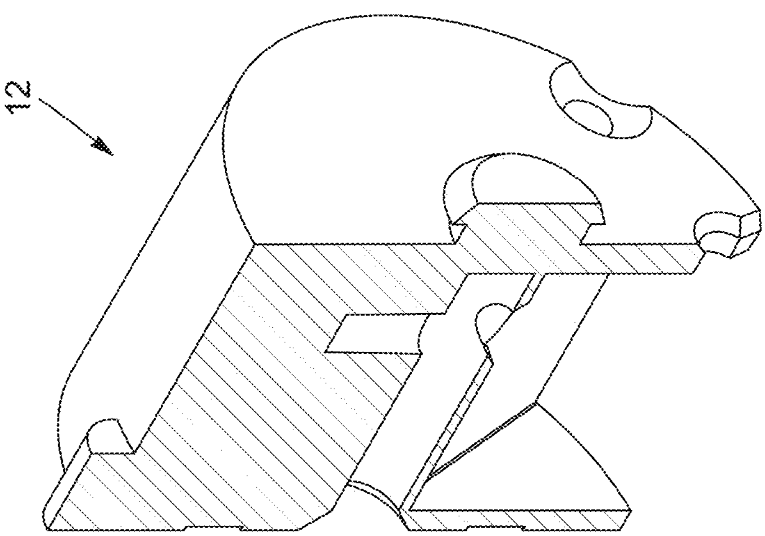
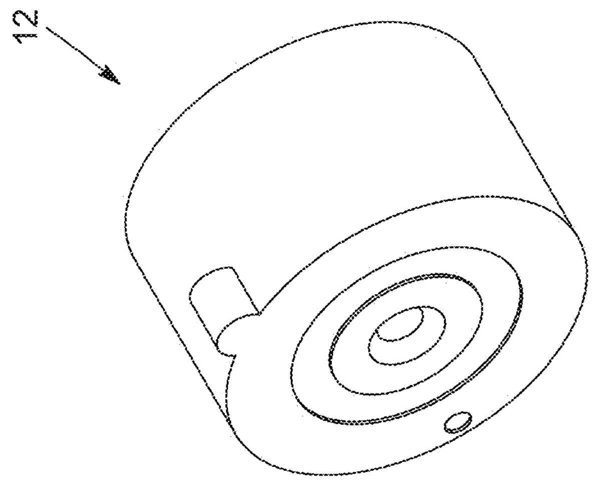


FIG. 14



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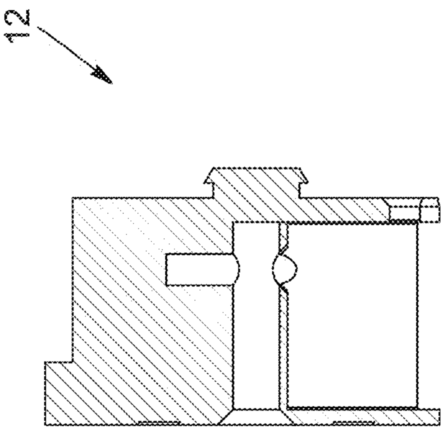

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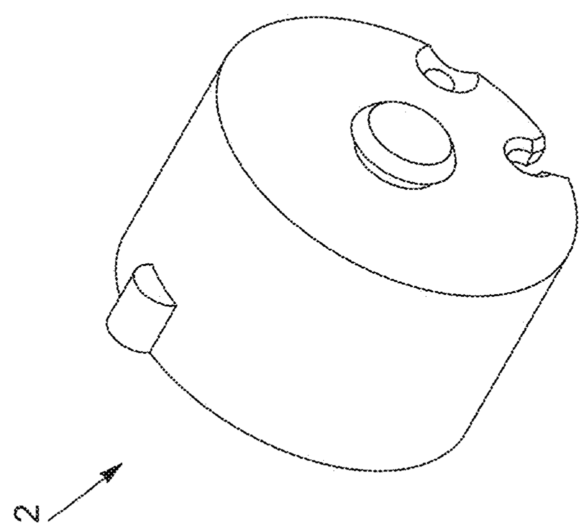

FIG. 17

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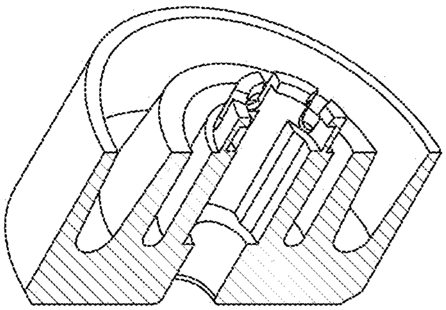

FIG. 20

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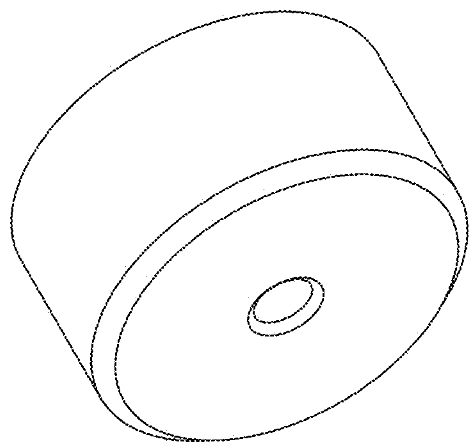

FIG. 21

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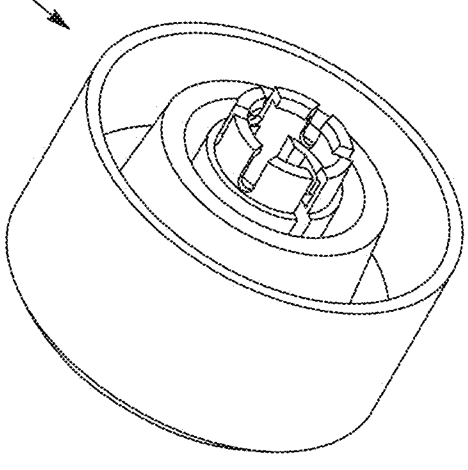


FIG. 19

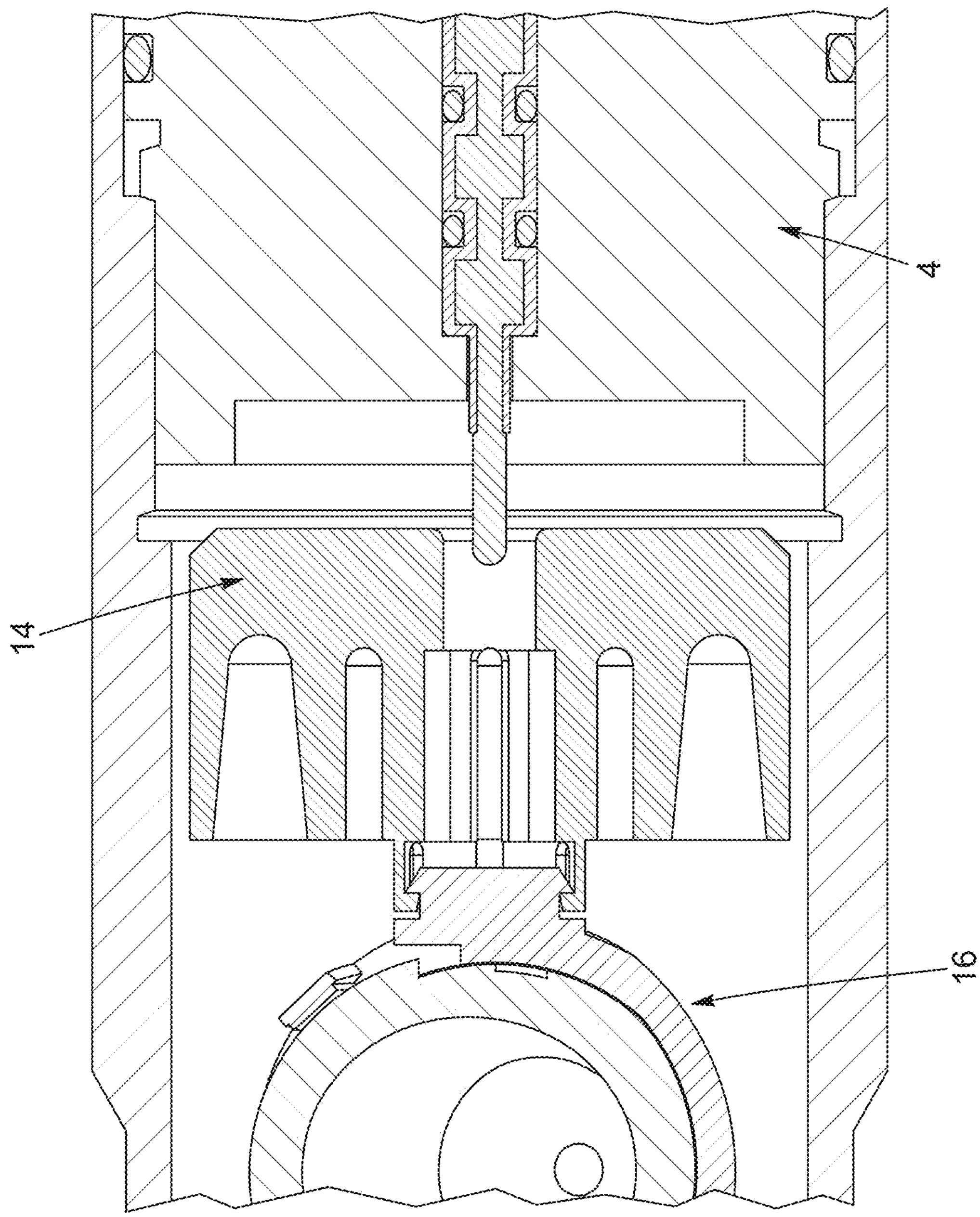


FIG. 22

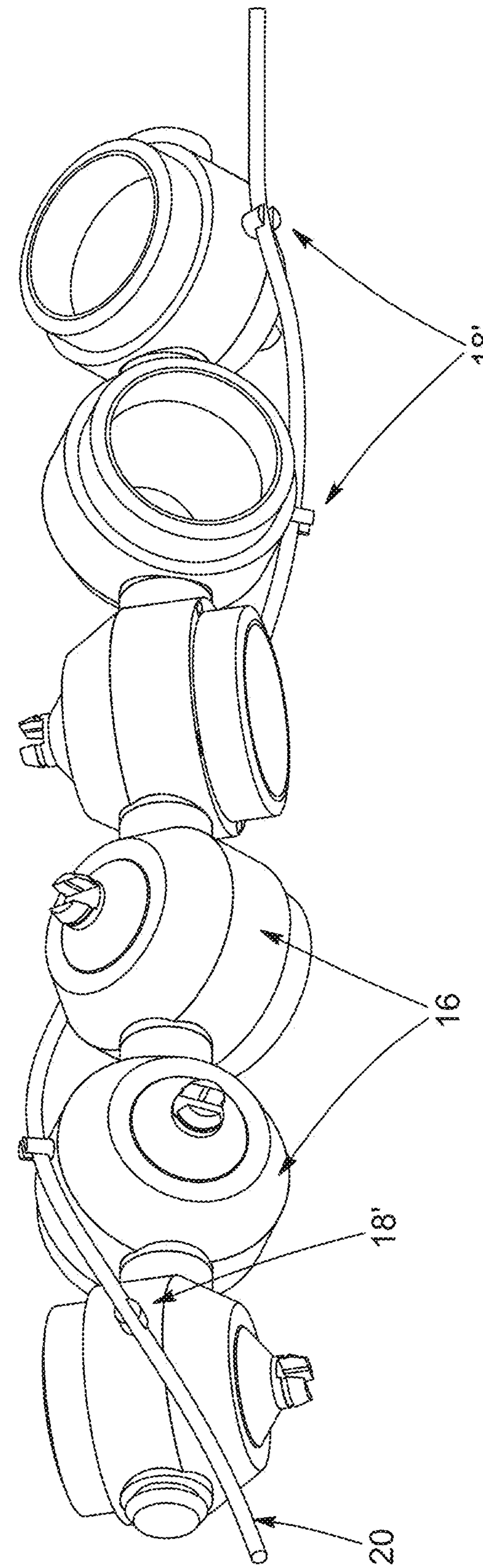
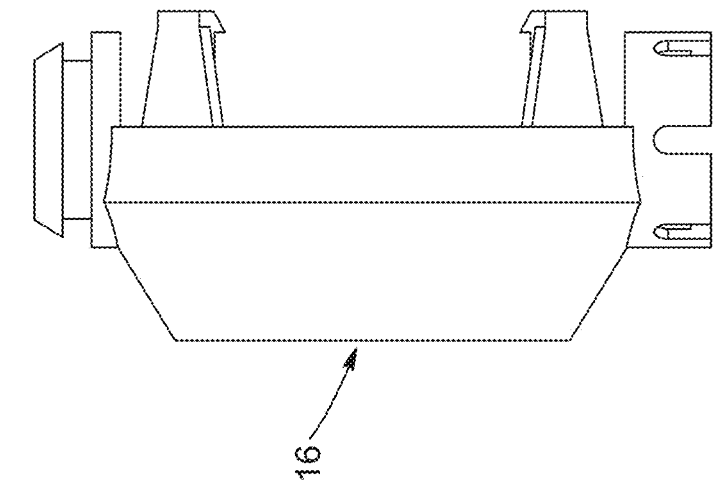


FIG. 23



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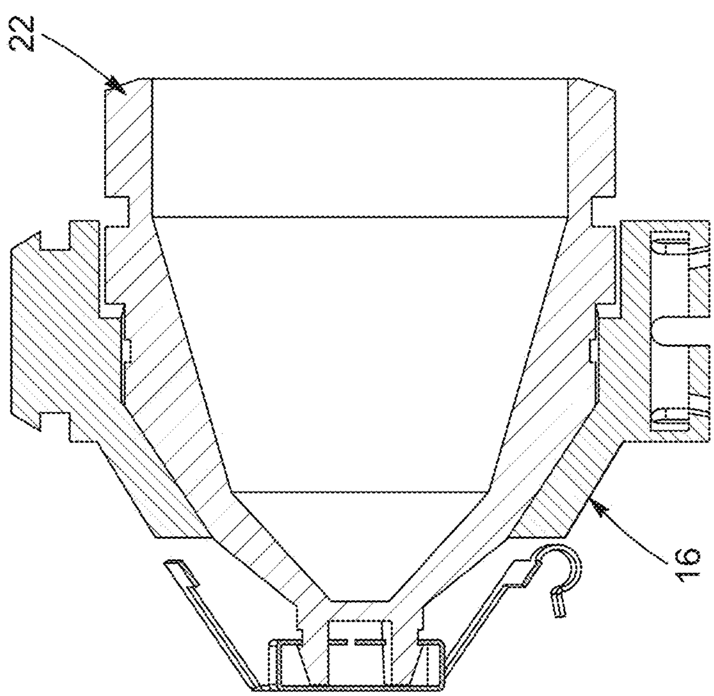

FIG. 24

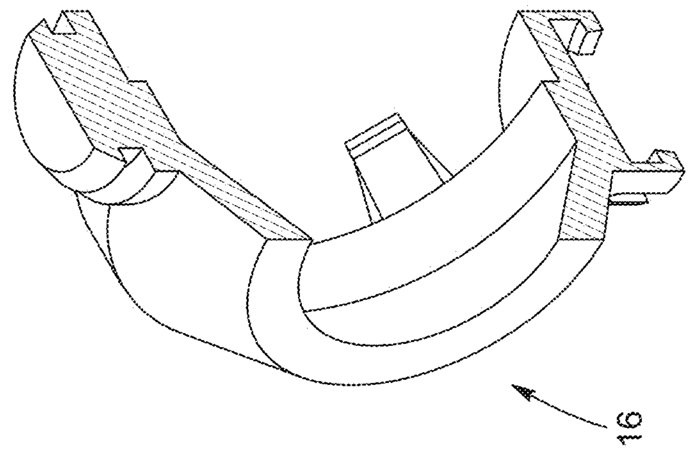

FIG. 27

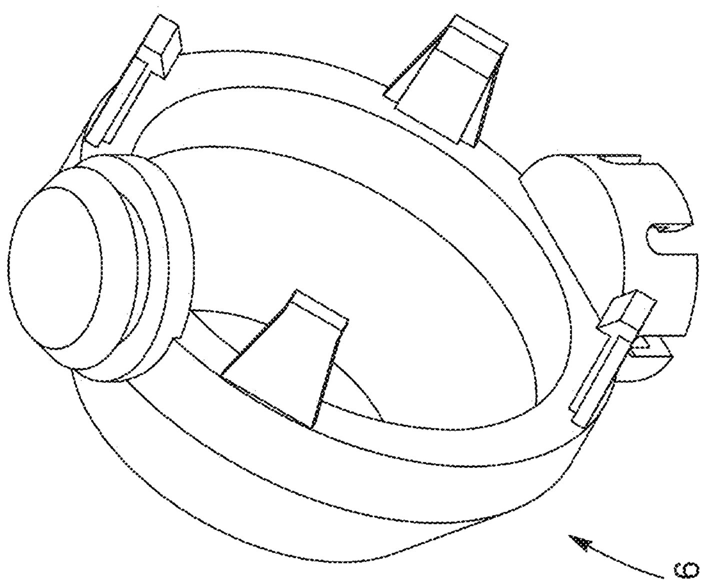

FIG. 26

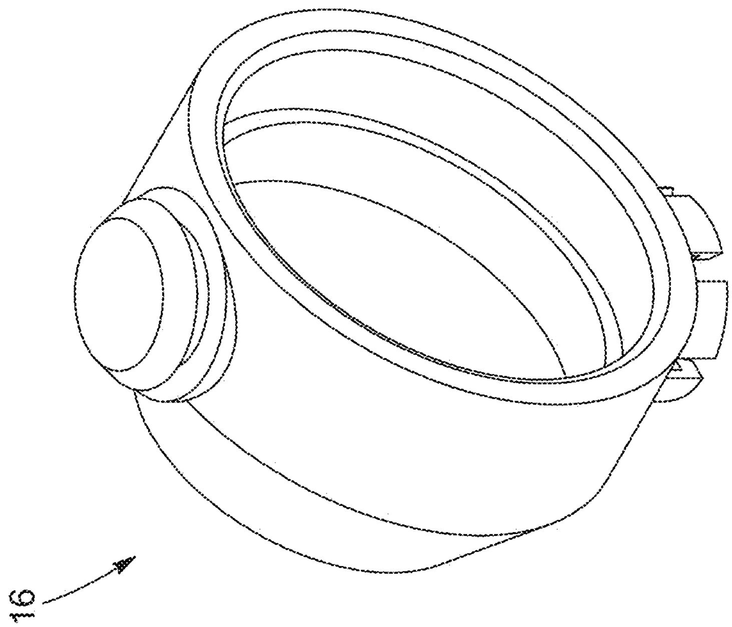

FIG. 29

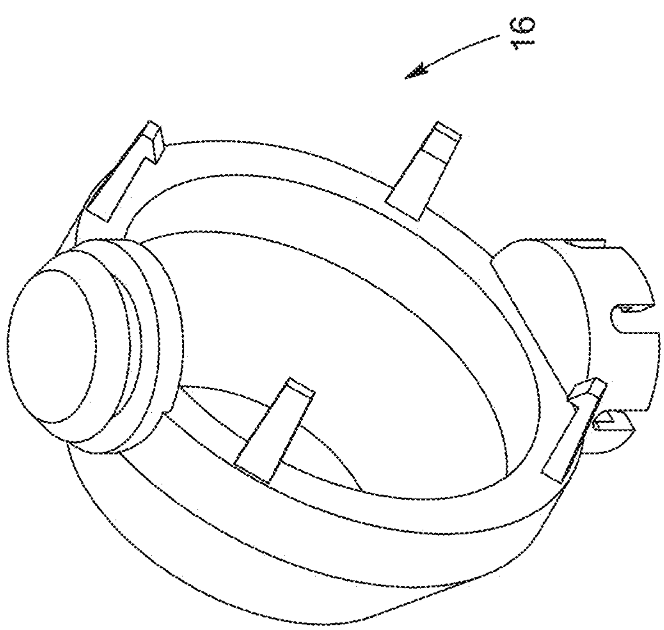

FIG. 28

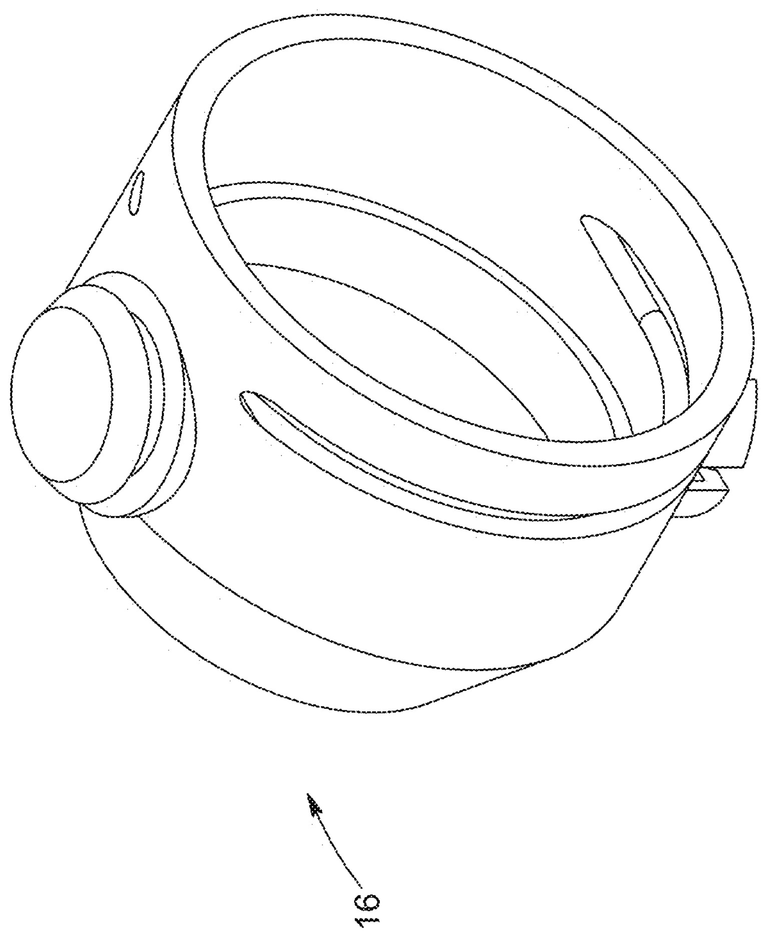

FIG. 30

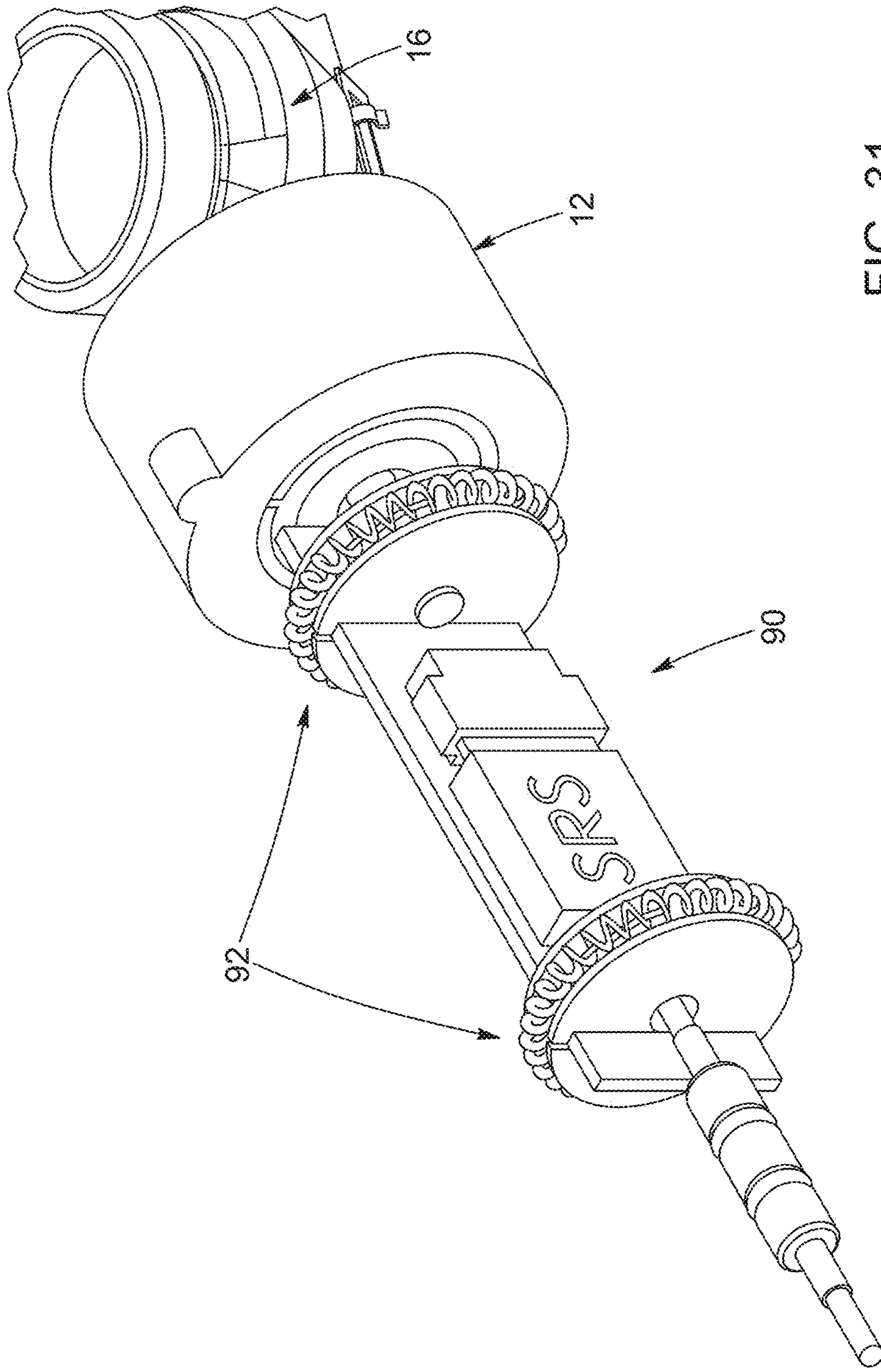

FIG. 31

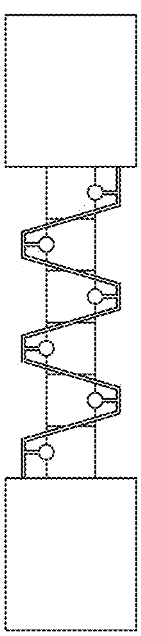
FIG. 32A

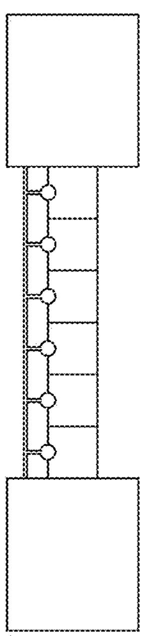
FIG. 32B

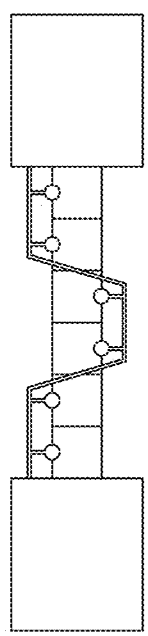
FIG. 32C

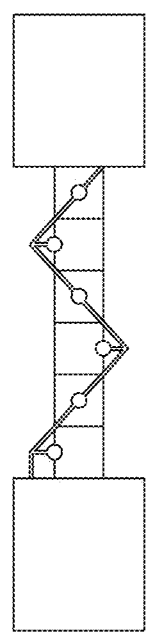
FIG. 32D

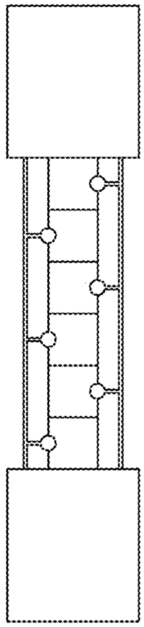
FIG. 32E

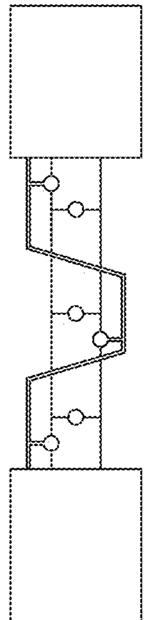
FIG. 32F

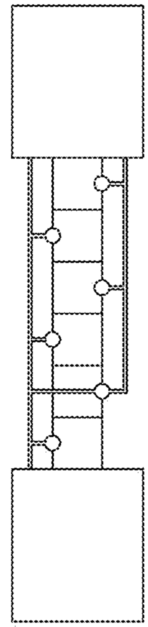
FIG. 32G

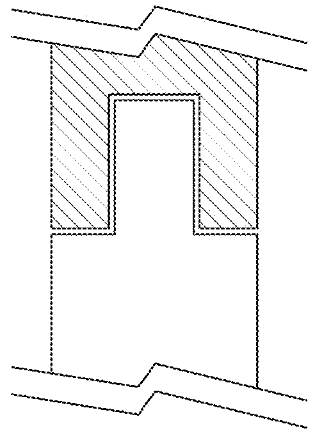

FIG. 34B

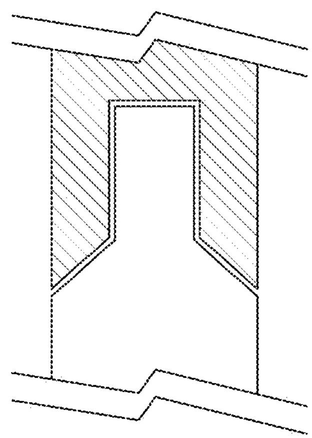

FIG. 34A

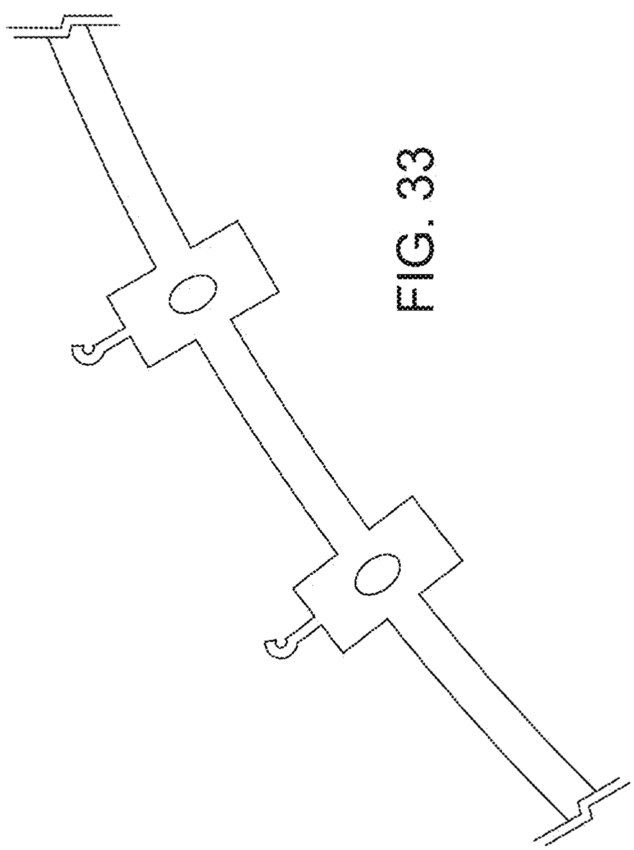

FIG. 33

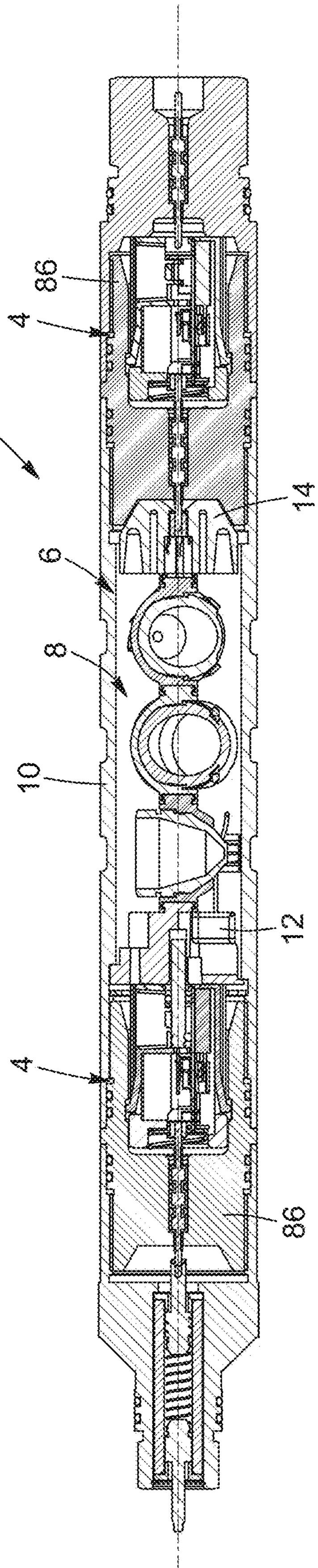

FIG. 35

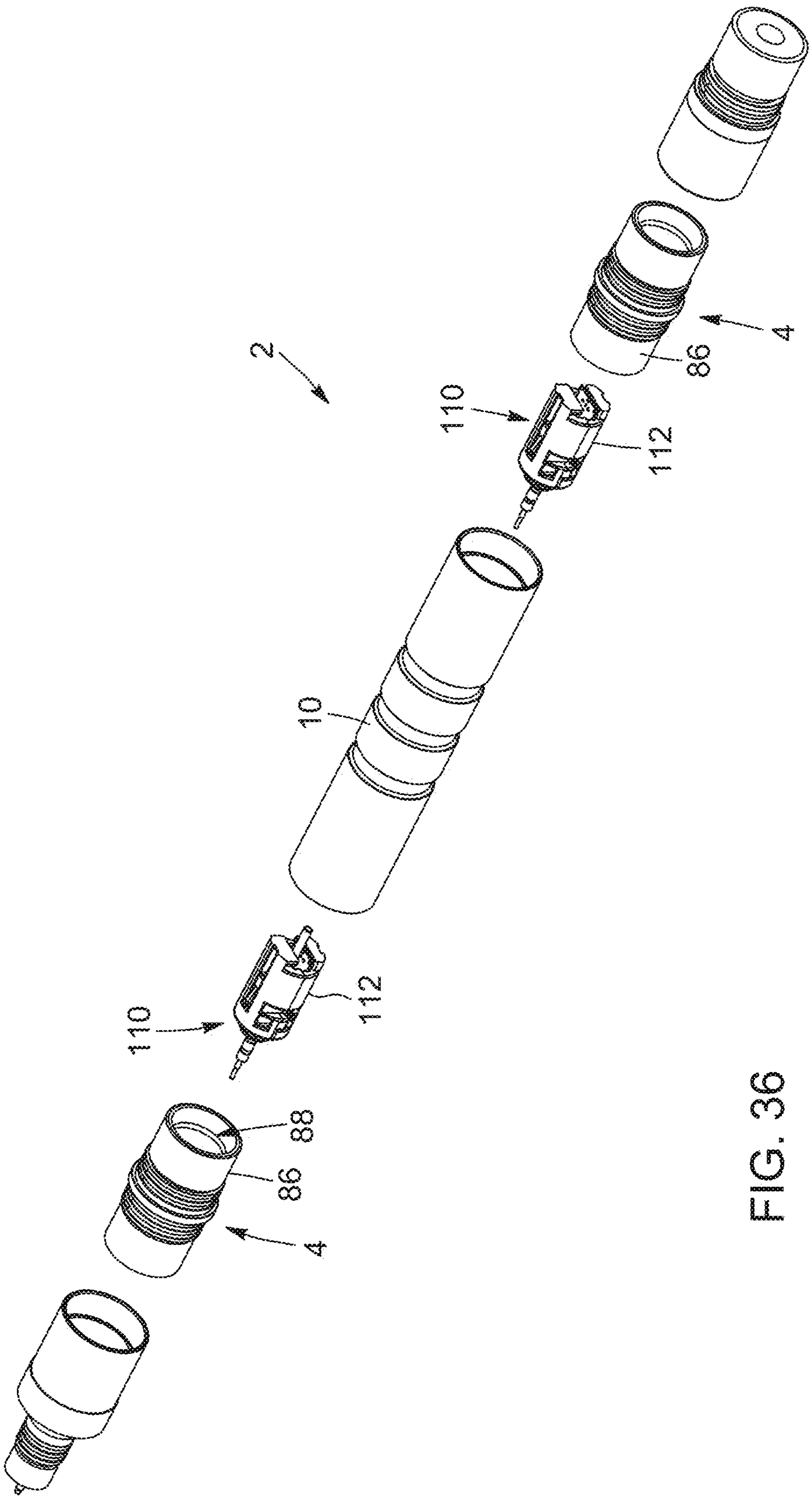

FIG. 36

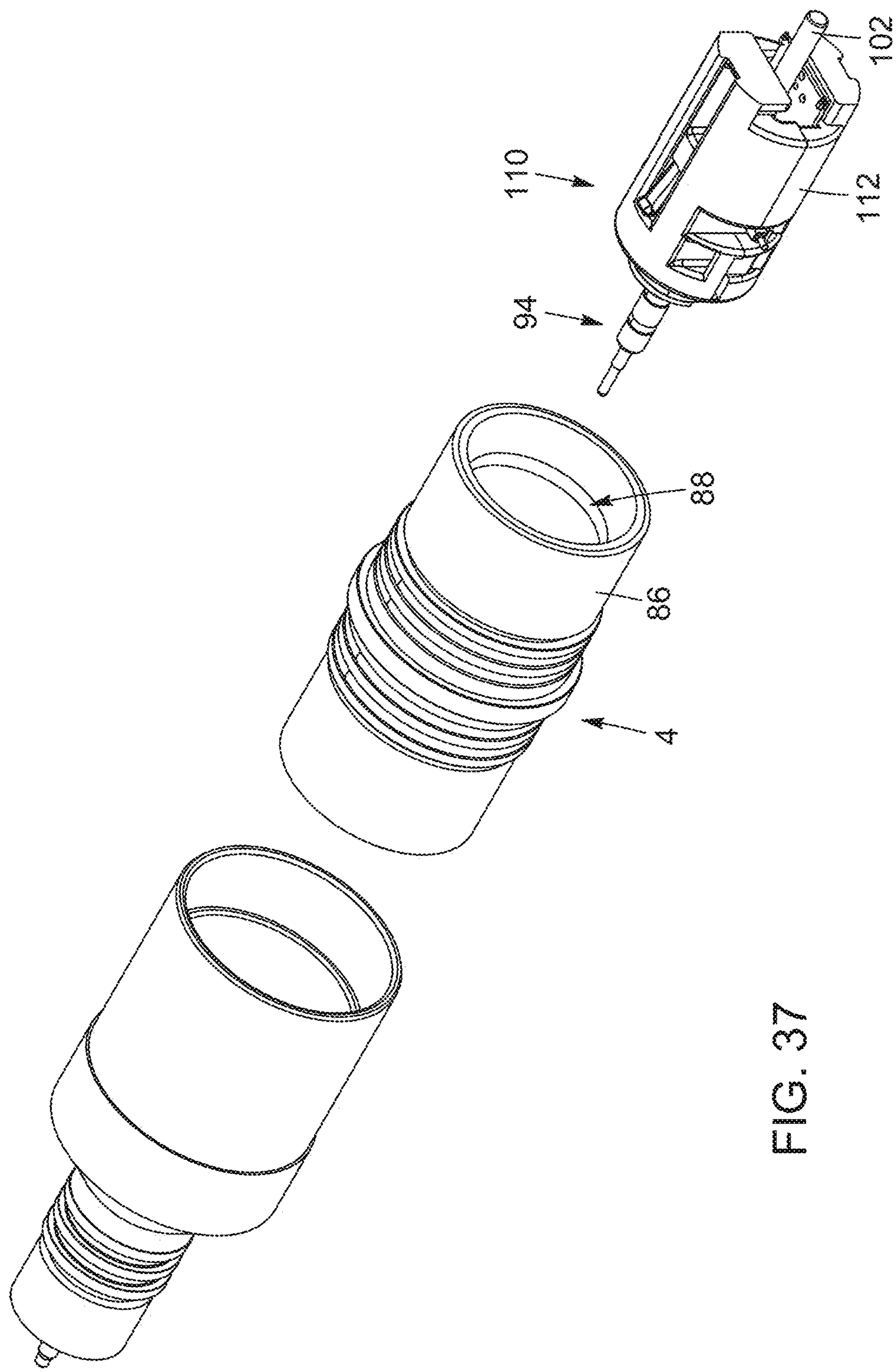

FIG. 37

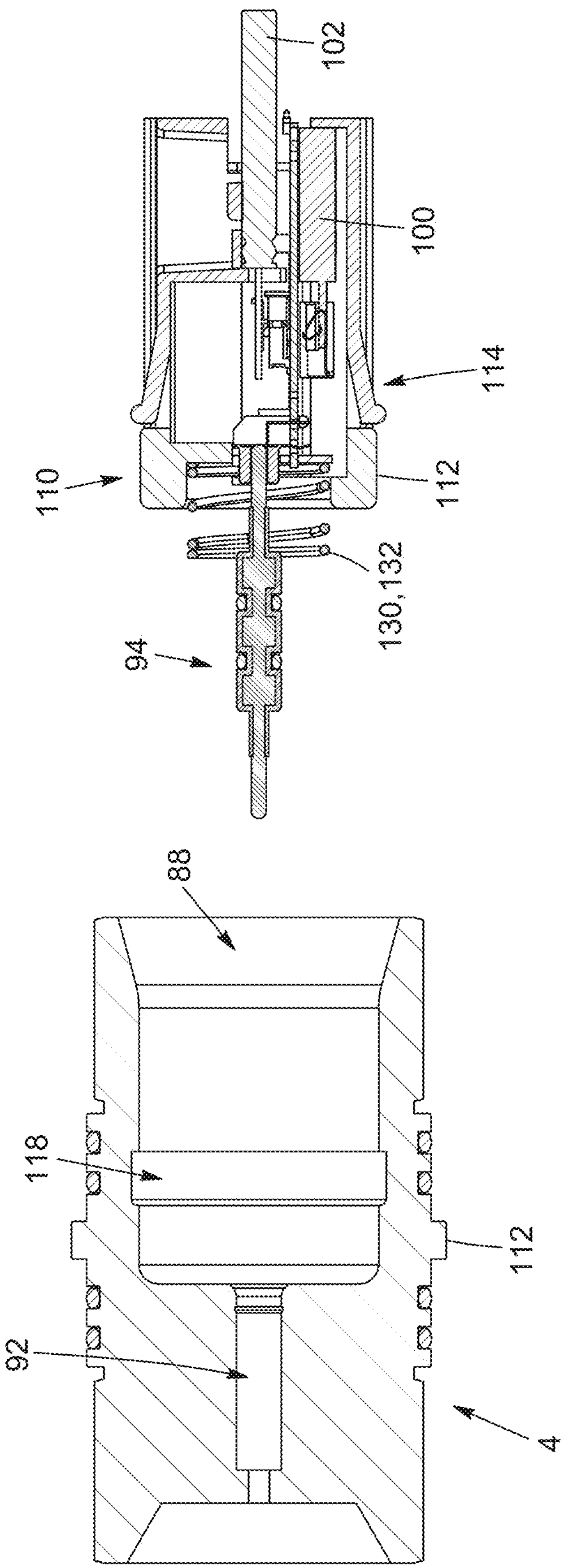

FIG. 38

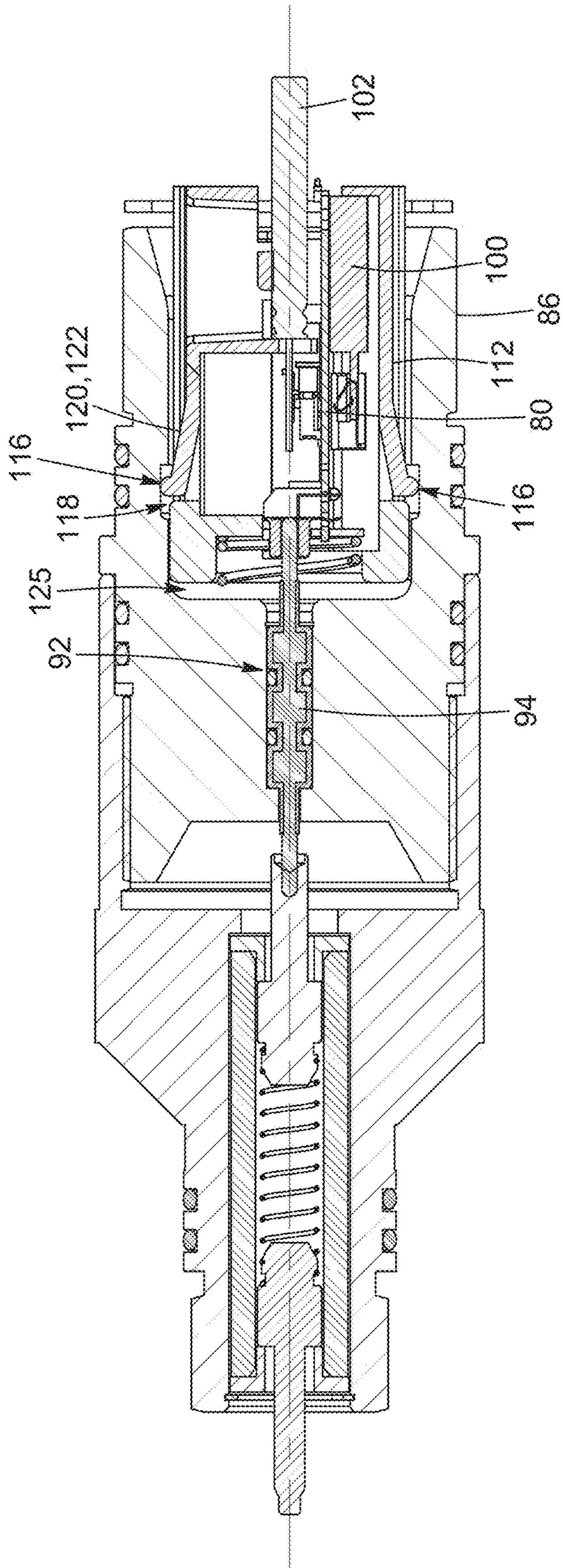

FIG. 39

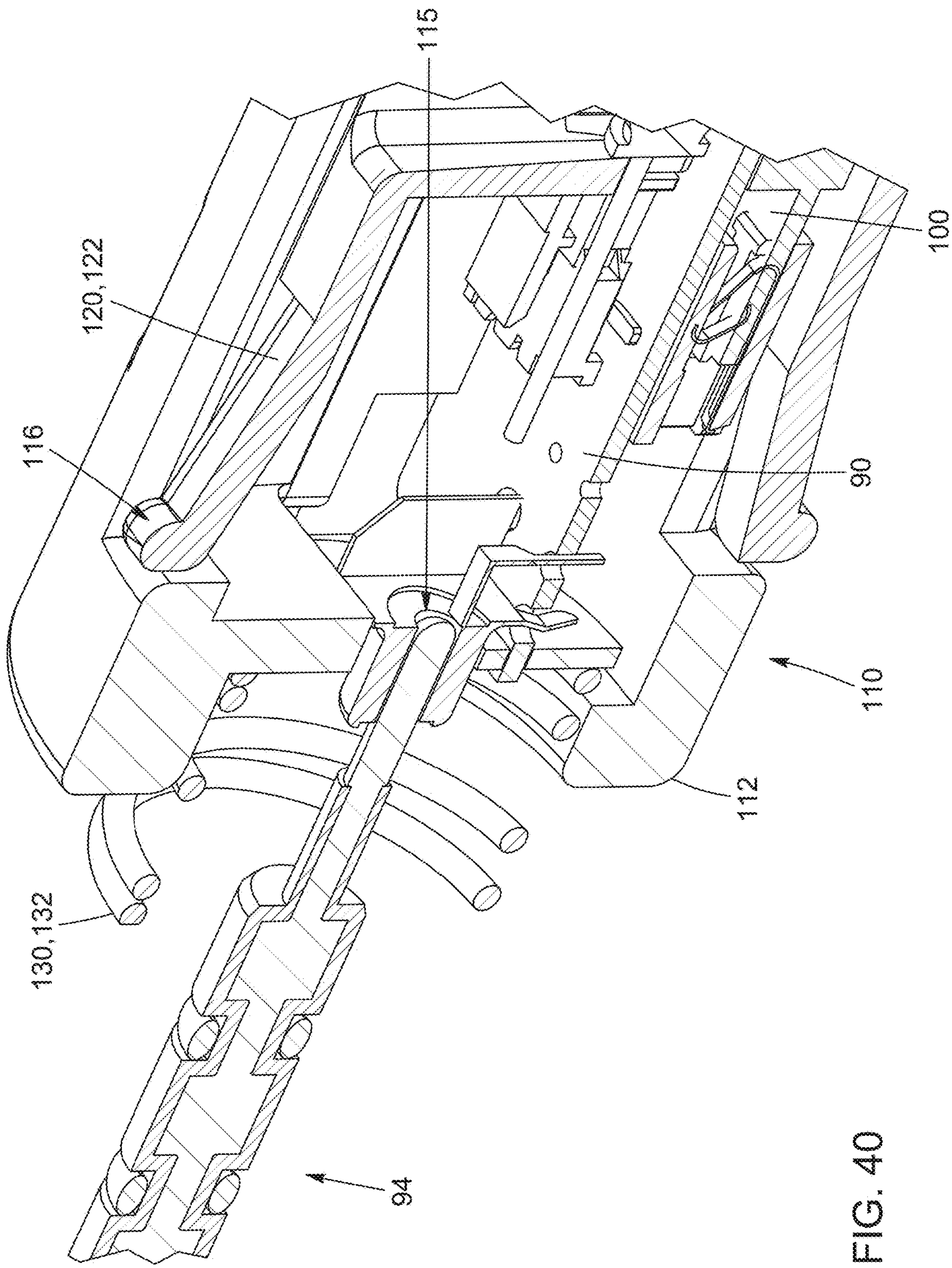

FIG. 40

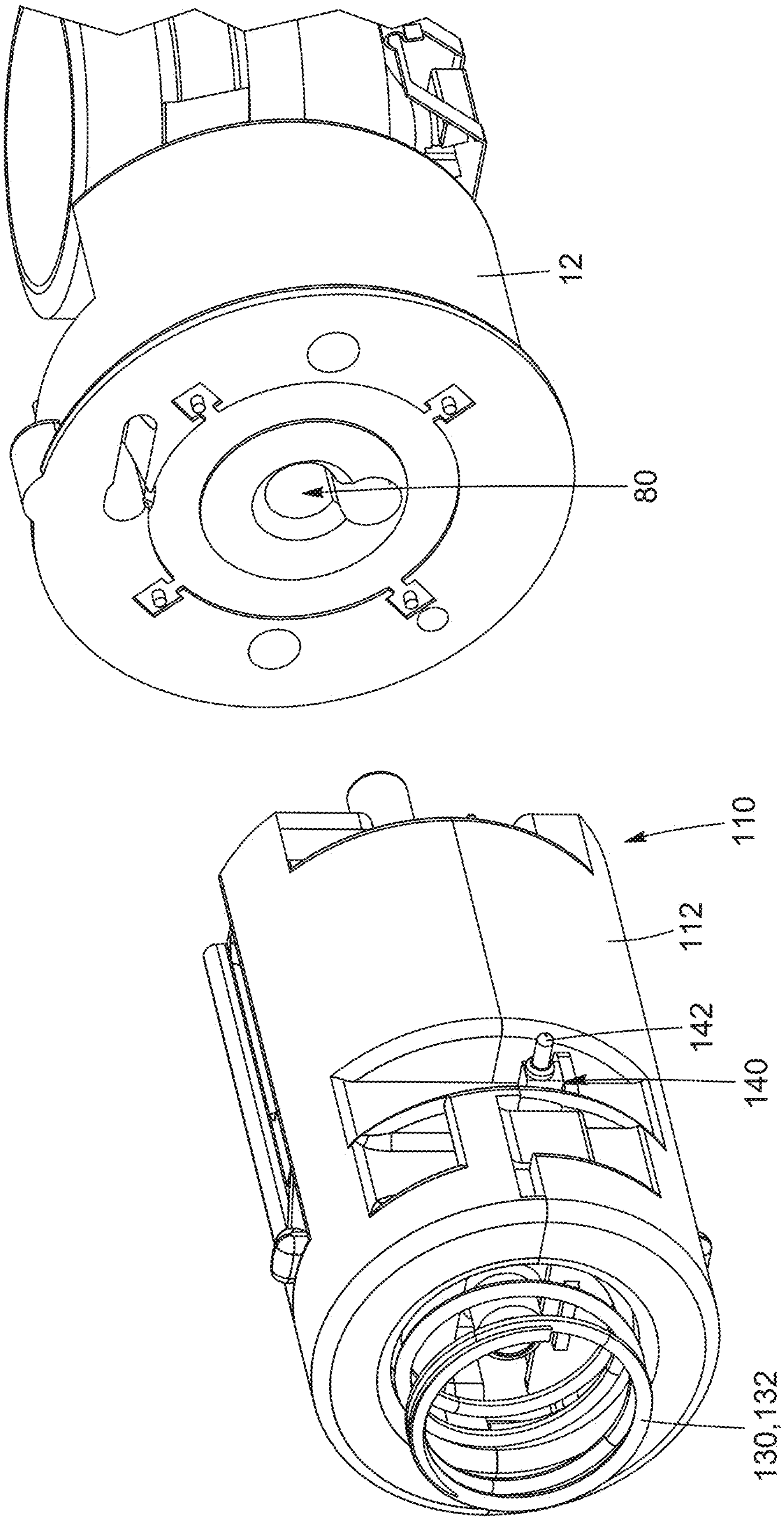

FIG. 41

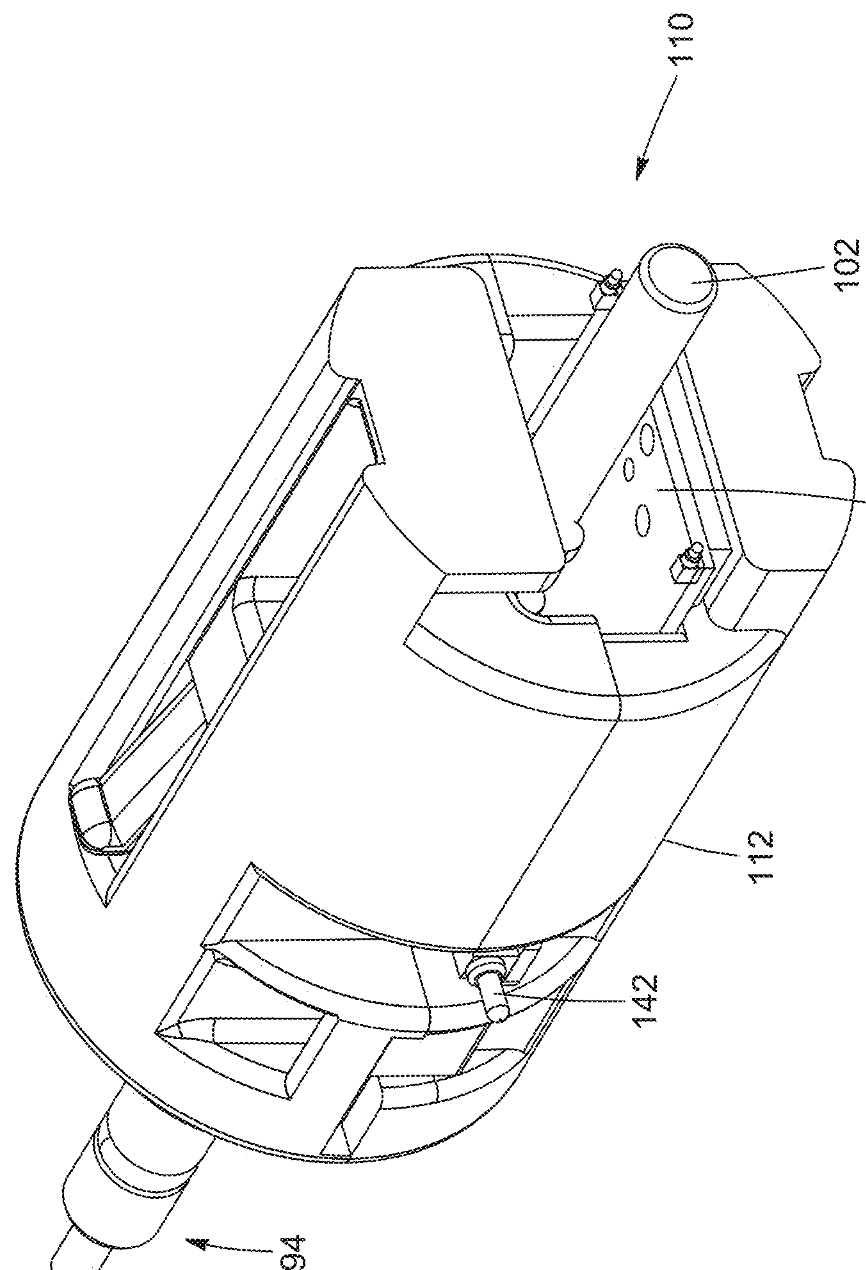

FIG. 42

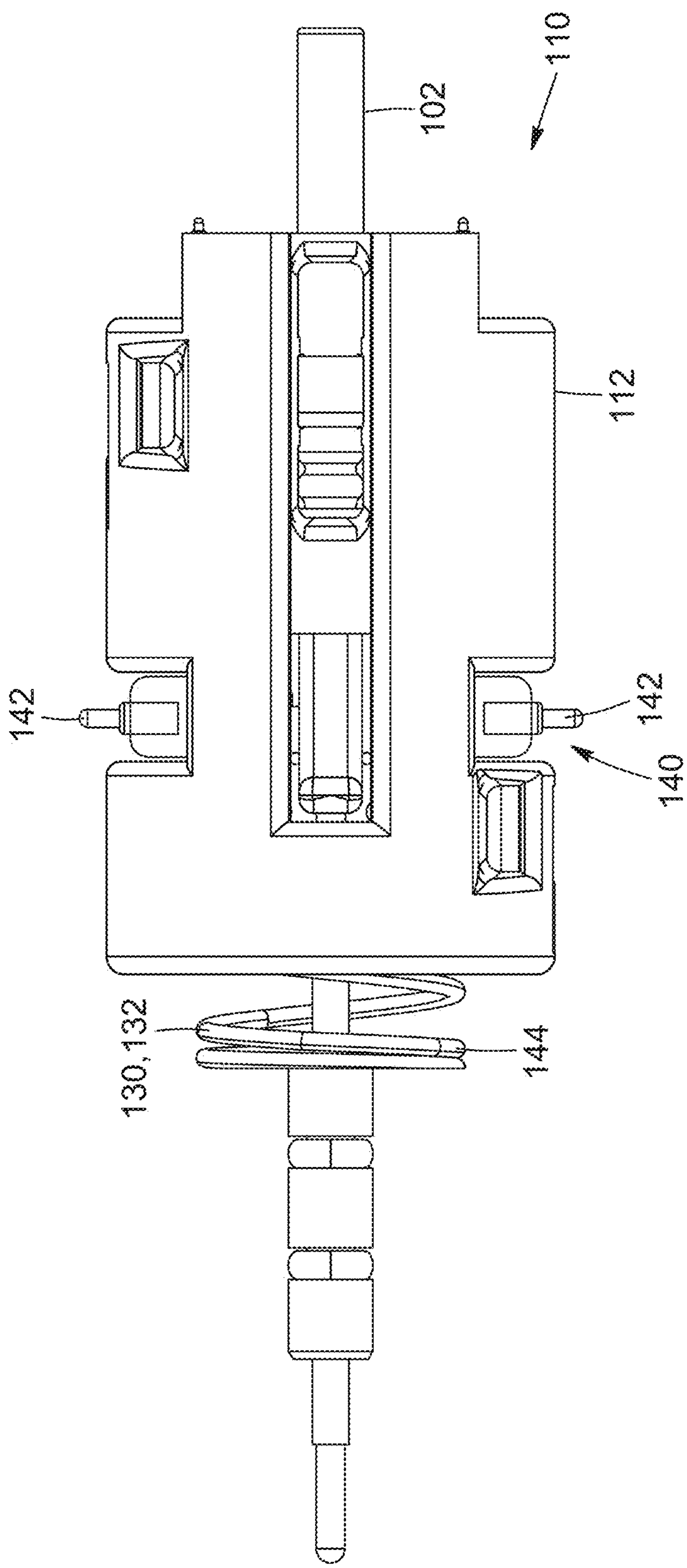

FIG. 43

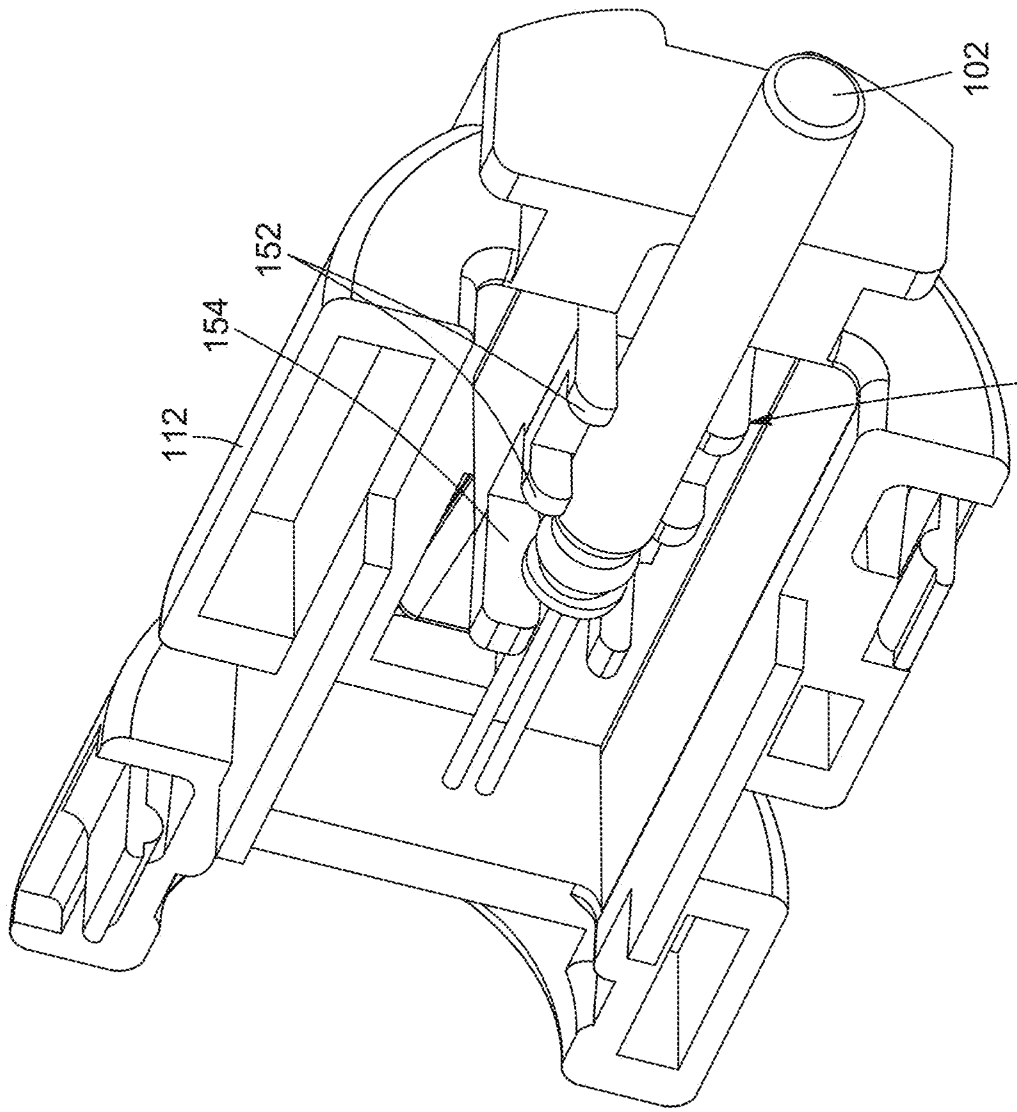

FIG. 44

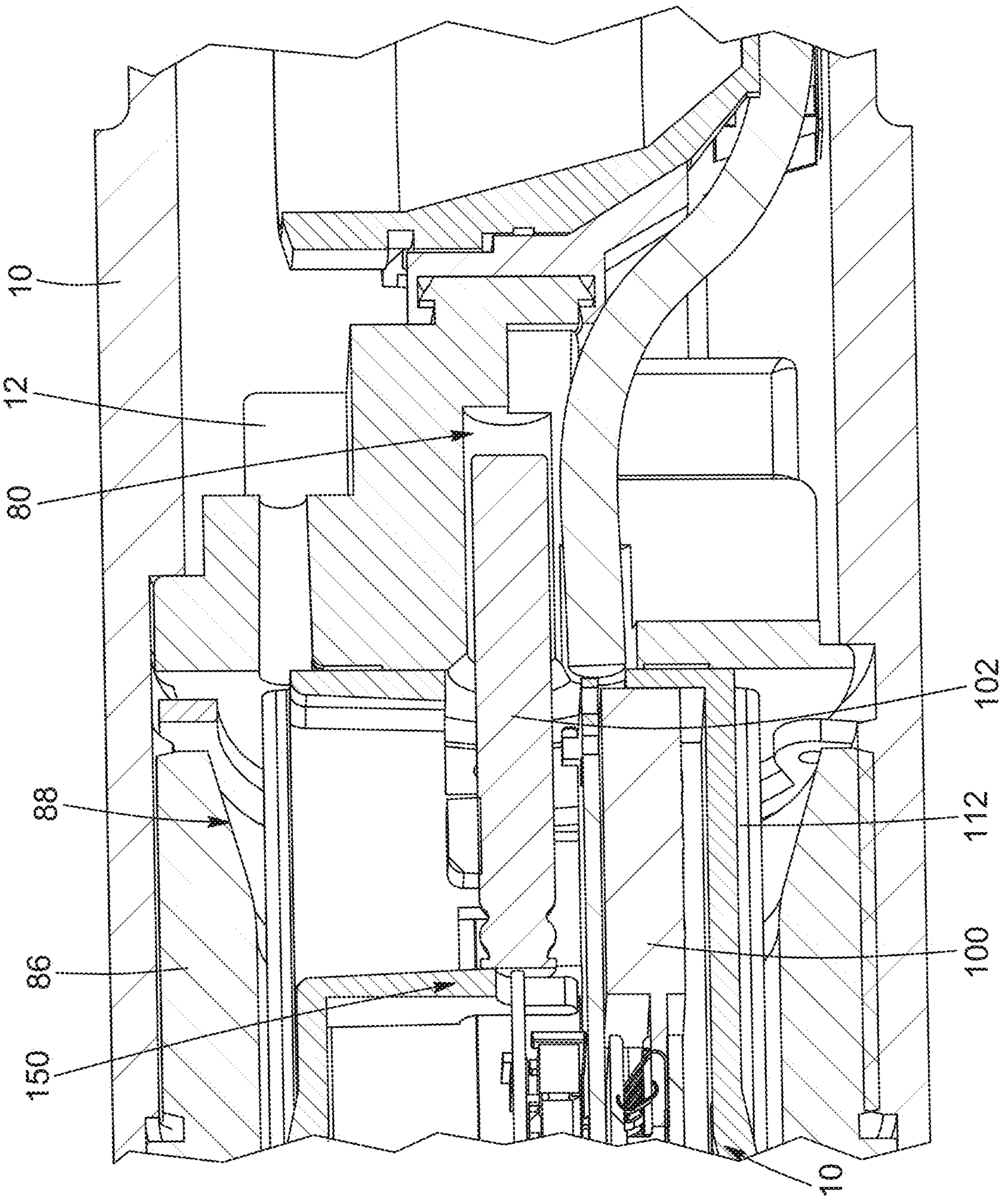

FIG. 45

SHAPED CHARGE PERFORATION GUN WITH PHASING ALIGNMENT AND RELATED EQUIPMENT AND METHODS

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional patent application 63/084,319, filed Sep. 28, 2020, the contents of which are hereby incorporated by this reference.

TECHNICAL FIELD

[0002] The technical field generally relates to perforating guns that utilize shaped charges, and more particularly to assemblies for holding and orienting shaped charges in certain phasing alignments.

BACKGROUND

[0003] Shaped charges are commonly used in perforating guns in order to create perforations extending from a wellbore through the casing and into the surrounding reservoir. Each shaped charge typically has certain components, including a conical metallic liner, the main explosive charge, the primer explosive, and the case that encloses the charge. The detonation of the charges is initiated via a denotator which is energetically coupled via a detonating cord to each of the shaped charges. Multiple shaped charges can be arranged in series within a tubular carrier that is deployed within the casing of a well. The shaped charges can also be arranged with a "phasing" where the explosive charges are oriented to face outwardly at different directions along the series of shaped charges. Typical phasing of shaped charges is at 60°, 90°, 120°, or 180° where the angle is the radial angle between adjacent shaped charges. The shaped charges must be held in place at the desired phasing, which has required dedicated tube assemblies typically cut by laser, or other plastic retaining functional equivalents. There are various challenges with respect to the manufacture, assembly, deployment and utilization of shaped charges, and there is a need for a technology that addresses as least some of those challenges.

SUMMARY

[0004] According to an aspect, a perforating gun for deployment in a wellbore extending within an underground reservoir is provided. The perforating gun includes a shaped charge holding assembly having shaped charge holders that are arranged in a side-to-side configuration, where adjacent pairs of the shaped charge holders are rotatable with respect to each other. The shaped charge holders are configured to receive and support respective shaped charges. The shaped charge holding assembly also has a mounting unit coupled to an end of the holding assembly; and an alignment system. The alignment system includes alignment connectors secured to respective shaped charge holders or to respective shaped charges, and an alignment rod having a mounting section configured to be mounted with respect to the mounting unit; and an alignment rod section extending from the mounting section along the holding assembly and configured to be connected to the alignment connectors. The alignment rod section has a configuration to define connection points that are axially spaced-apart from each other and positioned at radial locations for respectively coupling with the alignment connectors for orientation of the shaped charges at a predetermined phasing.

[0005] According to a possible implementation, the alignment rod section has a helical configuration.

[0006] According to a possible implementation, the helical configuration of the alignment rod section has a circular helical form.

[0007] According to a possible implementation, the helical configuration of the alignment rod section has a square helical form.

[0008] According to a possible implementation, the helical configuration of the alignment rod section has a regular helical form over a length thereof.

[0009] According to a possible implementation, the alignment rod section is arranged to wind helically around the holding assembly.

[0010] According to a possible implementation, adjacent alignment connectors define an axial holder spacing (S) therebetween, and the helical configuration of the adjustment rod section has a pitch (P) that is predetermined to position the connection points of the adjustment rod section at the radial locations for coupling with the alignment connectors.

[0011] According to a possible implementation, the axial holder spacing (S) is smaller than the pitch (P).

[0012] According to a possible implementation, the pitch (P) is an integer multiple of the axial holder spacing (S).

[0013] According to a possible implementation, the pitch (P) is equivalent to approximately 2S to provide a 180° phasing between adjacent shaped charge holders.

[0014] According to a possible implementation, the pitch (P) is equivalent to approximately 3S to provide a 120° phasing between adjacent shaped charge holders.

[0015] According to a possible implementation, the pitch (P) is equivalent to approximately 4S to provide a 90° phasing between adjacent shaped charge holders.

[0016] According to a possible implementation, the pitch (P) is equivalent to approximately 6S to provide a 60° phasing between adjacent shaped charge holders.

[0017] According to a possible implementation, the alignment rod section and the mounting section are formed as a one-piece solid rod.

[0018] According to a possible implementation, the alignment rod is composed of metal.

[0019] According to a possible implementation, the mounting unit comprises a slot and the mounting section of the alignment rod is shaped to be insertable within the slot.

[0020] According to a possible implementation, the slot has a circular cross-section and the mounting section has a cylindrical shape.

[0021] According to a possible implementation, the mounting section is straight.

[0022] According to a possible implementation, the mounting unit is a top mounting unit.

[0023] According to a possible implementation, the mounting unit is rotatably coupled to a top-most shaped charge holder.

[0024] According to a possible implementation, the perforating gun further comprises a carrier in which the mounting unit, the holding assembly and the alignment system are located.

[0025] According to a possible implementation, the mounting unit comprises an indexing tab extending radially therefrom and configured to fit within a corresponding groove of the carrier to prevent rotation between the carrier and the mounting unit.

[0026] According to a possible implementation, the carrier has a scalloped shape with narrower sections being aligned with respective shaped charges.

[0027] According to a possible implementation, the shaped charge holders are infinitely rotatable with respect to each other.

[0028] According to a possible implementation, the shaped charge holders are rotatably mounted directly to each other.

[0029] According to a possible implementation, the shaped charge holders each include an annular body comprising a first open end for receiving a shaped charge therein, and a second opening through which an end of the shaped charge can pass for connection with a detonation cord; a first coupling component extending from a first side of the annular body; and a second coupling component extending from a second side of the annular body, where the first coupling component and the second coupling component of adjacent shaped charge holders are rotatably connectable together to enable rotation of the adjacent shaped charge holders with respect to each other.

[0030] According to a possible implementation, the first coupling component is provided on a downhole side and the second coupling component is provided on an uphole side for each of the shaped charge holders.

[0031] According to a possible implementation, the first coupling component is a male component and the second coupling component is a female component.

[0032] According to a possible implementation, the male component comprises a mushroom-shaped member comprising a post extending from the annular body and a head.

[0033] According to a possible implementation, the post is cylindrical, and the head is inwardly tapered extending away from the post.

[0034] According to a possible implementation, the head has a frusto-conical shape.

[0035] According to a possible implementation, the female component includes side walls extending from the annular body and defining a chamber for receiving the head of the male component; and a lip extending inwardly from an extremity of the side walls.

[0036] According to a possible implementation, the lip and the head are configured such that, upon coupling of the male and female components, the lip fits over and retains the head within the chamber to inhibit axial displacement while allowing rotation between adjacent shaped charge holders.

[0037] According to a possible implementation, the first and second coupling components are configured to axially retain the holders together to resist or prevent decoupling.

[0038] According to a possible implementation, the male component has flexible members and the female component has a rigid wall.

[0039] According to a possible implementation, a top-most shaped charge holder is directly rotatably connected with respect to the mounting unit.

[0040] According to a possible implementation, each of the alignment connectors includes a main section for coupling the shaped charge with a detonation cord; and an alignment section configured to be secured to the alignment rod.

[0041] According to a possible implementation, the alignment section comprises an arm extending from the main section and comprising a clip securable about the alignment rod.

[0042] According to a possible implementation, the alignment connector comprises a second arm extending from the main section and comprising a second clip securable to a signal cord.

[0043] According to a possible implementation, the alignment connector is formed from a single sheet metal piece.

[0044] According to a possible implementation, the main section comprises a base plate, opposed side walls extending from the base plate, and an upper plate defining a detonator cord passageway, and wherein the upper plate has an opening defined therein for receiving an end of the shaped charge into the passageway for connection to the detonator cord.

[0045] According to a possible implementation, the arm comprises an oblique section extending at an angle toward the shaped charge, the clip being located at an extremity of the oblique section.

[0046] According to a possible implementation, the angle is between 30 and 60 degrees.

[0047] According to a possible implementation, the clip comprises a clamp comprising two opposed resilient members that define an insertion region therebetween and extend outwardly from the oblique section away from the shaped charge.

[0048] According to a possible implementation, the clamp is configured to receive and compress the alignment rod within the insertion region.

[0049] According to a possible implementation, the alignment connector is formed as an integral connected part of the alignment rod, or is formed as a separate piece.

[0050] According to a possible implementation, the alignment rod has a circular cross-section.

[0051] According to a possible implementation, the perforating gun further includes a bottom mounting unit that is rotatably coupled to a bottom-most shaped charge holder, and comprises a cavity to receive a free bottom end of the alignment rod.

[0052] According to a possible implementation, each of the shaped charge holders comprises resilient projections configured to retain the corresponding shaped charge in the holder.

[0053] According to a possible implementation, each of the shaped charge holders comprise a resilient mounting ring configured to retain the corresponding shaped charge in the holder.

[0054] According to a possible implementation, each of the shaped charge holders include a mounting ring comprising a slit and configured to receive the shaped charge; and a resilient retention wire insertable in the slit to engage and retain the corresponding shaped charge in the holder.

[0055] According to a possible implementation, the alignment connectors formed as part of respective holders.

[0056] According to a possible implementation, the alignment connectors are configured to couple the alignment rod section to the shaped charges.

[0057] According to another aspect, a kit for holding shaped charges at different phasings is provided. The kit includes a series of shaped charge holders that are rotatably connectable and configured to hold shaped charges; alignment connectors securable with respect to respective shaped charge holders and/or shaped charges; a mounting unit couplable to an end one of the shaped charge holders; and a set of alignment rods having different alignment rod configurations, each of the alignment rods being mountable to the mounting unit and to each of the alignment connectors and having a configuration for orientation of the shaped charge holders in a predetermined phasing.

[0058] According to another aspect, a use of a helical member for alignment of a series of shaped charges in a predetermined phasing in a perforation gun deployable within a wellbore is provided.

[0059] According to another aspect, a perforating gun for deployment in a wellbore extending within an underground reservoir is provided. The perforating gun includes a shaped charge holding assembly having shaped charge holders that are arranged in a side-to-side configuration and wherein at least some adjacent pairs of the shaped charge holders are infinitely rotatable with respect to each other in a rotation state; a mounting unit coupled to the holding assembly; and an alignment system. The alignment system includes alignment connectors securable with respect to respective shaped charge holders or shaped charges; an alignment member comprising a mounting section configured to be mounted with respect to the mounting unit to secure the alignment member with respect thereto; and an elongated alignment section extending from the mounting section along the holding assembly and configured to secure the shaped charges via the alignment connectors to orient the shaped charges in a predetermined phasing in an aligned state.

[0060] According to a possible implementation, the alignment member comprises an alignment rod.

[0061] According to a possible implementation, the alignment member comprises an alignment tube.

[0062] According to a possible implementation, the perforating gun further includes a cord or wire extending within a hollow core of the alignment tube to provide electrical communication or grounding.

[0063] According to a possible implementation, the alignment member comprises an alignment plate.

[0064] According to a possible implementation, the alignment member is composed of metal and provides electrical conduction.

[0065] According to a possible implementation, the alignment member comprises an electrically insulating sleeve around an outer surface thereof.

[0066] According to a possible implementation, the shaped charge holders are directly coupled to each other.

[0067] According to a possible implementation, the shaped charge holders are independently rotatable with respect to each other.

[0068] According to a possible implementation, the mounting unit comprise a slot shaped and sized to receive the mounting section of the alignment member.

[0069] According to a possible implementation, the slot and mounting section are configured so the mounting section has free axial movement within the slot.

[0070] According to a possible implementation, the alignment member has a single elongated alignment section.

[0071] According to a possible implementation, the alignment system has a single alignment member for phasing the shaped charges.

[0072] According to another aspect, a perforating gun for deployment in a wellbore extending within an underground reservoir is provided. The perforating gun includes a shaped charge holding assembly having shaped charge holders that are arranged in a side-to-side configuration along the perforating gun; a mounting unit coupled to an end of the holding assembly; and an alignment system. The alignment system has alignment connectors securable with respect to respective shaped charge holders and/or shaped charges; and an alignment rod comprising a mounting section configured to be mounted with respect to the mounting unit to secure the alignment rod with respect thereto; and a helical alignment section extending from the mounting section along the holding assembly and configured to secure each of the shaped charge holder and/or shaped charges via the alignment connectors, the helical alignment section having a predetermined helical configuration with a pitch for providing a predetermined phasing of the shaped charges.

[0073] According to a possible implementation, at least some of the shaped charge holders are rotatable with respect to each other prior to being held in place by the alignment system.

[0074] According to a possible implementation, the shaped charge holders are infinitely rotatable with respect to each other prior to being held in place by the alignment system.

[0075] According to another aspect, a shaped charge holder is provided. The shaped charge holder includes an annular body comprising a first open end for receiving a shaped charge therein, and a second opening through which an end of the shaped charge can pass for connection with a detonation cord; a first coupling component extending from a first side of the annular body; and a second coupling component extending from a second side of the annular body; and wherein the first coupling component and the second coupling component are configured such that adjacent shaped charge holders are rotatably connectable together by engagement of the first and second coupling components to provide infinite rotation with respect to each other about a longitudinal axis.

[0076] According to a possible implementation, the first and second coupling components are configured axially retain adjacent holders together to resist or prevent decoupling.

[0077] According to a possible implementation, the first and second coupling components provide a male-female connection.

[0078] According to a possible implementation, the male component is rigid, and the female component comprises resilient arms to receive and snap onto the male component.

[0079] According to a possible implementation, the female component comprises a cavity defined by rigid walls and the male component comprise resilient arms insert and snap into the female component.

[0080] According to another aspect, a multifunctional connector for use in a perforating gun is provided. The multifunctional connector includes a detonation cord clip for securing a detonation cord against a shaped charge; a signal cord clip for securing a signal cord extending along the perforating gun; and an alignment member clip for securing an alignment member that is configured to secure shaped charge holders in a phasing arrangement.

[0081] According to another aspect, a multifunctional connector for use in a perforating gun is provided. The multifunctional connector includes a detonation cord clip for securing a detonation cord against a shaped charge; an arm extending away from the detonation cord clip and comprising a clamp at an extremity thereof, the clamp being configured for securing to an alignment rod used to orient shaped charge holders in a phasing arrangement.

[0082] According to another aspect, a downhole tool for deployment in a wellbore extending within an underground reservoir is provided. The downhole tool includes a series of components that are arranged in a side-to-side configuration along the tool and wherein at least some adjacent pairs of the components are rotatable with respect to each other; a mounting unit coupled to an end of the series of components; and an alignment system comprising alignment connectors securable with respect to respective components; an elongated alignment member comprising a mounting section configured to be mounted with respect to the mounting unit to secure the alignment rod with respect thereto; and a helical alignment section extending from the mounting section along the series of components and configured to secure each of the components via the alignment connectors, the helical alignment section having a predetermined helical configuration with a pitch for providing a predetermined phasing of the components.

[0083] According to a possible implementation, the components comprise shaped charge holders or shaped charges.

[0084] According to another aspect, a process for perforating an underground reservoir is provided. The process includes deploying a perforating gun down a wellbore in an underground reservoir, the perforating gun being defined as described in any of the claims or otherwise herein; detonating the shaped charges to perforate the reservoir; and retrieving the perforating gun from the wellbore.

[0085] According to a possible implementation, the underground reservoir is suitable for geothermal activities.

[0086] According to a possible implementation, the underground reservoir comprises hydrocarbons for recovery.

[0087] According to another aspect, a method for manufacturing a perforating gun is provided. The method includes mounting a series of shaped charge holders together so as to be rotatable with respect to each other; mounting shaped charges within the holders; connecting a first end holder to a first mounting unit; aligning the shaped charges in a predetermined phasing, comprising providing an alignment system comprising an alignment member and alignment connectors, the alignment member having a predetermined configuration for the predetermined phasing; mounting the alignment member to the first mounting unit so that the alignment member extends along the series of shaped charge holders; rotating the holders to respective positions for being connectable with respect to the alignment member; and securing the shaped charges and/or the holders to the alignment member via the alignment connectors; mounting a second mounting unit to a second end holder opposite the first end holder, thereby forming a phased shaped charge system; and installing a carrier about the phased shaped charge system.

[0088] According to another aspect, a perforating gun for deployment in a wellbore extending within an underground reservoir is provided. The perforating gun includes shaped charge holders that are arranged in a side-to-side configuration and wherein adjacent pairs of the shaped charge holders are rotatable with respect to each other, the shaped charge holders being configured to receive and support respective shaped charges; an alignment system comprising an alignment rod extending along the shaped charge holders and being connectable to the holders or the shaped charges at respective predetermined connection points, the alignment rod having a configuration to orientate the shaped charges in a predetermined phasing upon coupling at the predetermined connection points.

[0089] According to another aspect, a perforating gun for deployment in a wellbore extending within an underground reservoir is provided. The perforating gun includes shaped charge holders that are arranged in a side-to-side configuration and wherein at least some adjacent pairs of the shaped charge holders are infinitely rotatable with respect to each other in a rotation state; an elongated alignment member extending along the shaped charge holders and configured to secure the shaped charges to orient the shaped charges in a predetermined phasing in an aligned state.

[0090] According to another aspect, a perforating gun for deployment in a wellbore extending within an underground reservoir is provided. The perforating gun includes shaped charge holders that are arranged in a side-to-side configuration; an alignment system comprising alignment connectors securable with respect to respective shaped charge holders and/or shaped charges; and an alignment rod comprising a helical alignment section extending along the shaped charge holders and configured to secure each of the shaped charge holders and/or shaped charges via the alignment connectors, the helical alignment section having a predetermined helical configuration with a pitch for providing a predetermined phasing of the shaped charges.

[0091] According to another aspect, a downhole tool for deployment in a wellbore extending within an underground reservoir is provided. The downhole tool includes a series of components that are arranged in a side-to-side configuration along the tool and wherein at least some adjacent pairs of the components are rotatable with respect to each other; an alignment system comprising a helical alignment section extending from the mounting section along the series of components and configured to secure each of the components via the alignment connectors, the helical alignment section having a predetermined helical configuration with a pitch for providing a predetermined phasing of the components.

[0092] According to another aspect, a method for manufacturing a perforating gun is provided. The method includes mounting a series of shaped charge holders together so as to be rotatable with respect to each other; mounting shaped charges within the holders; aligning the shaped charges in a predetermined phasing, comprising providing an alignment system comprising an elongated alignment member having a predetermined configuration for the predetermined phasing; mounting the elongated alignment member about the shaped charge holders; rotating the holders to respective positions for being connectable with respect to the elongated alignment member; and securing the shaped charges and/or the holders to the elongated alignment member to produce a phased shaped charge assembly; and installing the phased shaped charge assembly in a carrier.

BRIEF DESCRIPTION OF DRAWINGS

[0093] FIG. **1** is a partial transparent side perspective view of an example tandem sub coupled to a perforating gun with a holding assembly that includes rotatably mounted shaped charge holders, and an alignment system that includes an alignment rod secured with respect to the shaped charges within a tubular carrier.

[0094] FIG. **2** is a side perspective view of an example perforating gun internal subassembly that can include top and bottom mounting units and shaped charge holders.

[0095] FIG. **3** is a side cut view of part of an example perforating gun subassembly within a carrier.

[0096] FIG. **4** is a side perspective view of part of an example shaped charge holding assembly.

[0097] FIG. **5** is a perspective view of an example shaped charge holder.

[0098] FIG. **6** is a side view of an example perforating gun subassembly that includes holders for shaped charges as well as an alignment connector, which in this example also functions as a detonator cord clip or "det cord clip".

[0099] FIG. **7** is a perspective view of an example alignment connector.

[0100] FIG. **8** is a perspective view of an example top mounting unit.

[0101] FIG. **9** is a perspective view of an example bottom mounting unit.

[0102] FIG. **10** is a partially exploded, partially transparent, partially cut side view of an example tandem sub.

[0103] FIG. **11** is an example alignment rod.

[0104] FIG. **12** is a perspective view of a perforating gun subassembly with shaped charges.

[0105] FIG. **13** is a perspective view of part of a perforating gun subassembly and a tandem sub.

[0106] FIGS. **14** to **18** are views of an example top mounting unit.

[0107] FIGS. **19** to **21** are views of an example bottom mounting unit.

[0108] FIG. **22** is a side cut view of part of the perforating gun subassembly and part of the tandem sub.

[0109] FIG. **23** is a perspective view of part of an example holding assembly with alignment connectors integrated as part of the holders.

[0110] FIGS. **24** to **30** are views showing different example holders.

[0111] FIG. **31** is a perspective view of part of a PCB assembly coupled to a top mounting unit of a perforating gun.

[0112] FIGS. **32**A to **32**G are schematics of perforating gun subassemblies showing different phasing and alignment scenarios.

[0113] FIG. **33** is a schematic of a plate shaped alignment member with integrated clips.

[0114] FIGS. **34**A and **34**B are schematics of example rotatable connections between adjacent holders.

[0115] FIG. **35** is a cross-sectional view of another implementation of the perforating gun, showing a PCB assembly having a cartridge, according to an implementation.

[0116] FIG. **36** is a perspective exploded view of the perforating gun shown in FIG. **35**.

[0117] FIG. **37** is an enlarged view of a portion of the perforating gun shown in FIG. **36**, showing a cartridge insertable in a tandem sub, according to an implementation.

[0118] FIGS. **38** and **39** are cross-sectional views of the cartridge and tandem sub shown in FIG. **37**, showing a pressure bulkhead engageable between the tandem sub and the cartridge, according to an implementation.

[0119] FIG. **40** is a cross-sectional perspective view of a portion of the cartridge and tandem sub assembly shown in FIG. **39**, showing the pressure bulkhead engaging a connection bore of the cartridge, according to an implementation.

[0120] FIG. **41** is an exploded perspective view of the cartridge and a mounting unit of the perforating gun, showing a grounding system of the cartridge, according to an implementation.

[0121] FIG. **42** is a perspective view of the cartridge, showing a detonator extending therefrom, according to an implementation.

[0122] FIG. **43** is a side view of the cartridge shown in FIG. **42**.

[0123] FIG. **44** is a cross-sectional perspective view of a portion of the cartridge, showing the detonator supported by a support member within the cartridge, according to an implementation.

[0124] FIG. **45** is a cross-section view of a portion of the perforating gun shown in FIG. **35**, showing the detonator positioned proximate a detonation chord, according to an implementation.

DETAILED DESCRIPTION

[0125] Techniques described herein relate to methods and systems for holding shaped charges in a wellbore in the context of perforating operations. In some implementations, the shaped charges can be held in place with a desired phasing using shaped charge holders that are rotatable about the axis of the perforating gun and can connect to an alignment rod at predetermined locations due to the spacing between the holders and the configuration of the alignment rod. For example, the alignment rod can have a helical section having a certain pitch while the holders are spaced-apart axially to define a spacing such that connectors associated with respective holders intersect with the path of the helical alignment rod at certain radial locations, thus orienting the charges to have a desired phasing. In one example, the helical alignment rod can have a pitch that is six times the spacing between the connectors of the holders, thus enabling six holders to be connected per pitch length and thereby providing a shaped charge phasing of 60°. In a similar manner, the charge spacing and alignment rod pitch can be modified to provide the phasing desired for a given perforation operation, including a multitude of pitches. In addition, for a given holding assembly having a set spacing between holders, alignment rods of different pitches can be manufactured and used with the holding assembly in order to provide the desired phasing for the charges.

[0126] Referring to FIG. **1**, an example implementation of a perforating gun **2** is illustrated. The perforating gun **2** can include a shaped charge holding system **6** and a tandem sub **4**. The holding system **6** can also be referred to a perforating gun subassembly. The perforating gun subassembly **6** can include a shaped charge holding assembly **8**, opposing mounting units (including a top mounting unit **12** and, as shown in FIG. **2**, a bottom mounting unit **14**), and an alignment system. The perorating gun subassembly **6** is housed within a carrier **10** which has a tubular form. The holding assembly **8** can include one or more shaped charge holders **16** arranged in series, and which can be independently and infinitely rotatable with respect to each other. The holding assembly **8** can be made up of the holders **16** which are directly coupled together, or can include holders that are interconnected via other components that enable certain functions such as rotation between the holders, reinforcement, and so on.

[0127] The holding assembly **8** cooperates with an alignment system which can include multiple alignment connectors **18** that are operatively connectable with respect to respective charges **22**, and an alignment member **20** (e.g., alignment rod) that is securable to the top mounting unit **12** and to each of the alignment connectors **18** along its length.

The alignment connectors **18** can take the form of retaining clips that attach to the shaped charges, as illustrated here, or as connectors that are part of or attached to the holders **16**. The alignment rod **20** has a configuration, such as a helical configuration, that extends around and along the series of holders **16** such that the alignment rod defines connection points that are axially spaced-apart from each other and positioned at radial locations for respectively coupling with the alignment connectors **18** for orientation of the shaped charges **22** at a predetermined phasing. For example, the helical part of the alignment rod can have a pitch (P) that is coordinated with the spacing (S) between the connectors **18** such that the rod intersects with the axial positions of the connectors **18** at predetermined radial locations to provide a desired phasing of the shape charges **22**. Depending on the pitch of the helical segment of the alignment rod and the spacing between the connectors **18**, various phasing configurations can be achieved. FIG. **1** illustrates a phasing of 60°, for example.

[0128] In one implementation, a given holding assembly **8** can be designed to provide a set spacing between the connectors **18**, and multiple alignment rods **20** can be manufactured having different configurations (e.g., different pitches with the same diameter if helical) while being compatible with the set spacing of the holding assembly **8**. Thus, the same holding assembly **8** design can be used with any number of alignment rods **20** to enable the phasing of interest for the shaped charges. In FIG. **1**, for example, shaped charges **22** are illustrated mounted withing respective holders **16**.

[0129] FIG. **2** illustrates the perforating gun subassembly **6** that includes the top and bottom mounting units **12**, **14**, the shaped charge holding assembly **8**, and the alignment system including the alignment connectors **18** and the alignment member **20**. The subassembly **6** can be configured to be housed in the carrier and to be coupled to the tandem subs on either end.

[0130] Referring to FIG. **3**, the top mounting unit **12** can optionally have an alignment tab **23***a* that fits into a corresponding groove **23***b* or keyway in the carrier **10** to prevent rotation of the top mounting unit **12** within the carrier **10**. The alignment member **20** is insertable into the top mounting unit which is connected to the top-most shaped charge **22**. The alignment tab **23***a* of the top mounting unit fits into the groove of the carrier, which facilitates the indexing of the shaped charges based on the curvature or configuration of the alignment rod. The alignment tab **23***a* can therefore provide a fixed point so that the orientation of each charge is indexed relative to the keyway in the carrier. This can be useful for certain configurations, such as 0 or 180 degree phasings, where it is desirable for all of the charges along the entire perforating gun, including multiple holding assemblies, to be in the same phase. Alternatively, the assembly may not be indexed in this way so that the charges of a given assembly are in phase with each other but not necessarily with other gun assemblies above or below. The alignment tab can also serve the purpose of setting the internal assembly at a set depth in the carrier. It is noted that the tab and groove are not necessary, and the components can be allowed to rotate within the carrier or can be secured to the carrier in another fashion.

[0131] The top mounting unit **12** can be a single configuration plastic molded component that also provides an electrical path between guns. The top mounting unit **12** can be configured to align the first charge holder and det cord within the gun carrier for competent electrical connections and phasing. The bottom mounting unit **14** can also be a single configuration plastic molded component. The bottom mounting unit **14** can be configured to centralize last charge holder within gun carrier. Other centralizing mechanisms could also be used.

[0132] In addition, in some implementations, the alignment system could be coupled to the holding assembly **8** without being connected to the top or bottom mounting unit **12**,**14**. In this scenario, the holding assembly **8** would have the desired alignment and phasing of the shaped charges, as desired based on the alignment member that is used, but the holding assembly **8** could rotate freely with respect to the top and bottom units **12**,**14** if the end holders are rotatably coupled to those units. Thus, the shaped charges would retain their phasing, although they may not be "indexed" or fixed with respect to the top or bottom units. In another possible implementation, the top end-most holders **16** could be fixedly connected to the top unit **12** so that the holder does not rotate with respect to the top unit **12**, which the rest of the holders **16** are rotatably coupled to each other, and the alignment member could be attached only to the holders **16** to provide the phasing. In this implementation, the holders could be indexed or fixed relative to the top unit due to the connection of the top end-most holder **16** to the top unit **12**. A similar setup could be used where the bottom end-most holder **16** is fixedly connected to the bottom unit **14**. It is also possible to design the system such that one or more of the end-most holders is integral with the respective top or bottom unit. Thus, in light of the above, it is understood that the alignment bar may or may not be mounted to the top or bottom units, the end-most holders can be coupled to or part of the top or bottom units in various ways, and the holding assembly may or may not be free to rotate when in the aligned phased configuration depending on how it is coupled to adjacent components.

[0133] Furthermore, the top unit **12** can be provided to enable several functions of interest, e.g., providing a rotatable electrical path for signal communication, providing alignment for the detonator and detonating cord, aligning the shaped charges to their respective carrier scallops/grooves by indexing its assembled location to its respective carrier feature, and retaining and providing an indexable location/angle for the alignment rod. The top and bottom units can also provide centralizing functions within the carrier, as well as modularity for manufacturing perforating guns. However, it is noted that the system may be designed without a top unit and/or a bottom unit, such that the holding assembly is connected more directly to the adjacent components of the perforating gun. The perforating gun design could be adapted if the top and/or bottom units were removed, while keeping the alignment system for the shaped charges retained in the holders.

[0134] Referring to FIG. **2**, the holding assembly **8** is constructed such that the series of holders **16** are sandwiched in between opposing mounting units **12**, **14** and the alignment rod **20** is also inserted in place within at least one of the mounting units, e.g., the top mounting unit **12** as illustrated. The holders **16** can be mounted with respect to each other in various ways. For example, in the illustrated implementation, the holders are **16** are mounted directly to each other so as to be rotatable with respect to each other. Alternatively, the holders **16** could be interconnected via an intermediate mechanism that enables relative rotation between the holders **16**. The holders **16** could also be mounted about a central rod about which the holders could rotate. The holding assembly **8** could also include other components that provide structural and functional features of interest. The alignment rod **20** can be fixedly secured to the top mounting unit **12**, or it can simply be inserted into a slot and is prevented from coming out once it is mounted to the alignment connectors and the bottom mounting unit is attached to the bottom-most holder, thus enclosing the alignment rod axially with little to no play. It is also noted that the mounting unit to which the holders and alignment member are connected can take many forms and can also include multiple sub-components that are coupled together.

[0135] Referring to FIGS. **19** and **20**, the lower end of the alignment rod can be located within the annular cavity of the bottom mounting unit as a free end. The alignment rod has sufficient rigidity and strength such that when it is connected along the assembly is does not need securing at the bottom end, but simply floats in the cavity of the bottom mounting unit. Alternatively, the rod could be secured to or within the bottom unit. In addition, the bottom unit **14** can have an outer annular cavity for the alignment member, as well as an inner annular cavity that can be provided to receive excess wire, if needed.

[0136] The structure that enables rotation of the holders relative to each other can take various forms and can also enable different types of rotation. In some implementations, the holders **16** are infinitely and independently rotatable with respect to each other about a longitudinal axis extending along the holding assembly **8**. This means that each holder **16** can be rotated about the axis freely and independently without any structure causing rotation to stop. In an alternative implementation, the holders could be rotatable with respect to each other, but with some limitations in the rotation, e.g., only 360° rotation permitted back and forth rather than infinite rotation. It is also possible for certain stacks of holders **16** (e.g., two-holder stacks) to be fixed together at a predetermined phasing which being rotatably mounted to other holders **16** or stacks of holders **16**. The holders **16** nevertheless should have some degree of rotatability with respect to each other such that they can move to different phasings depending on the configuration of the alignment member **20**.

[0137] Referring to FIG. **5**, each holder **16** can include an annular body **24** comprising a first open end **26** for receiving a shaped charge therein, and a second opening **28**. The annular body has a shape and configuration to receive and housing the shaped charge, as shown in FIG. **6** where an end of the shaped charge passes through the second opening **28** and can attach to the alignment connector **18**. The annular body **24** can have a cup shape with a tapered inner surface, and can have projections **30** that extend away from the cup shape to cooperate with corresponding recesses of the shaped charge **22**. Various other configurations of the holder **16** are possible for retaining the shaped charge, and can be designed based on the particular shaped charge as well as other components of the system. For example, the holders may not have a tapered inner surface or other features should in the figures, depending on the charge that is used.

[0138] Turning back to FIG. **5**, in some implementations, the holder **16** also includes a first coupling component **32** extending from a first side of the annular body **24**, and a second coupling component **34** extending from a second side of the annular body **24**. The first and second coupling components **32**,**34** of adjacent shaped charge holders **16** are rotatably connectable together to enable rotation of the adjacent shaped charge holders **16** with respect to each other. The arrangement of the coupling components **32**,**34** can be seen in FIGS. **1**, **2**, **3** and **4**. The first coupling component **32** can be provided on a downhole side and the second coupling component **34** can be provided on an uphole side for each of the shaped charge holders **16**. As shown in FIG. **2**, the top mounting unit **12** can have a top attachment for rotatably coupling with the second coupling component **34** of the top-most holder **16**, and the attachment can have the same configuration as that of the first coupling component **32**. Similarly, the bottom mounting unit **12** can have a bottom attachment for rotatably coupling with the first coupling component **32** of the bottom-most holder **16**, and the attachment can have the same configuration as that of the second coupling component **34**.

[0139] Referring back to FIGS. **5** and **6**, the first coupling component **32** can be a male component and the second coupling component **34** can be a female component. The male component can include a mushroom-shaped member comprising a post **36** and a head **38**. The post **36** can be mounted to a disk **40** that is disposed on a side of an annular wall **42** of the body **24**. The post **36** can be cylindrical, and the head **38** can be inwardly tapered extending away from the post and can have a flat end. Of course, various structures are possible for the male component to enable coupling within the female component of an adjacent holder **16** to facilitate retention therein and rotation therebetween.

[0140] Still referring to FIGS. **5** and **6**, the female component **34** can include side walls **44** extending from the annular body and defining a chamber for receiving the head **38** of the male component **32**. The side walls **44** can have notches **46** distributed around the periphery, which can facilitate bending of the outer part of the side walls **44** to facilitate insertion of the male component **32**. Turning briefly to FIG. **3**, the female component **34** can include a lip **48** extending inwardly from an extremity of the side walls **44**. The lip **48** can fit in the space adjacent the post **36** and in between the head **38** and the disk **40** of the male component **32**. The lip **48** fits over the head **38** and retains it within the chamber of the female component **34**. The lip **48** and head **38** are part of an example structure that enables the female component to receive and retain the male component while enabling relative rotation along the longitudinal axis. Other structures are also possible.

[0141] The connection between the holders **16** can enable axial retention, as with the mechanism shown in FIGS. **5** and **6** for example, but the connection could alternatively provide little to no axial retention since the tower of holders could be retained within the carrier and sandwiched between the top and bottom mounting units, such that external structures keep the holders together. In this case, the holders could have a male-female configuration, e.g., as shown in FIGS. **34**A and **34**B. In another example, the connection between shaped charge holders can be a clip instead of a male-female insertion, and the clip could be designed to make separation difficult. However, the holders could be secured together in this manner since they do not need to be decoupled because to phase or rephase one can simply attach different alignment member.

[0142] Turning now to FIG. **4**, the alignment member **20** can include a mounting section **50** and an alignment section

52. The mounting section **50** is securable with respect to the top mounting unit **12**, while the alignment section **52** has a configuration that enables connection to the alignment connectors **18** of the holders **16** to provide the desired positioning and phasing. In the illustrated implementation, the alignment member **20** is in the form of an alignment rod, with both the mounting and alignment sections being in rod form. However, it is noted that the alignment member could take forms other than a rod and could also include multiple distinct elements that are each secured to the mounting unit and configured to cooperate with certain holders. Nevertheless, the illustrated implementation shows an alignment rod **20** where the mounting section **50** is a straight segment of the rod while the alignment section **52** is a helical segment of the same rod.

[0143] The alignment section **52** can have a helical configuration, which can be circular, square, or another configuration. The helical form can be regular with a consistent diameter and pitch, or it could vary along the length of the alignment section **52**. The alignment section **52** has a configuration that, upon securing with respect to the mounting unit **50**, provides connection points along the holding assembly that are securable to respective alignment connectors **18** to position the holders in a predetermined phasing. The alignment section **52** is shown as extending around and outside of the holders **16**, but other arrangements could also be possible as long as the alignment connectors and holders are arranged and configured accordingly. Being arranged on the outside of the holding assembly can facilitate construction, assembly and minimizing interaction with the holders themselves.

[0144] Thus, adjacent alignment connectors **18** of the shaped charge holders **16** define an axial holder spacing (S) therebetween, and the helical configuration of the adjustment section **52** has a pitch (P) that is predetermined to position the connection points of the adjustment section **52** at the radial locations for attaching to the connectors **18** that position the shaped charge holders **16**. The axial holder spacing (S) can be smaller than the pitch (P), and the pitch (P) can be an integer multiple of the axial holder spacing (S). For instance, the P can equivalent to approximately 2S, 3S, 4S, 5S or 6S, to provide a phasing between adjacent shaped charge holders of 180°, 120°, 90°, 72° or 60°, respectively. Of course, other relationships between P and S are possible for providing different phasings.

[0145] Still referring to FIG. **4**, the mounting section **50** of the alignment rod **20** can be a straight bar that inserts into a corresponding slot **54** of the mounting unit **12**. The slot **54** can have a circular cross-section and the mounting section **50** can have a cylindrical shape, although they can have other shapes and configurations for securing one to the other. Alternatively, the alignment member **20** could have another type of system for securing it to the mounting unit **12**.

[0146] Turning now to FIG. **11**, the alignment member **20** can have certain properties to provide desired structural characteristics. For example, when in the form of an alignment bar, it can have a length and diameter that provide certain rigidity to retain the holders in a desired phasing while having a flexibility to facilitate some bending during installation and winding around the holding assembly. The alignment bar **20** can be composed of various materials, such as metal (e.g., steel), composite materials, or polymeric materials. The alignment member can also have a solid structure, such as a solid metal bar, or could be configured as a tubular structure that is hollow depending on the materials and method of manufacture. The alignment member can be made as a one piece integral structure, such as an elongated bar that has been reformed from a straight bar to have a certain configuration (e.g., straight segment and helical segment). Alternatively, the alignment member could be made from multiple components that are themselves attached together. As noted above, there could be two or more alignment bars that are provided for a single holding assembly, where the alignment bars are secured to the same mounting unit or to respective top and bottom mounting units.

[0147] In some implementations, the alignment bar has a diameter of about 1/16 inch to about 3/16, or 1/8 inch. The alignment bar can have a length from about 10 inches to about 20 inches, and the bar can have a total length of about 12 inches to 28 inches, for example. The alignment bar can be made of various materials, such as steel (e.g., carbon steel) or other comparable metals, composites, or high strength materials.

[0148] In some implementations, the alignment bar could be configured to serve an electrical purpose as well as the phasing alignment purpose. For instance, the alignment bar could be provided as a possible ground path or through-communication path if sufficiently insulated. For example, the alignment bar could be configured as a tubular member with a bore through which a through-wire can pass to extend along the entire length of the perforating gun to enable communication. The mounting units could be adapted appropriately to include structures and openings to enable passage of the wire. When the rod is composed of metal, the conductivity of the rod could be leveraged, e.g., to provide redundant ground in addition to the gun body. The alignment bar can of course be configured in terms of size and shape depending on the functionalities of interest and the other components of the overall perforating gun. Thus, the insulation, through-wire, bore, and so on, can be sized and provided for the desired function. In addition, the alignment member could be coupled to the det cord (e.g., where the det cord is within a tubular alignment member which has apertures through which portions of the det cord can protrude to contact the charges; or where the det cord is clipped or otherwise connected to the alignment member to follow a same trajectory along the holding assembly).

[0149] It is noted that the alignment member could have various structures and cross-sections. A bar with a solid cylindrical structure is illustrated in various figures, but the alignment member could have other cross-sectional configurations, such as an H, an I, a U, an L or a T shaped cross-section. The alignment member could also have a plate shape, or a circular or square tubular shape. The alignment member could have the same cross-sectional shape along its entire length or it could vary by including two or more, such as those described above. FIG. **33** is a schematic of a part of a plate shaped alignment member with integrated clips.

[0150] Referring now to FIGS. **1** to **4**, the alignment connector **18** is configured and arranged to secure a point on the alignment member **20** with respect to the corresponding holder **16**. In some implementations, the alignment connector **18** is configured such that it can be positioned at one axial position along the holding assembly **8** but can be moved to any radial point around the longitudinal axis upon rotation of the corresponding holder **16**. In this way, the alignment connector can be moved to any radial point at which the alignment member **20** may intersect, depending on the configuration of the alignment member **20**.

[0151] The alignment connector **18** can take various forms and can be integrated into the system in various ways. For example, in the illustrated implementation as best shown in FIG. **6**, the alignment connector is mounted to a back end of the shaped charge **22** rather than to the holder **16** itself. Thus, in this scenario, the alignment connector **18** is not directly connected to the holder **16** but it is able to secure the holder in place because the shaped charge **22** is secured to the holder **16**. Alternatively, the alignment connector **18** could be directly connected to the corresponding holder **16** as a separate piece or as an integral part of the holder **16**.

[0152] Referring to FIGS. **6** and **7**, an implementation of the alignment connector **18** will be described in greater detail. The alignment connector **18** can be part of the same unit that is used as a detonator cord clip and/or for securing a flexible line (e.g., a signal cord) that is part of the perforating gun. For example, the alignment connector **18** can include a main section **56** for coupling the shaped charge with a detonator cord, and an arm **58** extending from the main section **56** and comprising a clip **60** securable to the alignment member **20**. The alignment connector **18** can include a second arm **62** extending from the main section **56** and comprising a second clip **64** securable to a signal cord.

[0153] The main section **56** of the alignment connector **18** can have various structures designed based on the type of shaped charge to be used. In the case of a universal shaped charged, for example, the illustrated main section can be used where it has a base plate **66**, opposed side walls **68**, and an upper plate **70** defining a detonator cord passageway **72**. The passageway also receives the notched end **74** of the shaped charge **22**, as shown in FIG. **6**. The upper plate **70** has an opening **76** defined therein for receiving the notched end **74** of the shaped charge **22** for connection to the detonator cord.

[0154] Still referring to FIG. **7**, the arm **58** can be angled with respect to the base plate **66**. The arm **58** can include a first oblique section **78** extending at an angle toward the shaped charge, the clip **60** being located at an extremity of the first oblique section **78**. The angle can be between 30 and 60 degrees, for example. The first oblique section **78** can be a U-shaped plate including two parallel strips that are joined by an end strip thereby defining an opening. The clip **60** can include a hook-shaped member that extends outwardly from the first oblique section **78**, and may define a rod-receiving region that faces away from the shaped charge and the holder. In addition, the clip **60** can be formed to be flexible to enable insertion of the alignment member and then to exert a compression force to help secure it. The connector **18** and/or one or more of its structures, can be formed from a single piece of sheet metal. The arms can be formed such that they have some flexibility and resilience, thus facilitating manipulation when securing the clip **60** to the alignment member.

[0155] In some implementations, the orientation of each clip-type alignment connector can be predetermined and it can be rotationally locked or secured in place when connected to the charge when the detonation cord is secured in place. This can be due to the geometry of the rod, charge, and clip-type alignment connector, for example, such that all of those components find themselves positioned in the desired location for phasing alignment when the charges are rotated about the perforating gun axis. In other implementations, when the alignment connectors **18'** are part of or fixed to respective holders, as shown in FIG. **23** for example, the orientation and configuration of each alignment connector can also be predetermined and fixed. Alternatively, the alignment connectors could be configured to have some movement (e.g., rotational, pivotal) with respect to the holder bodies or the charges.

[0156] As can be appreciated, the alignment connector **18** can be a multifunctional connector that serves as a detonation cord clip, a signal cord clip and an alignment member clip that holds these three components of the perforating gun in place. The multifunctional connector can take various forms that are based on conventional or known detonation cord clips with the addition of an alignment member clip which can be in the form of an arm extending away from the main clip unit. A few example detonation cord clips are described in U.S. Pat. Nos. 4,762,067, 4,716,832, 4,542,695, 3,991,679, 9,598,941, for example.

[0157] The alignment member can couple to the charges in various ways. For example, as shown in FIG. **1**, the alignment member can take the form of a rod or another elongated structure that is secured to clip-type alignment connectors attached to respective shaped charges. Alternatively, as shown in FIG. **23**, the alignment member can attach to alignment connectors that are part of the holders.

[0158] In another alternative configuration, the alignment member and the alignment connectors can be formed as a one-piece structure, that can be arranged so that the alignment connectors attach to the holders and/or charges as the alignment member is configured to provide the phasing to the charges. For instance, the alignment member could take the form of a sheet that has a helical shape with clip geometry features arranged in spaced relation along its length to act as the alignment connectors. In this example, the predefined helix and connectors can be built into the sheet, and the alignment sheet can connect to all of the charges or holders. The alignment sheet could also be configured such that the built-in alignment connectors could also function as detonation cord clips. This example could take the form of an elongated det cord clip with a helical profile and multiple built-in det cord clip parts. In this regard, it should be noted that the alignment member could include clip-type connectors along its length and the holders or charges could include a cylindrical component around which the clip-like connectors can fit to provide retention.

[0159] In another alternative configuration, the alignment member (e.g., rod shaped) could include notches to define locations in which the alignment connectors can sit. The alignment member (e.g., rod shaped) could include an insulative sleeve that is configured to be clipped or otherwise attached to the alignment connectors. The sleeve could also facilitate electrical grounding path applications by excluding the charge from the circuit.

[0160] The attachment of the alignment member (e.g., rod shaped) to the holders could be done in various ways. For example, the alignment member could attach to a rotational pivot joint on the side of the holder and which would clip onto the alignment member or slide onto the rod. The attachment could also be provided such that the alignment connectors take the form of a through-hole that passes through part of the side of the holder into which the alignment member could slide or clip. When the alignment member is a tube with a hollow center, the tubular alignment member could be provided with apertures and the alignment connectors could include insertion elements that could be inserted inside the apertures for securing the components together. The alignment connector could of course be configured and shaped depending on the shape of the alignment member (e.g., rod, sheet, tube, or other).

[0161] In other alternative designs, the connection between the alignment member and the holders or shaped charge could take the form of a magnetic attachment mechanism or adhesive based attachment. A magnetic attachment mechanism could include a pair of magnetically attractable elements provided on the holder or charge as well as the alignment member such that when aligned the magnetic elements hold together with sufficient force to retain the components in place. Adhesive based methods could include the use of an adhesive compound, such as glue, that can be manually applied to the appropriate locations of the alignment member and the holder or shaped charge during assembly. In such cases, the holders or charges could be provided with a mark that indicates the desired location for applying the adhesive for securing to the alignment member.

[0162] Regarding the arrangement of the holders, in some implementations each holder of a shaped charge is rotatable with respect to adjacent holders and, for the upper- and lower-most holders, with respect to the top and bottom mounting units respectively. However, in alternative implementations, the holders can have different arrangements and rotatability with respect to certain components. For example, the assembly can include sets of holders with multiple holders in each set, where one or more of the sets can be made up of holders that are fixed with respect to each other while the adjacent sets are rotatable with respect to each other. This can facilitate providing multiple charges per plane. In addition, in such configurations, the alignment member can be configured to retain each set of charges at a desired phasing location and thus each set could include one or more alignment connector. In addition, the holders could be designed such that a single holder component can receive multiple charges that have the same or different orientation, and such multi-charge holders could be rotatably coupled to each other as described above.

[0163] Regarding the holders, the design can be adapted based on various factors including the size and configuration of the shaped charge to be used, the manner in which the shaped charge is retained by the alignment member, and so on. FIGS. **5** and **24** to **27** show an example design of a holder **16** that male-female components **32**, **34** for the rotational coupling, projections **30** that facilitate retention of the shaped charge, and the body has a certain configuration. The projections **30** can include tab section extending from the body and a distal catch confirmed to fit into a groove or lip of the shaped charge. The projections **30** can also each include wings that are integrated with or extend from either side of the tab section. The projections **30** can be configured to be resilient such that they deflect outwardly upon insertion of the shaped charge, and then snap back to engage the shaped charge in place. In addition, the projections **30** can configured to allow free rotation of the charge within the cavity of the body, and/or to also allow the charges to be removed, if desired, by bending back the projections and popping the charge out.

[0164] In addition, the holders **16** can be composed of plastic materials and can be made by molding processes. The holders can alternatively be made of other materials, such as composites, and can be made using other manufacturing methods. The holders **16** can be made based on a single design configuration so they are all identical and interchangeable. The rotatable coupling between the holders can also be provided for the top and bottom connectors, although the holders could be rotatably coupled together using one mechanism and then coupled to the top and bottom connectors using other mechanisms.

[0165] FIG. **28** shows an alternative design where the projections **30** are thinner and lack the wing members of the other design. FIG. **29** shows an alternative design of the holder **16** where projections are not provided for retaining the shaped charge, but rather includes a mounting ring with a retention lip for retaining the shaped charge. The charge can be inserted into the cavity and the retention lip fits over and around part of the charge to retain it. The mounting ring can also provide additional support for the male and female components **32**, **34** to be aligned along the central axis of the perforating gun, since in the design of FIG. **28** and others the male and female components **32**, **34** partially hang over the rim of the body. FIG. **30** shows another alternative design where the holder **16** includes a slit through which a resilient retention wire or other structure can be inserted for retaining the charge in the cavity of the holder **16**. It should be understood that various other structures could be used in holder designs for retaining the charges and for enabling the rotational movement, as the case may be.

[0166] Referring to FIG. **10**, the shaped charge holding system can be coupled to a tandem sub **4**. The tandem sub **4** facilitates gun-to-gun connection and further enhances the modularity of the overall system. For example, multiple shaped charge holding systems can be coupled together via corresponding tandem subs **4**, with each tandem sub **4** being located in between two adjacent holding systems. The tandem sub **4** is configured to provide structural and electrical connection between the holding systems. The tandem sub **4** thus has a bottom end that can be coupled to a top end of a holding system, as shown in FIG. **1**; and the tandem sub **4** also has a top end that can be connected to the bottom end of an uphole holding system.

[0167] Turning to FIG. **8**, with continued reference to FIG. **10**, the top mounting unit **12** includes a detonator insertion bore **80** for receiving the detonator from the tandem sub **4**, as well as an annular strip **82** for electrical connection with he tandem sub **4**. Similarly, as shown in FIG. **9**, the bottom mounting unit **14** has a configuration and connection structures for coupling with the holding assembly **8** on one side and a downhole tandem sub **4** on the other, as the case may be. FIG. **9** also shows a bottom attachment **84** that is configured to be rotatably connected to the male component of the bottom-most holder.

[0168] FIG. **13** shows the top mounting unit **12** coupled to the tandem sub **4**, and FIGS. **14-16** show the internals of the top mounting unit which are provided to receive certain components including the det cord and the alignment member, and part of the tandem sub. The det cord is inserted into the top mounting unit and guided into overlapping contact with the denotator. FIGS. **17** and **18** show the opposed sides of the top mounting unit **12**.

[0169] Referring to FIG. **10**, in some implementations the tandem sub **4** can include a sub body **86** that defines a cavity **88** for receiving a printed circuit board (PCB) assembly **90** as well as a bore **92** for receiving a pressure bulkhead **94**. The PCB assembly **90** has redundant grounding enabled by garter springs **96** that can fit into corresponding seats **98** in the cavity **88**. The PCB assembly **90** also has an addressable switch **100**, a detonator **102**, a signal input **104**, and a signal output. In operation, the detonator **102** of the tandem sub **4** can be inserted into the bore defined in the top mounting unit for connection with the appropriate detonation cord. Appropriate seals are also provided around the sub body **86**.

[0170] The garter springs **96** can be configured to provide a ground path, connect the detonator to the board, centralize the PCB within the cavity **88**, and secure the PCB in the cavity **88**. FIG. **31** provides an illustration of the printed circuit board (PCB) assembly **90** mounted to the top mounting unit **12**. FIG. **22** provides an illustration showing the bottom mounting unit **14** interfacing with the tandem sub **4** which helps to align the bottom mounting unit along the centerline.

[0171] With reference to FIGS. **35** to **45**, another implementation of the perforating gun **2** is shown. The perforating gun subassembly **6**, which includes the shaped charge holding assembly **8**, the top mounting unit **12** and the bottom mounting unit **14**, is coupled between a pair of tandem subs **4** which can house respective PCB assemblies. In this implementation, the PCB assembly **90** includes a cartridge **110** having a cartridge body **112** adapted to be connected to the sub body **86** within the cavity **88**. The cartridge body **112** can be adapted to house electrical components (e.g., the printed circuit board, among others) and the detonator **102** configured to cooperate with the shaped charge holding assembly to operate the perforating gun (e.g., to detonate the shaped charges). The detonator receives the electrical signal from the electronic components within the cartridge body **112**, which is adapted to relay the electrical signal received from the bulkhead assembly **94**.

[0172] It should be noted that the perforating gun **2** can be operated as a top-fired perforating gun, where the shaped charges are detonated in sequence from top to bottom (e.g., from an upholemost shaped charge to a downholemost shaped charge). Alternatively, the perforating gun **2** can be operated as a bottom-fired perforating gun where the shaped charges are detonated in sequence from bottom to top. In some implementations, the perforating gun includes a plurality of shaped charge holding assemblies which can be respectively operable in a top-fire or a bottom-fire configuration. In other words, each shaped charge holding assembly can be fired using the same operation sequence (e.g., top-fired or bottom-fired), or fired using varying operation sequences (e.g., a first gun is top-fired and a second gun is bottom-fired). In this implementation, although the detonator **102** is positioned within the tandem sub **4** positioned uphole relative to the shaped charges, the perforating gun can still be operated in either one of the top- and bottom-fire configurations.

[0173] As seen in FIGS. **38** to **40**, the cartridge **110** can be provided with a coupling assembly **114** configured to engage the tandem sub **4** for securing the cartridge body **112** within the cavity **88**. It is appreciated that securing the cartridge **110** within the cavity positions the electrical components of the PCB assembly in a predetermined position relative to the perforating gun subassembly and/or relative to the bulkhead assembly. In this implementation, the coupling assembly **114** includes one or more protrusions **116** shaped and sized to engage the inner surface of the sub body **86**. The inner surface of the sub body **86** can include one or more recesses **118** for receiving respective protrusions **116** and holding the cartridge **110** within the cavity. In some implementations, the recess **118** extends circumferentially around the surface of the cavity **88** such that the protrusions **116** can engage the recess at any point therealong (e.g., 360 degrees around the inner surface of the cavity).

[0174] The coupling assembly **114** can further include a resilient element **120** adapted to bias the protrusions **116** outwardly to facilitate engagement with the recess **118**. In this implementation, the resilient element **120** can include a resilient arm **122** extending outwardly from the cartridge body **112** and having a free distal end, where the protrusion **116** is positioned proximate the free distal end **74**. It is noted that the resilient arm **122** is adapted to exert an outward radial force to bias the protrusion outwardly and within the recess. It should therefore be understood that the resilient arm **122** is adapted to pivot (e.g., about its base) to enable its free end to move radially relative to the inner surface of the cavity **88**. It is thus appreciated that the cartridge **110** can be connected to the tandem sub **4** by sliding the cartridge body **112** within the cavity **88** until the protrusions **116** engage the recess **118**. As seen in FIGS. **38** to **40**, the coupling assembly **114** can include two resilient arms **122**, and therefore two protrusions **116** adapted to engage the recess on opposite sides of the cartridge. However, it is appreciated that other configurations are possible, such as having additional resilient arms and/or protrusions, either aligned with one another to engage the same recess, or offset axially along the cartridge body to engage additional recesses defined within the cavity, for example.

[0175] As mentioned, the PCB assembly **90** is adapted to be operatively connected to the bulkhead assembly, and can be adapted to be electrically connected to the pressure bulkhead **94**. As seen in FIG. **40**, the cartridge body **112** includes a connection bore **115** defining a PCB assembly input adapted to receive a connection pin of the pressure bulkhead therein when positioning the cartridge **110** within the cavity. The connection bore **115** and the pressure bulkhead **94** are slidably connected together, where the connection pin slides into the connection bore **115** when the cartridge **110** is positioned within the cavity **88** (e.g., similar to an RCA-type connection). As such, it is appreciated that the contact surface between the connection bore **115** and the connection pin can correspond to the lateral surface of the connection pin along which the sliding connection is defined. In other words, the sliding connection is defined by a radial connection of the pressure bulkhead (e.g., of the connection pin) within the connection bore **115**, instead of an end-to-end connection

[0176] It is noted that, by coupling the cartridge body **112** within the cavity via the engagement of the recess with the protrusions, combined with the generally static pressure bulkhead **94** secured within the bore **92** defines and generally robust connection between the connection pin and the connection bore **115** (i.e., the configuration of the tandem sub and cartridge is adapted to prevent disconnection between the components housed therein). The cartridge can thus be in a predetermined position (e.g., when the protrusions engage the recess) and the position of the bulkhead assembly is in a similarly predetermined position (e.g., when secured in the bore) such that the position of the connection pin relative to the connection bore **115** can be guaranteed along the sliding connection.

[0177] In this implementation, the recess **118** is larger than the protrusions **116** to enable movement of the cartridge **110** within the cavity **88** (e.g., axially along the cavity). As seen in FIG. **39**, the cartridge body **112** defines a play **125** (e.g., a void or generally empty space enabling movement therein) with the axial surface of the cavity **88**, which can substantially correspond to the amount of play between the protrusion and the uphole portion of the larger recess. The size of the protrusions **116**, the recess **118** and the play **125** are adapted to enable movement of the cartridge during operation of the perforating gun, e.g., during detonation of the shaped charges. As such, the electronic components are at least partially protected from shocks, such as shocks created from operating the perforating gun and/or other energetically or hydraulically actuated tools. It should be noted that, during movement of the cartridge body, the connection bore **115** is adapted to slide along the connection pin of the pressure bulkhead, thereby keeping the electrical connection established between the bulkhead assembly and the PCB assembly.

[0178] In this implementation, the PCB assembly can be provided with a resilient component, such as a spring, adapted to bias the cartridge in a predetermined position, absorb at least some of the shock (e.g., from the detonation) and/or revert the cartridge body **112** back into the predetermined position following movement thereof within the cavity. As seen in FIGS. **38** to **40**, the PCB assembly **90** can include a biasing element **130**, such as a spring **132**, coupled to the cartridge and extending between the cartridge and an axial surface of the cavity. The spring **132** can be adapted to protect the cartridge by absorbing at least some of the forces (e.g., from the detonation) and revert the cartridge body **112** back in its initial position (e.g., abutting against the top mounting unit) following movement thereof within the cavity. It should thus be noted that the electrical connection system and the tandem sub facilitate connection (both structural and electrical) between the various components of the perforating gun.

[0179] Now referring to FIGS. **41** to **43**, the PCB assembly **90** further includes a grounding system **140** defining one or more ground paths for the various electrical connections of the electrical connection system. It should be understood that the grounding system **140** is configured to ensure electrical communication to and through the PCB assembly, e.g., ensure electrical connection with the switch and the detonator. In this implementation, the grounding system **100** is adapted to define a plurality of independent ground paths between the PCB assembly **90** and the tandem sub. The grounding system **140** can include one or more grounding pins **142** coupled to the PCB assembly **90** and extending therefrom to engage a grounding surface, such as the tandem sub, for example. It is appreciated that the tandem sub can be at least partially made of a metallic material in order to define the grounding surface for the grounding pins **142**.

[0180] The grounding pins **142** can be independent from one another, and thereby define independent grounding paths. As such, if one grounding pin **142** malfunctions (e.g., breaks and/or is no longer adapted to contact the tandem sub), then another one of the grounding pins **142** can still provide the required grounding path. In some implementations, the grounding pins **142** include pogo pins having a spring-loaded retractable head which can facilitate engagement of the cartridge within the cavity **88**, and engagement of the pins with the grounding surface.

[0181] In this implementation, the grounding system **140** includes a secondary grounding component **144** defining a secondary grounding path (i.e., the grounding pins **142** respectively defining primary grounding paths). More specifically, the spring **132** extending between the cartridge body **112** and the tandem sub **4** can be made of a metallic material, and can therefor be adapted to conduct electricity therebetween. The secondary grounding path is independent from the grounding paths defined by the grounding pins **142**, and can thus serve as increased security to have a grounding path between the PCB assembly and the tandem sub. It is therefore noted that the PCB assembly includes components adapted to protect the electric components. For instance, the cylindrical plastic housing and the grounding system **140** protect the electrical components from mechanical- and electrical-based complications, such as the forces created from detonating the detonation cord, by providing a bearing surface to take the brunt of the shock (e.g., the spring **132**), and by providing grounding paths to protect the electrical components.

[0182] Now referring to FIGS. **39**, **44** and **45**, the detonator **102** can be removably coupled within the cartridge body **112** and in electrical communication with the addressable switch **100**. In some implementations, the cartridge body **112** includes a support member **150** shaped and adapted for receiving the detonator **102** and positioning the detonator in a predetermined position within the cartridge body **112**. As seen in FIG. **45**, the tandem sub **4**, and the cartridge **110** held within, are adapted to be positioned adjacent the top mounting unit **12** of the shaped charge holding assembly. In addition, the top mounting unit **12** includes a detonator insertion bore **80** configured to receive a portion of the detonator **102**, which extends further than the cartridge body **112** (as seen in FIGS. **38**, **39**, **44** and **45**). More particularly, the detonator **102** has a proximal end adapted to abut a portion of the support member **150** within the cartridge body **112**, and a distal end extending outwardly from the cartridge body **112**. The distal end can thus be adapted to engage the detonator insertion bore **80** prior to the cartridge body contacting the mounting unit.

[0183] In this implementation, the support member **150** includes support arms **152** having a U-shaped supporting surface for holding the detonator **102**. In some implementations, the detonator **102** can clip into the support arms **152** to secure its position therein, although other configurations are possible. As seen in FIGS. **44** and **45**, the proximal portion of the detonator **102** is held in the support member **150**, with the distal portion extending outwardly to engage the mounting unit and the detonation cord. The support member **150** can further include a rear support **154** adapted to block axial movement of the detonator **102** in one direction (e.g., toward the inside of the cartridge). More specifically, the proximal end surface of the detonator **102** is adapted to abut against the rear support **154**, which blocks movement thereof and thereby positions the detonator in a predetermined position within the cartridge body **112**. Is it thus noted that the length of the distal portion of the detonator **102** extending into the detonator insertion bore **80** of the mounting unit **12** can be determined when the cartridge is in position (e.g., relative to the tandem sub and/or the mounting unit). It should be noted that some of the implementations described above are described further in Applicant's co-pending application No. 63/260,892, which is hereby incorporated by reference in its entirety.

[0184] In terms of assembly and deployment of the perforating gun, the tandem sub **4** and the holding system **6** can be pre-assembled off-site and shipped together to the well site as a unit, if desired. Alternatively, the unit could be pre-assembled at a manufacturing site except for the alignment bar such that an alignment bar having the desired configuration to provide a particular phasing for each perforating gun can be installed before shipping, based on well design criteria. In some implementations, the bottom mounting unit can be removed and the alignment rod can be placed over the tower of holders until the mounting section connects into the top mounting unit and the alignment connectors are clipped onto the alignment bar; then the bottom mounting unit is reinstalled onto the bottom-most holder; and then the carrier is installed over the perforating gun subassembly. The detonation cord and signal cord can be run in the same helical manner and direction as the alignment rod, for example. It is also noted that inventory of the various components can be kept such that perforating guns can be assembled efficiently where only the selection of the alignment member is required for providing a certain desired phasing for the charges. Thus, a set of different alignment members can be kept in inventory while the remainder of the components are standard and used for all phasing implementations.

[0185] While the alignment concept has been described herein in connection with aligning shaped charges for a perforation gun, it is noted that the concept could also be used in other tools and operations in oil and gas applications, geology applications requiring downhole tools, or other applications that require phasing of certain components. For example, the alignment bar could be used to align any components that are rotatably coupled along a longitudinal axis of a tubular wellbore tool, or other device, in order to align the components at a desired phasing. Such components could be shaped charge holders, as described in detail herein, and could also be components such as valves, sensors, inflow or outflow devices, tubular sections, and so on.

[0186] The alignment strategy described herein can facilitate freedom of manufacturing, for example since a single design of the holding assembly and mounting units can be manufactured to cooperate with multiple different alignment member designs to provide the phasing of interest for a given perforation gun. Each perforation gun can be provided with its own desired phasing by simply using a corresponding alignment member, while the rest of the components of the perforating gun remain the same. The alignment member can be a relatively simple component, such as a single-piece rod that has been formed to provide an alignment configuration when secured to the alignment connectors along the holding assembly. Indexing the charge orientation to the carrier can involve the charge orientation being couple to the top mounting unit which is rotationally secured to the carrier via a system, such as a groove-and-key system. However, it is also possible to not index relative to the carrier since each holder assembly itself is provided with the desired charge phasing via the alignment member. When multiple guns are to be phased or indexed relative to each other, then indexing to the carrier can be an effective method to do so, but in cases where gun-to-gun orientation is not important then the system may or may not be indexed to the carrier. In other words, the system can be configured such that if the alignment tab is removed, the charges and top mounting unit would remain connected in the desired phasing but they could be allowed to freely rotate within the gun carrier.

[0187] Referring to FIGS. **1** and **3**, the carrier **10** can have a scalloped shape that includes thinner scallop sections around the entire circumference at each shaped charge location, such that the shaped charges do not need to be oriented with respect to the carrier. No matter where each shaped charge is oriented after connection to the alignment member, the charge will face part of a scallop section to facilitate operation of the charges when detonated. The use of a scalloped carrier also enables inventory enhancements as a single carrier design can be used for any phasing arrangement. In addition, if the alignment member provides some play or small error in the phasing, the scalloped design of the carrier maintains good performance.

[0188] Referring to FIGS. **32**A to **32**G, it is noted that various configurations are possible for phasing the charges using the alignment member. These figures schematically show six holders in between top and bottom mounting units, with an alignment system coupled to the holders. FIG. **32**A shows a 180 degree phasing, FIG. **32**B shows 0 degree phasing, FIG. **32**C shows a hybrid 0 and 180 degree phasing where adjacent pairs of charges are oriented together, and FIG. **32**D shows 90 degree phasing. FIG. **32**E shows an alternative arrangement where two alignment members are used to provide 180 degree phasing. It is noted that two or more distinct alignment members could be provided, each being inserted into a corresponding location in the top mounting unit, and configured such that the set of alignment members provide a desired phasing while not being located in front of the charges. For multiple alignment members, the top mounting block could be provided with appropriate number of openings, and the alignment members could be the same or different from each other and could be straight or helical or have another configuration. FIG. **32**F shows an arrangement where adjacent pairs of holders are connected together and the alignment member is connected to each pair by a single alignment connector. FIG. **32**G shows a branched alignment member that provides 180 degree phasing. It should be understood that numerous variants of these arrangements can be implemented to provide the desired phasing of the shaped charges.

[0189] In some implementations, the alignment member is manufactured in the predetermined configuration to provide a certain phasing once installed. Thus, a straight steel bar can be subjected to a bending process to make the helical section of the alignment bar, which can then be installed in the perforating gun to provide the desired phasing. Alternatively, the alignment member could be given the desired helical configuration "in situ", e.g., but mounting a straight bar to the top and bottom mounting units and then using relative rotation between the two opposed unit to cause the bar to twist into the desired helical configuration. The mounting units could be provided with a clocking system to provide the desired degree of rotation. Appropriate metalwork equipment and processing could be used in conjunction with this method of making helical alignment bars.

1.-**94**. (canceled)

95. A perforating gun for deployment in a wellbore extending within an underground reservoir, comprising:

a shaped charge holding assembly, comprising:

shaped charge holders that are arranged in a side-to-side configuration and wherein at least some adjacent pairs of the shaped charge holders are infinitely rotatable with respect to each other in a rotation state;

a mounting unit coupled to the holding assembly; and

an alignment system comprising:
alignment connectors securable with respect to respective shaped charge holders or shaped charges;
an alignment member comprising:
a mounting section configured to be mounted with respect to the mounting unit to secure the alignment member with respect thereto; and
an elongated alignment section extending from the mounting section along the holding assembly and configured to secure the shaped charges via the alignment connectors to orient the shaped charges in a predetermined phasing in an aligned state.

96. The perforating gun of claim **95**, wherein the alignment member comprises an alignment rod.

97. The perforating gun of claim **95**, wherein the alignment member is composed of metal and provides electrical conduction.

98. The perforating gun of claim **95**, wherein the shaped charge holders are independently rotatable with respect to each other.

99. The perforating gun of claim **95**, wherein the alignment system has a single alignment member for phasing the shaped charges.

100. A shaped charge holder, comprising:
an annular body comprising a first open end for receiving a shaped charge therein, and a second opening through which an end of the shaped charge can pass for connection with a detonation cord;
a first coupling component extending from a first side of the annular body; and
a second coupling component extending from a second side of the annular body,
wherein the first coupling component and the second coupling component are configured such that adjacent shaped charge holders are rotatably connectable together by engagement of the first and second coupling components to provide infinite rotation with respect to each other about a longitudinal axis.

101. The shaped charge holder of claim **100**, wherein the first and second coupling components are configured to axially retain adjacent holders together to resist or prevent decoupling.

102. The shaped charge holder of claim **100**, wherein the first and second coupling components provide a male-female connection.

103. The shaped charge holder of claim **102**, wherein the male component is rigid, and the female component comprises resilient arms to receive and snap onto the male component.

104. The shaped charge holder of claim **102**, wherein the female component comprises a cavity defined by rigid walls and the male component comprise resilient arms insert and snap into the female component.

105. A perforating gun for deployment in a wellbore extending within an underground reservoir, comprising:
shaped charge holders coupled in a side-to-side configuration and wherein adjacent pairs of the shaped charge holders are infinitely rotatable with respect to each other, the shaped charge holders being configured to receive and support respective shaped charges;
an alignment system configured to orientate the coupled shaped charge holders in a predetermined phasing configuration.

106. The perforating gun of claim **105**, wherein the alignment system is configured to secure the shaped charge holders to prevent rotation thereof once positioned in the predetermined phasing configuration.

107. The perforating gun of claim **105**, further comprising a top mounting unit rotatably coupled to a top-most shaped charge holder.

108. The perforating gun of claim **105**, further comprising a carrier in which the top mounting unit, the shaped charge holders and the alignment system are located.

109. The perforating gun of claim **105**, wherein the shaped charge holders are rotatably mounted directly to each other.

110. The perforating gun of claim **105**, further comprising a bottom mounting unit rotatably coupled to a bottom-most shaped charge holder.

111. The perforating gun of claim **105**, wherein the shaped charge holders are infinitely rotatable with respect to each other prior to being held in place by the alignment system.

112. A method for manufacturing a perforating gun, comprising:
mounting a series of shaped charge holders together so as to be rotatable with respect to each other;
mounting shaped charges within the holders;
aligning the shaped charges in a predetermined phasing, comprising:
rotating the holders to respective positions; and
securing the adjacent shaped charges so as to be non-rotatable to produce a phased shaped charge assembly; and
installing the phased shaped charge assembly in a carrier.

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