(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 020 482 A2**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
04.02.2009 Bulletin 2009/06

(21) Application number: **08105836.4**

(22) Date of filing: **15.05.2002**

(51) Int Cl.:
E21B 23/04 *(2006.01)* ***E21B 23/06*** *(2006.01)*
E21B 33/04 *(2006.01)* ***E21B 33/12*** *(2006.01)*
E21B 43/10 *(2006.01)*

(84) Designated Contracting States:
DK FR GB

(30) Priority:
18.05.2001 US 292049 P
31.08.2001 US 316459 P
31.08.2001 US 943854
31.08.2001 US 943701
31.08.2001 US 316572 P
17.10.2001 US 981487
19.10.2001 US 83320
04.12.2001 US 4945
04.12.2001 US 4588
02.05.2002 US 136969
02.05.2002 US 136992

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
06012127.4 / 1 712 729
02736875.2 / 1 392 953

(71) Applicant: **Dril-Quip, Inc.**
Houston, Texas 77040 (US)

(72) Inventors:
- **Yokley, John M.**
  Kingwood, TX 77339 (US)
- **Reimert, Larry E**
  Houston, TX 77024 (US)

(74) Representative: **Lockey, Robert Alexander**
Forrester & Boehmert
Pettenkoferstrasse 20-22
80336 München (DE)

Remarks:
This application was filed on 20-11-2008 as a divisional application to the application mentioned under INID code 62.

(54) **Liner Hanger, Running Tool and Method**

(57) A tool for use in a subterranean well to seal with a generally cylindrical interior surface of a tubular or another downhole tool, the tool comprising:
a conveyance tubular for positioning the tool at a selected location below the surface of the well;
an annular seal assembly disposed about the conveyance tubular, the seal assembly having a reduced diameter run-in position and an expanded sealing position;
a wedge ring having a substantially conical outer surface configured to radially expand the annual seal assembly upon axial movement of the annular seal assembly relative to the wedge ring such that the seal assembly is expanded from its run-in position to its expanded sealing position wherein the seal assembly is in sealing engagement with the generally cylindrical interior surface; and
the annular seal assembly including a metal framework having a radially inward annular base and a plurality of metal ribs each extending radially outward from the base, the metal framework including an upper downwardly angled primary seal metal rib for sealing pressure below the seal assembly, a lower upwardly angled primary seal metal rib for sealing pressure above the seal assembly, a primary elastomeric seal in a cavity readially outward from the base and axially between the upper primary seal metal rib and the lower primary seal metal rib, an upper downwardly angled secondary seal metal rib spaced axially above the upper primary seal metal rib, and a lower upwardly angled secondary seal metal rib spaced axially below the lower primary seal metal rib.

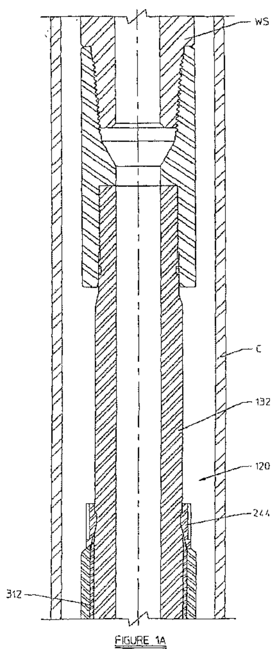


FIGURE 1A

EP 2 020 482 A2

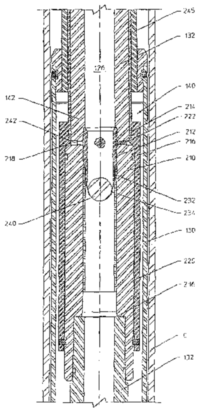


FIGURE 1B

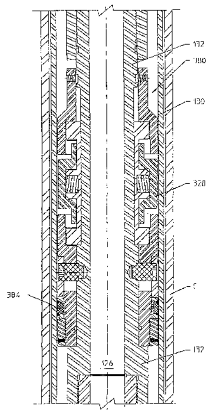


FIGURE 1C

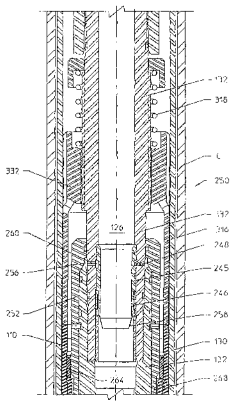


FIGURE 1D

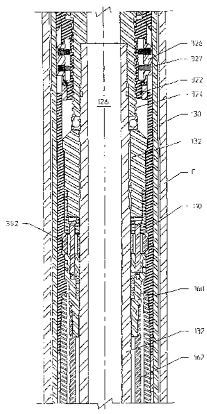


FIGURE 1E

(Cont. next page)

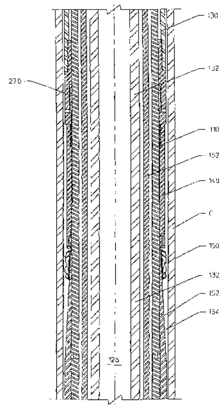


FIGURE 1F

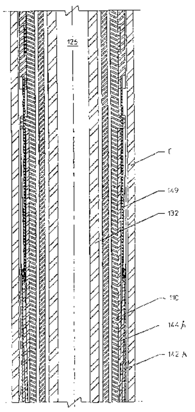


FIGURE 1G

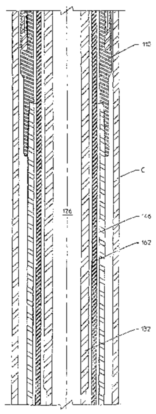


FIGURE 1H

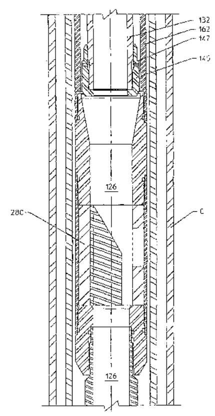


FIGURE 1I

(Cont. next page)

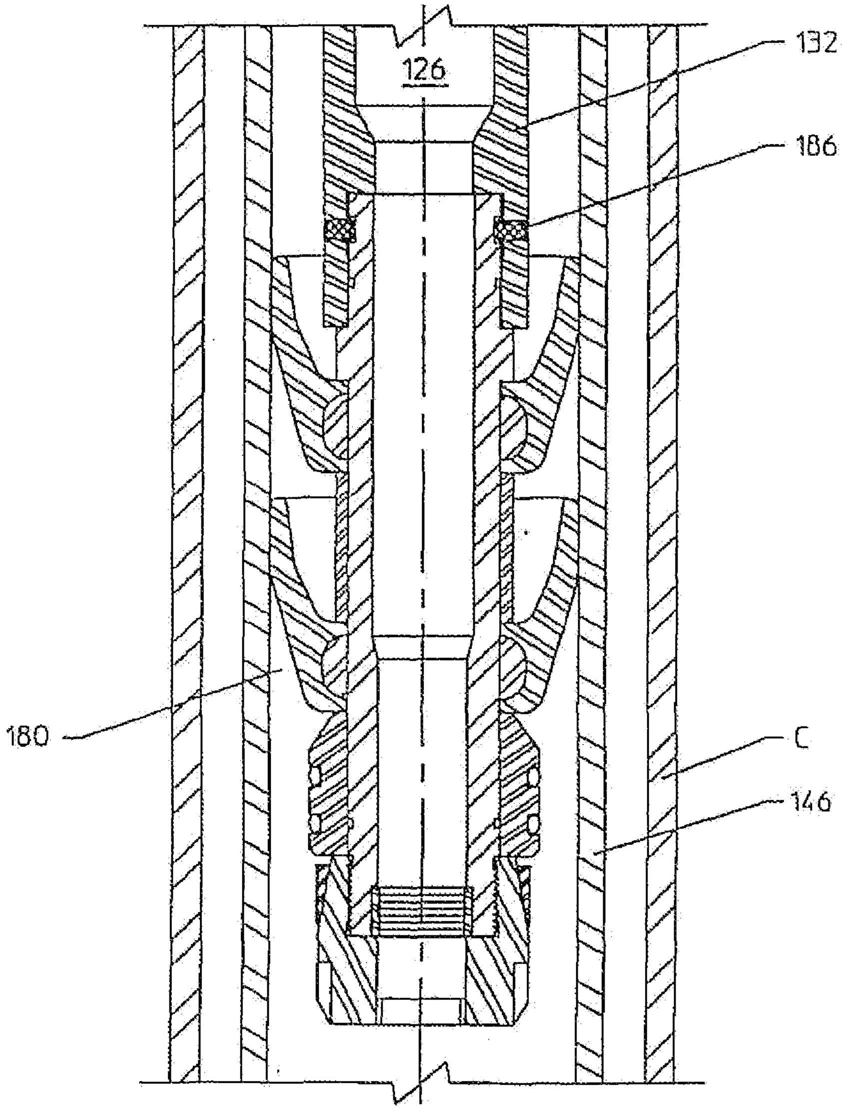


FIGURE 1J

Description

Related Applications

[0001] The present application claims priority from:

U.S. Provisional Serial 60/292,049 filed May 18, 2001 (attorney ref: 108-P); U.S. Provisional Serial No. 60/316,572 filed August 31, 2001 (attorney ref: 108-1); U.S. Provisional Serial No. 60/316,459 filed August 31, 2001 (attorney ref: 111); U.S. Serial No. 09/943,854 filed August 31, 2001 (attorney ref: 118); U.S. Serial No. 09/943,701 filed August 31, 2001 (attorney ref: 119); U.S. Serial No. 09/981,487 filed October 17,2001 (attorney ref: 123); U.S. Serial No. 10/083,320 filed October 19, 2001 (attorney ref: 111-1); U.S. Serial No. 101004,945 filed December 4, 2001 (attorney ref: 106);U.S. Serial No. 10/004,588 filed December 4,2001 (attorney ref: 124); U.S. Serial No. __________________ filed May 2, 2002, entitled *Apparatus For Use In Cementing An Inner Pipe Within An Outer Pipe Within A Wellbore* (attorney ref: 116); U.S. Serial No. __________________ filed May 2, 2002, entitled *Slip Assembly For Hanging An Elongate Member Within A Wellbore* (attorney ref: 117).

Background of the invention

[0002] When drilling a well, a borehole is typically drilled from the earth's surface to a selected depth and a string of casing is suspended and then cemented in place within the borehole. A drill bit is then passed through the initial cased borehole and is used to drill a smaller diameter borehole to an even greater depth. A smaller diameter casing is then suspended and cemented in place within the new borehole. This is conventionally repeated until a plurality of concentric casings are suspended and cemented within the well to a depth which causes the well to extend through one or more hydrocarbon producing formations.

[0003] Rather than suspending a concentric casing from the bottom of the borehole to the surface, a liner is often suspended adjacent to the lower end of the previously suspended casing, or from a previously suspended and cemented liner, so as to extend the liner from the previously set casing or liner to the bottom of the new borehole. A liner is defined as casing that is not run to the surface. A liner hanger is used to suspend the liner within the lower end of the previously set casing Typically, the liner hanger has the ability to receive a tie back tool for connecting the liner with a string of casing that extends from the liner hanger to the surface.

[0004] A running and setting tool disposed on the lower end of a work string may be releasably connected to the liner hanger, which is attached to the top of the liner. The work string lowers the liner hanger and liner into the open borehole so that the liner extends below the lower end of the previously set casing or liner. The borehole is filled with fluid, such as a selected drilling mud, which flows around the liner and liner hanger as the liner is run into the borehole. The assembly is run into the well until the liner hanger is adjacent the lower end of the previously set casing or liner, with the lower end of the liner typically slightly above the bottom of the open borehole.

[0005] When the liner reaches the desired location relative to the bottom of the open borehole and the previously set casing or liner, a setting mechanism is conventionally actuated to move slips on the liner hanger from a retracted position to an expanded position and into engagement with the previously set casing or liner. Thereafter, when set down weight is applied to the hanger slips, the slips are set to support the liner.

[0006] The typical liner hanger may be actuated either hydraulically or mechanically. The liner hanger may have a hydraulically operated setting mechanism for setting the hanger slips or a mechanically operated setting mechanism for setting the slips. A hydraulically operated setting mechanism typically employs a hydraulic cylinder which is actuated by fluid pressure in the bore of the liner, which communicates with the bore of the work string. When mechanically setting the liner hanger, it is usually necessary to achieve relative downhole rotation of parts between the setting tool and liner hanger to release the hanger slips. The hanger slips are typically one-way acting in that the hanger and liner can be raised or lifted upwardly, but a downward motion of the liner sets the slips to support the hanger and liner within the well.

[0007] To release the running tool from the set liner hanger, the setting tool may be lowered with respect to the liner hanger and rotated to release a running nut on the setting tool from the liner hanger. Cement is then pumped down the bore of the work string and liner and up the annulus formed by the liner and open borehole. Before the cement sets, the setting tool and work string are removed from the borehole. In the event of a bad cement job, a liner packer and a liner packer setting tool may need to be attached to the work string and lowered back into the borehole.

[0008] The packer is set utilizing a packer setting tool. Packers for liners are often called "liner isolation" packers. A typical liner isolation packer system includes a packer element mounted on a mandrel and a seal nipple disposed below the packer. The seal nipple stings into the tie back receptacle on top of or below the previously set and cemented liner hanger. A liner isolation packer may be used, as explained above, to seal the liner in the event of a bad cement job. The liner isolation packer is typically set down on top of the hanger after the hanger is secured to the outer tubular, and the packer is set by the setting tool to seal the annulus between the liner and the previously set casing or liner. Generally, the deeper a well is drilled, the higher the temperature and pressure which is encountered. Thus, it is desirable to have liner packers which will ensure quality cementing of the liner so as to provide a high safety factor in preventing gas from the formation from migrating up the annulus between the liner and outer casing.

[0009] During the cementing operation, fluid such as drilling mud in the annulus between the liner and outer casing is displaced by cement as the cement is pumped down the flow bore of the work string. First, the drilling mud and then the cement flows around the lower end of the liner and up the annulus. If there is a significant restriction to flow in the annulus, the flow of the cement slows and a good cementing job is not achieved. Any slowing of the cementing in the annulus allows time for the gas in the formation to migrate up the annulus and through the cement to prevent a good cementing job.

Running Tool Release Mechanism

[0010] As a practical matter, the liner hanging running tool must include a release mechanism so that, once the liner is reliably set to the lower end of the casing, the running tool can be released from the liner hanger and retrieved to the surface. Conventional liner hanger running tool releasing mechanisms include hydraulically actuated mechanisms, and release mechanisms that are manipulated by left-hand rotation of the running string. The left-hand rotation of the running string is, however, generally considered undesirable since it may result In an unintended disconnection of one of the Joints of the running string, thereby causing separation of the running string and a fishing operation to retrieve the running tool, which may have been damaged by the unintended disconnection. For various reasons, hydraulically operated running tool release mechanisms may fail to operate, or may prematurely release the running tool from the liner hanger.

[0011] Accordingly, improvements in release mechanisms are desired which will reliably release the running tool from the set liner only when intended, particularly when retrieving is easily accomplished and premature disengagement of the running tool from the liner is highly unlikely.

Packoff Bushing

[0012] A liner hanger packoff bushing conventionally seals between the liner hanger and the running tool, and thus between the liner and the running string or work string, which conventionally may be drill pipe. A packoff bushing is particularly required during cementing operations so that fluid pumped through the drill pipe continues to the bottom of the well and then back up into the annulus between the well bore and the liner to cement the liner in place. During cementing operations, the seal body of the packoff bushing is fitted in the annulus between the liner hanger and the running tool, and includes OD seals for sealingly engaging the liner hanger and ID seals for sealingly engaging the running tool. Packoff bushings are preferably retrievable with the running tool to prevent having to drill out the bushings after the cementing operation is complete. Also, a packoff bushing is preferably lockable to the liner hanger by locking within a profile to prevent the bushing from moving axially with respect to the liner hanger. If the packoff bushing is not lockable to the profile of the liner hanger, the bushing may get "pumped out" through the top of the receptacle, thereby losing a cementing job.

[0013] A conventional retrievable and lockable packoff bushing includes metal dogs or lugs which are locked into engagement with the liner hanger to prevent the packoff bushing from moving axially during the cementing operation. The packoff bushing is retrievable with the running tool, and thus eliminates the need to drill out the bushing after cementing operations are complete. Depending on the manufacturer, retrievable packoff bushings are also referred to as retrievable seal mandrels or retrievable cementing bushings. Regardless of the terminology, the retrievable and lockable packoff bushing seals the annulus between the running string and the top of the liner, and may be locked in a profile of the liner hanger by the slick joint to prevent the bushing from being pumped out of the liner hanger.

[0014] Cooperating surfaces on the liner running adapter, the slick joint on the running tool, and the seal body of the packoff bushing axially interconnect the bushing to the liner hanger while running the liner hanger into the well. These cooperating surfaces may be unlocked to release the running tool from the liner hanger and allow axial manipulation of the running tool and slick joint relative to the packoff bushing. The slick joint thus seals with the packoff bushing during axial movement of the running tool. Once the cooperating surfaces are unlocked from each other, shoulders on the packoff bushing and the running tool engage after a predetermined amount of axial movement between the running tool and the seal body, so that the packoff bushing may be retrieved to the surface with the running tool after the cementing operations is complete: A conventional packoff bushing is disclosed in U.S. Patent 4,281,711.

[0015] A significant limitation on prior art packoff bushings concerns their desired retrievability with the running tool, when coupled with the desire to pick up the running tool relative to the packoff bushing before the cementing operation. An operator will typically want to pick up the running tool after release from the liner hanger to ensure that these tools are disconnected. The length of the running tool slick joint determines the maximum length that the running tool should be picked up after release from the liner hanger. When the packoff bushing is pulled out of the liner hanger, the dogs or lugs conventionally carried by the packoff bushing are allowed to move radially inward, thereby preventing the retrievable packoff bushing from being stabbed back into and locked into the liner hanger. Conventional liner hanger running tools do not allow the packoff bushing to be "re-stabbed" into the liner hanger and thereby re-establish pressure integrity between the liner hanger and the running tool. In many applications, it is difficult for the operator to determine the exact amount the running tool has been picked up, particularly when operating in deep or highly deviated wells. If the operator picks up the running tool an axial distance not permitted by the length of a slick joint, the packoff bushing will be pulled up with the running tool and will disengage from the liner hanger, which may cause a cementing failure costing the operator millions of dollars in lost time and money. The consequences of unintentionally unseating the packoff bushing from the liner hanger and not being able to re-stab and lock into the liner hanger may thus be severe.

[0016] The slick joint used with the liner hanger running tool has a polished OD surface which seals against the ID seals on the seal body of the packoff bushing. The slick joint OD surface can become scratched or damaged during handling, thereby causing a cementing leak during the cementing operation. Since the running tool is designed to move axially substantial distances relative to the packoff bushing, the inner seals on the seal body may wear out during the cementing process due to the reciprocation of the running tool slick joint. This problem is exacerbated when the quality of the polished surface on the slick joint has deteriorated. Axially long slick joints are expensive to manufacture and maintain.

[0017] Another problem with prior art packoff bushing concerns the limited load capacity of the lugs that lock the packoff bushing to the liner hanger. Conventional packoff bushings utilize multiple lugs protruding from the packoff seal body, which increases the complexity and the cost of the packoff bushing. The limited size of these lugs nevertheless restricts or limits the cementing pressure capacity of the packoff bushing.

Packer Setting Assembly

[0018] A conventional liner hanger running tool includes a packer setting assembly, which allows the activation and packoff of the liner top packer. Conventional packer setting assemblies incorporate multiple spring-loaded dogs or lugs which may be compressed to a reduced diameter position by insertion into the packer setting sleeve when running the liner hanger in the well and when cementing the liner within the casing. When the packer setting assembly is raised out of the packer setting sleeve, the dogs or lugs expand to a diameter greater than the ID at the upper end of the setting sleeve, which is also the tie back receptacle of the liner hanger. When the dogs engage the top of the setting sleeve, a setting force may be transferred from the running string through the dogs and to the packer setting sleeve as running string weight is slacked off to set the packer element.

[0019] Some prior art packer setting assemblies include an axial bearing to facilitate rotation of the work string while setting the packer element. Other packer setting assemblies include both a bearing and a shear indicator to provide a visual confirmation that the proper setting load was applied to the packer, and/or an unlocking feature that allows the packer setting assembly to be pulled out of the packer setting sleeve one time without exposing the setting dogs. This latter tool allows re-stabbing the packer setting assembly into the packer setting sleeve one time, thereby arming the setting dogs so they are ready to expand the second time the dogs are pulled out of the setting sleeve.

[0020] A primary problem concerning prior art packer setting assemblies is poor reliability. In some well environments, the packer setting dogs of conventional packer setting assemblies collapse and re-enter the setting sleeve without setting the packer element. Manufacturers have provided more dogs or lugs to alleviate this problem, and/or have provided heavier springs to bias the dogs radially outward. These changes have had little if any affect on achieving higher reliability.

[0021] The disadvantages of the prior art are overcome by the present invention, and an improved liner hanger running tool is hereinafter disclosed which includes improvements to a running tool release mechanism, a retrievable packoff bushing, and a packer setting assembly. In addition, the improved packer setting assembly may be used in operations not involving a liner hanger running tool.

Summary of the invention

[0022] A preferred embodiment of a liner hanger running tool of the present invention incudes improvements to one or more of the running tool release mechanism, the retrievable packoff bushing and the packer setting assembly. The running tool may be used for positioning a liner within a casing in a wellbore and subsequently cementing the liner in place, then retrieving the running tool to the surface with the packoff bushing and the packer setting assembly. The packer setting assembly may be used in other downhole packer setting applications.

Running Tool Release Mechanism

[0023] The liner hanger running tool release mechanism preferably incudes a hydraulically actuated mechanism for releasing the running tool from the set liner hanger in response to fluid pressure within the running tool, and also a mechanical right-hand release mechanism which, if necessary, allows the running tool to be mechanically released from the liner hanger by right-hand rotation of the work string. The combination of the hydraulic release mechanism and the right-hand release mechanism significantly improves reliability of the running tool.

[0024] It is an object of the present invention to provide an improved running tool release mechanism for releasing a running tool from a set liner hanger. The running tool may be hydraulically released, but also may be released by right-hand rotation of the running string. A first piston is used for hydraulic release. A second piston is used to disengage a clutch, thereby allowing a nut to move downward along the right-hand threads on the running tool mandrel due to right-hand rotation of the running string. Once the nut has moved axially downward on the mandrel, the work string may be picked up to disengage the running tool from the liner hanger.

[0025] Yet another feature of the invention is that, after the clutch has been disengaged to allow right-hand release of the running tool, fluid pressure may be used to reengage the clutch to allow rotation of the liner during a cementing operation.

[0026] Yet another feature of the invention is that fluid within the running tool which transmits fluid pressure to the piston for hydraulic release of the running tool may be isolated by a sleeve, such that the sleeve shifts downward to expose a port and allow hydraulic fluid to release the running tool.

[0027] A significant feature of the running tool release mechanism is that the release mechanism may be actuated both hydraulically and by right-hand rotation of the running string or work string.

[0028] A related feature of the running tool release mechanism is that reliability of the release operation is significantly improved with little if any cost increases.

Packoff Bushing

[0029] During the cementing operation, the packoff bushing serves its function of providing a seal between the liner hanger and the running string. The packoff bushing may be axially fixed to the liner hanger during the cementing operation by a C-shaped lock ring, which is held locked in a groove in the liner hanger by a fluid pressure responsive piston. The packoff bushing is designed such that it may be reinserted into the liner hanger when the packoff bushing is raised with the running string relative to the set liner hanger. Accordingly, the cost of the slick joint may be avoided. The liner hanger packoff bushing may thus be removed from the liner hanger when the operator picks up the running tool to check for release of the running tool from the liner hanger and verify that the liner is properly set in the casing. When the running tool is slacked back off into the liner hanger before pumping cement, the packoff bushing can be re-stabbed and resealed to the liner hanger. When pressure is subsequently applied to the running string during a cementing operation, the packoff bushing will be locked to the liner hanger by the fluid pressure to prevent movement out of the liner hanger. Fluid pressure thus keeps the packoff bushing locked to the liner hanger, while the absence of pressure in the running string allows the packoff bushing to be picked up out of the liner hanger and subsequently reinserted into the liner hanger. The liner hanger running tool thus includes a packoff bushing which maybe repeatedly "re-stabbed" back into the liner hanger, as desired by the operator, to re-establish pressure integrity between the running tool and the liner hanger.

[0030] By providing a re-stabbable packoff bushing, the operator has much more flexibility when picking up to check for release of the running tool. By providing a packoff bushing which may be repeatedly reinserted into the liner hanger so that a seal may be repeatedly established between the running string and the liner hanger, the operator avoids much of the risk of a bad cementing job, and the significant loss of time and money to correct a bad cementing job. The re-stabbable packoff bushing may be used on a running tool with or without a liner hanger packer for seating between the casing and the liner hanger.

[0031] The packoff bushing is preferably designed with a C-shaped lock ring to increase the cementing pressure capability of the packoff bushing. Compared to prior art packoff bushings, the one-piece lock ring avoids the use of multiple lugs and springs which add length and complexity to the packoff bushing without significantly increasing the cementing pressure capability of the packoff bushing when locked to the liner hanger.

[0032] It is an object of the present invention to provide a liner hanger running tool with the packoff bushing which may be repeatedly restabbed into the top of the liner.

[0033] A feature of this invention is that the packoff bushing incorporates a C-shaped one-piece lock ring, which effectively looks the packoff bushing to the liner hanger in response to fluid pressure, which acts on a piston to retain the lock ring in the lucked position. The absence of fluid pressure allows the lock ring to be collapsed, thereby permitting the restabbing of the packoff bushing into the top of the liner hanger. The C-shaped lock ring may include radially external or internal slots for facilitating expansion and contraction of the lock ring.

[0034] The packoff bushing includes a radially outer shoulder for engaging a radially inner shoulder on the liner hanger when the lock ring is aligned with the groove in the liner hanger, so that set down weight may be applied to the liner hanger. The packoff bushing also includes a radially inner shoulder, so that the packoff bushing is retrieved with the tool to the surface. In addition to the packoff bushing, the running tool may include a packer setting assembly for activating the packer element to seal between the casing and the liner hanger.

[0035] It is a feature of the invention that the running tool may include a retrievable packoff bushing which may be reinserted or "restabbed" into the liner hanger numerous times. A related feature of the invention is that the cost of a slick joint may be avoided.

[0036] It is a further feature of the present invention to provide an improved liner hanger running tool packoff bushing wherein fluid pressure keeps the packoff bushing locked to the liner hanger, while the absence of fluid pressure may allow the packoff bushing to be picked up out of the liner and subsequently reinserted into the liner. A related feature of the running tool with the improved packoff bushing is the reduced risk of a bad cementing job.

Packer Setting Assembly

[0037] The packer setting assembly may be used with the liner hanger running tool to set the liner top packer after the liner hanger has been set, and after the running tool has been released from the liner hanger. The packer setting assembly may be positioned on the running tool at a desired location, which may be axially between the liner hanger releasing assembly and the slip setting assembly at the lower end of the running string or work string. When the running tool is assembled at the surface, the packer setting assembly is thus contained within the tie back receptacle or setting sleeve of the liner hanger assembly.

[0038] The packer setting load is preferably transferred to the packer setting sleeve through a one piece C-shaped setting ring. The C ring design enables more weight to be set down on the setting sleeve than with the plurality of dogs used in the prior art. A lock out feature keeps the setting ring in weight-transfer engagement with the setting sleeve so that the setting ring will not prematurely snap radially inward toward the packer setting housing before the packer is set. Seals on both the ID and the OD of the packer setting assembly also ald in setting the packer. Once the initial load has been set down on the liner hanger, the ID seal which seals to the running tool mandrel, and the OD seal which seals to the setting sleeve, act as a piston responsive to pressure applied to the annulus to assist in setting the packer element. This fluid pressure assist along with the set down weight achieves the proper setting force to the liner top packer element. By using annulus pressure to aid in setting the packer element, a significant additive hydraulic force complements the set down weight to reliably set the liner hanger packer element.

[0039] A preferred packer setting assembly includes an unlocking feature that allows the assembly to be pulled out of the packer setting sleeve one time without releasing a setting ring. Upon re-stabbing the assembly into the setting sleeve, the packer setting ring becomes activated and is ready to expand the second time the packer setting assembly is pulled out of the setting sleeve. An adjustable shear indicator may be included to provide immediate visual confirmation, when the running tool is retrieved to the surface, that adequate setting force was applied to the liner top packer. A bearing assembly in the packer setting tool allows rotation and slack off of the running string without damaging the packer setting sleeve or settling ring. Rotation also breaks the static friction between the running string and the casing, thereby reducing buckling and insuring maximum transfer of setting force to the liner packer element.

[0040] It is an object of the present invention to provide a packer setting assembly which uses an expandable and collapsible one-piece C-ring to set weight down to a packer element. The packer setting assembly also includes O.D. seals and I.D. seals, so that fluid pressure may be used to increase the setting force applied to the packer element.

[0041] It is a feature of the packer setting assembly according to the present invention that the C-ring may be locked in a collapsed position by a locking mechanism to prevent the C-ring from moving to its expanded position. This allows the packer setting assembly to be pulled out of the tie back receptacle one time without releasing the C-ring, and allows the lockout mechanism to engage the top of the tie back receptacle for weight set down. The next time the packer assembly is pulled out of the tie back receptacle, the C-ring is allowed to expand radially outward for engagement with the top of the tie back receptacle.

[0042] It is a further feature of the present invention that the packer setting assembly has multiple uses. The packer setting assembly may be used as part of a liner hanger running tool, although the packer setting assembly may also be used for other applications wherein an operator desires to radially set a downhole packer.

[0043] It is a feature of the invention that the packer setting assembly transfers the packer setting load to the packer setting sleeve through a C-shaped setting ring.

[0044] A related feature is that seals on both the I.D. and O.D. of the packer setting assembly may assist in setting the packer.

[0045] Yet another feature of the packer setting assembly is that the setting ring may be easily and reliably locked out to prevent premature actuation.

[0046] Yet another feature of the packer setting assembly is that it may include an unlocking feature so that the assembly may be pulled out of the packer setting sleeve one time without releasing the setting ring.

[0047] An advantage of the improvements to each of the running tool release mechanism, the retrievable packoff bushing, and the packer setting assembly is that these mechanisms rely upon components which have been found highly reliable in the oilfield services industry. The complexity of the running tool with one or more of these features is not significantly increased and, in many cases, is made simpler. Tool reliability has been increased to perform the desired downhole operations.

Brief Description of the Drawings

[0048]

Figures 1A-1J illustrate sequential lower portions of a liner hanger setting tool run into a well. Figure 1A illustrates the interconnection of the tool to a work string. Figure 1B illustrates the liner hanger slip setting assembly. Figure 1C illustrates the packer setting assembly. Figure 1D illustrates the liner hanger releasing assembly. Figure 1E illustrates the retrievable cementing bushing. Figure 1F illustrates the packer element. Figure 1G illustrates the hanger slip assembly.

Figure 1H illustrates the lower end of the running tool mandrel. Figure 1I illustrates the ball diverter. Figure 1J illustrates the liner wiper plug.

Figure 2A illustrates the tie back receptacle raised to set the slips. Figure 2B illustrates the slips in the set position.

Figure 3A shows the upper seat after release of the ball. Figure 3B shows the ball landed on the lower seat. Figure 3C illustrates the lower seat moved downward to open ports and allowed the lock ring of the releasing assembly to contract.

Figure 4A illustrates the ball released from the lower seat and dropped into the diverter. Figure 4B is a crossed section through Figure 4A.

Figure 5A illustrates the pump down plug landed on the wiper plug. Figure 5B illustrates the liner wiper plug and pump down plug released. Figure 5C illustrates the plug set landed within a landing collar.

Figure 6A illustrates the tool positioned to weight set the packer element.

Figure 6B illustrates the packer element in the set position.

Figure 7A illustrates the running tool packoff bushing unlocked from the liner hanger.

Figures 8A and 8B show the lower end of the running tool released from and pulled upward from the set liner hanger, with the upper portion of the set liner hanger being shown in Figures 8C and 8D.

Figure 8E shows one embodiment of a slip element raised into engagement with the casing; Figure 9A shows the packer elements and another embodiment of a slip assembly in the run in position. Figure 9B shows the components moved to set slip assembly. Figure 9C shows the slip assembly engaged with the casing and the packer element moved to seal with the casing.

Figures 10A and 10B illustrates running tool components for a hydraulic release when run in the well. Figure 10C illustrates the components once the pressure is increased to shift the ball seat, thereby releasing the running tool and disengaging a clutch. Figure 10D illustrates fluid pressure acting on the second piston so the clutch can reengage the liner hanger.

Figures 11A and 11B show sequential components of the running tool during a mechanical release from the liner hanger. Figure 11C shows the components with the ball seat shifted to release the running tool and disengage the clutch.

Figure 11D illustrates the second piston activated to engage the clutch with the running tool released.

Figure 12A is a cross-sectional view of a preferred retrievable packoff bushing according to the present invention, which may be positioned below a liner hanger packer setting assembly and above the ball diverter.

Figure 12B is a cross-sectional view of the retrievable packoff bushing shown in Figure 12A.

Figure 13 is a cross-sectional view of a preferred embodiment of a packer setting assembly on a liner hanger running tool according to the present invention.

Figure A1 is a vertical cross-sectional view of the head itself;

FIGS. A1A and 1B are a top view and a cross-sectional view,

Fig. A1C is a bottom view of the head Fig. A1, and Fig. A1D is a side view of a part of the head; and

Figure A2 is another, enlarged vertical sectional view of the head installed between a cementing swivel and a lower indication sub connecting to the work string, and showing the balls and plugs in the passages in position to be dropped.

Figs. B1A and B1B are respectively an elevational view, broken away in part, and an end view of the c-ring along in its fully contracted position wherein its side edges are engaged with one another; the outer side of the c-ring having vertical slots to facilitate the passage of fluid between the liner and outer well casing when the slip is expanded.

Figs. B2A and B2B are similar views of the c-ring in fully expanded position.

Figs. B3A and B3B are vertical sectional views of the slip assembly wherein the collapsed c-ring is shown in Fig. B3A disposed about the liner with its lower end received within the recess of the liner, and in Fig. B3B, raised from the recess and expanded to a position in which the liner may be raised to move its outer side upwardly.over the frusto conical surface of the liner so as to cause its teeth to engage the well casing; and

Fig. B3C is an enlarged detailed view of a portion of Fig. 3B to illustrate the controlled friction teeth on the inner slide of the c-ring.

Figs. B4, B5, and B6 are enlarged vertical sectional views of the assembly showing the c-ring as it moved by the liner from the retracted to the expanded position, the c-ring being shown in retracted position in Fig. 4, raised out of the recess by the tie bar in Fig. 5 to release it for expanding outwardly to engage the casing, and, in Fig. 6, the tie bar has raised frusto conical surface of the liner over the inner surface of the c-ring to cause the c-slip to be moved outwardly into engagement with the well casing.

Figs. B3AA and B3BB are detailed sectional views as indicated on Figs. B3A and B3B.

Figure C1 is a vertical sectional view of the outer casing joint having its bore configured to cooperate with a hanger mounted on an inner casing or liner as it is lowered into the outer casing.

Figure C2 is a view of the liner with the hanger mounted thereon for landing within the profiles in the outer casing;

Figure C3 is a view similar to Figure C2, but showing the liner and its hanger being lowered into the outer casing; and

Figure C4 is another similar view, but with the liner lowered further to cause its hanger to engage with the profile in the outer casing, and then lowered to a position to lock the hanger In position.

Figure D1 is a half-sectional view of the seal element according to the present invention positioned at the lower end of a tie back receptacle for moving down along a cone and sealing with a casing.

Figure D2 is an enlarged view of a seal element shown in Figure 1 positioned when the seal element initially engages the casing.

Figure D3 is a cross-sectional view of the seal element in its final set position for sealing engagement between the cone and the casing.

Figure E1 is a vertical sectional view of the diverter including the sub from which the cementing assembly is suspended.

Figure E2 is a view similar to Figure E1, with a ball landed in the diverter pocket.

Figure E3 is a cross sectioned view of the diverter, as seen along broken lines 3-3 of Figure E2, but on a larger scale to illustrate the "U" shaped slot formed in the ramp to one side of the diverted ball to permit passage of a pump down plug.

Figure E4 is another vertical sectional view of the liner beneath the diverter and showing the pump down plug following passage through the slot in the ramp and into a landed position in the liner wiper plug of the cementing equipment; and

Figure E5 is a further vertical sectional view, but in which the connection of the wiper plug has been sheared from the lower end of the tubular member beneath the ball diverter.

Figure F1 is a cross-sectional view of a plug holder sub according to the present invention, illustrating the position of components for attachment to the liner wiper plug on the left side of the centerline and positioned for release of the liner wiper plug from the plug holder sub on the right side of the centerline.

Figure F2 is a cross-sectional view of a lower portion of plug holder sub shown in Figure f1, illustrating the upper portion of a liner wiper plug attached to the plug holder sub on the left side of the centerline, and released on the right side of the centerline.

Detailed Description of Preferred Embodiments

Figures 1-9 Running Tool

[0049] To hang off the liner, the running tool 120 may initially be attached to the lower end of a work string WS and releasably connected to the liner hanger, from which the liner is suspended for lowering into the bore hole beneath the previously set casing or liner C. The assembly may easily be run in at a rate that does not adversely affect the well formations or the running tool.

[0050] A tie back receptacle 130 as shown in Figure 1B is supported about the running tool 120, with its upper end having the liner hanger slip setting assembly 140. The upper end of the tie back receptacle 130, upon removal of the running tool, provides a means by which a casing tie back (not shown) may subsequently extend from its upper end to the surface. As shown in Figures 1A-1I, the tool 120 includes a central mandrel 132, which may comprise multiple connected sections.

[0051] The lower end of the tie back receptacle 130 is connected to the packer element pusher sleeve 148 as shown in Figure 1F, whose function will be described in connection with the setting of the packer element 150 about an upper cone 152, as well as setting of one alternative embodiment of slip 142A about a lower cone 144A (see Figure 1G) below the packer element 150. The running tool 120 includes a cementing bushing 160 (see Figure 1E) from which a tubular body 162 is suspended for supporting the ball diverter 280 (see Figure 1I) and liner wiper plug 180 (see Figure 1J) at the lower end of the running tool. The retrievable cementing bushing 160 provides a retrievable seal between the running tool 120 and the liner hanger assembly for fluid circulation purposes. By incorporating an axially movable slick joint, the running tool can be moved without breaking the seal provided by the packoff bushing.

[0052] The liner hanger slip setting assembly 140 as shown in Figure 1B includes a sleeve 212 disposed within and axially moveable relative to a portion 210 of the running tool mandrel 132. The piston sleeve 212 is held in its upper position by shear pins 222 in mandrel portion 210. A tubular ball seat 232 is supported at the lower end of sleeve 212. The lower end of the ball seat has a neck portion 234 which is reduced in diameter and is thinner for the purpose described below. A ball 240 is dropped from the surface into the running tool bore 126 and onto the seat 232. An increase in fluid pressure within the mandrel 132 will shear the pins 222 and lower the ball seat to a landed position in the bore of the running tool, e.g., against the stop shoulder 236.

Ball Dropping Head

[0053] This invention also relates to improved apparatus for dropping a ball as above mentioned which includes a head suspended from a top drive for use in sequentially dropping balls and plugs into a liner suspended from the head. More particularly, it relates to the use of such equipment in cementing the liner within the outer casing, wherein the one or more balls are to be dropped onto a seat within the liner to actuate certain parts for the purpose of hanging the liner in the outer casing, followed by the dropping of pump down plugs through the liner for pumping cement beneath them into the annulus between the liner and outer casing.

[0054] In previous heads of this type, the balls and wiper plugs were mounted in individual manifolds with each having an opening onto a bore leading to the equipment to be actuated. As will be appreciated, this increased greatly the vertical height of the equipment beneath the top drive, thus making it that much more inaccessible, not only during loading and releasing of the balls and pump down plugs, but also in obtaining visual access to the interior of each manifold in which the plugs and balls were located.

[0055] U.S. Patent Nos. 6,182,752 and 6,206,095 allege to solve the problem of excess height by means of heads of such construction as to permit the balls and plugs to be mounted and dropped from essentially the same vertical location beneath the top drive. Nevertheless, their construction is complicated and requires large internal rotating parts which increased the possibility of leakage and other need for repair.

[0056] It is therefore another object of this invention to provide such a head in which the balls and plugs are mounted on generally the same level, but which does not include the large rotating parts and other mechanisms increasing the risk of repair and replacement.

[0057] This and other objects are accomplished, in accordance with the illustrated embodiments of this invention, by a housing having an inlet adapted to be fluidly connected In line with the lower end of a top drive, an outlet generally aligned with the inlet, and passages extending downwardly within the housing at circumferentially spaced locations. Each passage has an upper end opening to the side of the inlet and a lower end connecting with the outlet, and lateral passages in the housing each connect the inlet with a passage. A closure member is removably mounted in the upper end of each passage to permit a ball or plug to be installed therein, and plug valves are mounted in the housing each for opening and closing a passage beneath the lateral passage connecting thereto so as to support the ball or plug, when closed, and permit it to pass therethrough, when open. Circulating fluid may pass downwardly through an open passage when a ball or plug is not in the passage.

[0058] With reference now to the details of Figures A1 and A2, the head A10 comprises a housing A11 having a vertical opening A12 in its upper end and a vertical opening A13 in its opposite lower end, the openings being generally vertically aligned. The upper opening is threadedly connected to a tubular member A14 whose upper end is threaded for connection with a top drive.

[0059] Intermediate the upper and lower ends of the member A14 is a Kelly valve A16 installed for opening or closing its bore A15. When closed, the valve allows cement to be supplied to the bore A15 through one or more side openings A16 in member A14 beneath the Kelley valve. The member A14 is installed on a swivel A20 which has openings therethrough aligned with openings A16 in fittings A17 leading to the bore A15 of the member. As well known in the art, this permits relative rotation between the swivel and tubular member so that the tubular member and cementing truck are fluidly connected during relative rotation.

[0060] The lower end opening A13 in the head is threadably connected to the upper end of a sub A21 having a bore A22 therethrough adapted to be connected with the liner or other tubular member suspended therefrom. A "flag" A23 is mounted on a stem A24 rotatable in the sub for indicating the passage of a ball or plug therethrough.

[0061] As shown, the housing is of a generally frustoconical shape and has four passages P_1, P_2, P_3 and P_4 extending downwardly and inwardly therethrough to connect at their lower ends with the opening A13. More particularly, these passageways are equally spaced apart about the center line of the housing, and thus to opening A12, to connect at their lower ends with a common opening A21A In the upper end of the sub A21.

[0062] The upper end of each passage is adapted to receive a closure member 25, the threaded connection between each closure member and its passage enabling the closure member to be selectively removed or installed. The housing also has a lateral opening A26 connecting the lower end of its upper opening A12 with one of the passages P_1, P_2, P_3 and P_4 beneath the closure member therefor.

[0063] Each passage P_1, P_2, P_3 and P^4 is in turn open and closed by means of through bore plug valves PV_1, PV_2, PV_3, and PV_4 installed in the housing beneath the lateral openings A26, and vertically staggered to accommodate the valves. These valves of course control the passage of a plug or a ball as well as circulating fluid through the top drive, the head and into the liner below it. Thus, with the valves controlled in the manner to be described, circulation of the fluid may be continuous through at least one passage, even though the individual passages are closed to contain balls or wiper plugs.

[0064] As shown, each plug valve comprises a body having an opening A30 therethrough adapted, upon rotation of the body between its alternate positions, for alignment with or across a passage. These valve bodies may of course be rotated In any suitable manner and are held in place by a mounting plate MP bolted to the outside of the housing.

[0065] As indicated in Figure A2, one of the passages may receive a ball B between the top closure member and valve, while another passage may receive a pump down plug PDP. One of the other passages may be used to receive a ball or a plug, depending on the use of the balls and plugs in the system in which the head is installed. The fourth passage may be left open for enabling fluid to be freely circulated downwardly therethrough on a continuous basis.

[0066] A plug or a ball may be installed in a passage by removal of the closure member A25, which provides easy visual access to the passage to determine if the ball or plug in place or has been dropped downwardly. Each ball drops freely by virtue of its own weight when the plug valve in its passage is opened. The pump down plug, however, has wiper blades on it which are flexibly engaged with the passage, so that the downward movement of the wiper blade into the liner may be assisted by the passage of fluid through the ports connecting with the passage. The fourth passage may receive either a plug or a ball, depending on the needs of the system in which the head is installed or left open for free downward flow of the circulating fluid.

[0067] As will be understood, the only parts of the head requiring movement, and thus bearings and seals, are the plug valves PV for the individual passages. Closure of the plug valve in the three passages may facilitate downward pressure through the fourth passage when its plug valve is open, thus forcing the ball or plug downwardly into the liner.

[0068] As shown, each plug valve is mounted for rotation within its passage by means of a mounting plate MP bolted to a recessed portion of the outer side of the head and engaging an annular shoulder about the plug valve member.

Running Tool

[0069] Continuing with a description of the running tool 120 previously described, piston sleeve 220 is disposed about and is axially moveable relative to portion 210. An upper sealing ring 214 is disposed about a smaller O.D. of the running tool mandrel than is the lower seating ring 216 to form an annular pressure chamber 218 between them for lifting the tie back receptacle 130 from the position shown in Figure 1B to an upper position, as will be described in connection with setting the slips 142A. Ports 242 formed in the running tool mandrel 132 connect the running tool bore with the surrounding pressure chamber 218 once the sleeve 212 is lowered. An increase in pressure through the ports 242 will raise the piston sleeve 220. Upward movement of the sleeve 220 causes the upper end 312 of the piston sleeve 220 to overcome the resistance of the split ring 244 as shown in Figure 1A in order to raise the tie back receptacle 130, as shown in Figure 2A, and thereby raise the slips 142A, as shown in Figure 2B. Sleeve 245 as shown in Figure 1D may move downward to expose ports 260, raising the piston 252 to release the ring 244 which was connected to the top of the tie back receptacle 130. A further increase in pressure will force the ball through the reduced neck of the seat 232 to pump the ball to a seated position on a lower seat 246 (see Figure 1D), which is similar to the upper seat 232.

[0070] One problem with a conventional slip assembly is the need to coordinate the setting of the individual slips so that teeth thereof engage the outer casing substantially simultaneously. Also, it is of course costly to machine multiple wedge surfaces about the liner, as well as to provide multiple slip elements, and it is the principle object of this invention to provide a slip assembly for this purpose which requires only a single slip element cooperable with only a single wedge surface of the liner or other elongate member.

[0071] Thus, in the embodiment of Fig. 9A-9C, and as also shown and described in the aforementioned provisional application 60/292,099, the slip assembly include slip segments 141 which are raised by a tie bar over the outer conical surface of a cone 143 to cause teeth 142 about the slips to grip the casing C. In a preferred embodiment of the invention, the frusto conical surfaces of the member and slip extend downwardly and inwardly, the lower end of the slip is received in an upwardly facing recess in the member, and the teeth of the c-ring face downwardly in position to engage the wellbore, as the c-ring is raised over the surface of the member whereby the member may be suspended within the wellbore. The means for raising the lower end of the c-ring from the recess to a position for sliding along the conical surface of the member comprises at least one tie bar extending vertically through the member for guided reciprocation with respect thereto. More particularly, the inner side of the c-ring and lower end of the tie bar have interfitting parts which enable the lower end of the c-ring to be raised out of the recess, but which are disengageable when the bar is raised to permit the ring to expand into engagement with the wellbore.

[0072] Preferably and as illustrated, the inner frusto conical surface of the c-ring has relatively blunt teeth about its frusto conical surface for engagement with the frusto conical surface of the member so as to control the friction between them, and thus control the force applied to the casing.

[0073] As illustrated and described, the elongate member is a liner and the recess to receive the end of the slip is of annular shape.

C-Ring Slip

[0074] With reference to the above described drawings, and as best shown in Figs. B3A and B3B, the liner B20 has a downwardly and inwardly extending frusto conical surface B22 thereabout above an upwardly facing annular recess B23. The liner has been lowered on a suitable running tool (not shown) to a position in the outer well casing in which the liner is to be hung off.

[0075] As will be described in more detail to follow, c-ring C is initially expanded to permit it to be disposed about the conical wedge surface of the liner. It may then be contracted and forced downwardly to cause its lower end B26 to move into the recess B23. When so installed, the c-ring slip is held in retracted position in a shape somewhat larger than its fully contracted shape of Figs. B1A and B1B.

[0076] When the c-ring has been pulled upwardly to remove its lower end from the recess B23, it expands towards its fully expanded position of Figs B2A and B2B, whereby downwardly facing teeth B22 about its outer side engage the outer well casing, as shown in Fig. B3B, in a somewhat less than fully expanded position. The, when the c-slip is raised, the inner surface of the c-ring will slide over wedge surface B22 to urge it outwardly to cause its teeth to bite into the outer well casing, and thus permit the weight of the liner and its associated parts to be hung off on the casing.

[0077] As shown in Figs. B3A and B3B and in detail in Figs. B3AA and B3BB, the inner frusto conical surface of the c-ring slip has blunt teeth CF thereon which, as well known in the slip art, control the frictional engagement with the liner and thus the outward force applied to the casing. Thus, as the teeth take on initial bite into the casing, the blunt teeth on the inner side of the slip will begin to gall the wedge surface of the liner so as to control the extent to which the teeth bite into the casing. The force thus applied to the casing and liner may be controlled by the relationship of the inner and outer teeth to one another. Although the teeth CF are preferred, the inner surface of the c-ring may be smooth.

[0078] With reference to Figs. B4 to B6, one or more tie bars B30 extend downwardly through a slot B40 in the liner for guided reciprocation with respect thereto. The lower end of each tie bar is connected to the upper end of the slip for raising its lower end out of the recess. Thus, as shown in Figs. B4 - B6, the lower end of each tie bar B30 has a flange 50 which is received in a groove B36 about the inner diameter of the c-ring, as the c-ring is initially mounted in the recess.

[0079] As the tie bar is raised to lift the c-ring out of the recess B23, the flange B50 on its lower end moves out of the groove B36 to release the c-ring therefrom, as shown in Fig. B5. At this time, of course, the weight of the liner may be slacked off on to the outer frusto conical surface of the c-ring to force the teeth of the c-ring outwardly into gripping engagement with the outer casing as shown in Fig. B6.

[0080] As an alternative to slip assemblies, as previously described, other apparatus for this purpose - i.e. hanging an inner casing within an outer casing, have locking elements adapted to be expanded into matching locking grooves formed in the outer casing. In some cases, the locking elements are adapted to be spring biased into matching grooves formed In the outer casing. However, these springs are susceptible to breaking or other malfunctions. This is especially true since the hanger often comprises a large number of intricate parts which are expensive to replace, and which require a delay in the overall well operations. In still other cases, the hangers having only a single latching part for fitting within a single groove, thus limiting its load carrying capacity. Another object of this invention is to provide a casing hanger system which overcomes these and other problems inherent In prior hangers for such systems.

[0081] These and other objects are accomplished, in accordance with the illustrated embodiment of this invention, by a liner hanger system comprising a joint of casing adapted to be connected as part of an outer casing installed within a wellborn, and a liner adapted to be lowered and landed within the outer casing. The bore of the casing joint has a polished bore and vertically spaced, upwardly facing landing surfaces formed therein, and the liner includes a tubular body having a recess formed about its body, and a hanger element comprising a circumferentially expandible and contractible C-ring disposed within the recess. The ring has teeth on its outer diameter for landing on the landing surfaces of the casing joint when in its expanded portion, and upon relative vertical movement with respect to the liner, is expanded outwardly against the polished bore. Upon continued relative movement of the liner and ring, the teeth will move into a position in which they expand further outwardly into landed positions on the landing surfaces to permit the liner to be suspended therefrom.

<u>Liner Hanger</u>

[0082] With reference now to Figure C1, ths joint C10 of the outer casing section is threaded at its upper and lower ends to permit it to be connected as part of the outer casing installed in the well bore, as in the liner hanger systems referred to above. The polished bore of the casing section has an annular recess C11 in its lower portion, and a series of vertically spaced, upwardly facing landing shoulders C12 above the recess C11 and separated therefrom by annular restriction C14. There is another annular recess C15 formed in the bore above and separated from the landing surfaces C12 by means of an upper restriction C16 above an annular recess C13. The restrictions and landing shoulder are of essentially the same diameter of the polished bore above them.

[0083] Hanger C17 is shown in Figure C2 to be carried within a recessed portion 18 about the liner L. The hanger C17 is a C ring split about its circumference in position to be urged circumferentially outwardly to engage the inner diameter of the casing when expanded, but held in its contracted position, as shown, as the liner is run into the outer casing. In this position, its lower end C20 is adapted to be received within a groove C19 in the upper end of an enlarged outer diameter portion C21 of the liner.

[0084] The upper end of the hanger has teeth C22 formed thereabout in vertically spaced relation corresponding to the landing surfaces C12 of the casing and fitting within recess C18 about the liner. The toothed section and lower end of the ring are connected by an outwardly enlarged cylindrical portion C35 whose inner surface engages the outer surface of enlargement C25 about the liner.

[0085] As will be described and shown in Fig. C3, the hanger is adapted to be raised relative to the liner to release it for expansion outwardly into engagement with the polished bore of the outer causing. Thus, liner hanger system includes a suitable mechanism to raise the hanger out of its retained position, to free its lower end from groove C19. This may be accomplished by raising the hanger by means of tie bars C30 connected at their upper ends to a cone C cover which a packing element is adapted to be lowered to set it against the outer casing. The tie bars extend through vertical slots in the recessed portion of the liner, and have an outer flange C31 releasably connected in a groove C32 about a lower extension of the cone C.

[0086] Thus, it will be seen, from a comparison of Figure C2 and Figure C3, that raising of the packer cone will raise the lower end of the hanger free from the retaining groove C19, and thus permit the hanger to expand outwardly to the position of Figure C3. This then permits rib C61 on the lower end of the tie bar to disengage from groove 62 in the lower end of the hanger and release the tie bars from the hanger as it moves into its upper relative position with respect to the liner This relative vertical movement between the liner and packer element cone has resulted from shearing of pin C33 releasably connecting them in the position of Figure C2. This of course can be accomplished by raising of the packer cone relative to the liner, prior to lowering of the hanger into a position opposite the grooves forming landing surfaces in the bore of the outer casing.

[0087] Upon lowering of the hanger with the liner from the Figure C2 to the Figure C3 position, the lower radially enlarged section C35 of the hanger, which extends over the outer enlargement 25 of the liner, is free to move outwardly into the recess C11 in the outer causing. Thus, when lowered to a position opposite the landing surfaces C12 within the outer casing, the teeth C22 about the upper end of the hanger move outwardly onto the landing surfaces, thus forming multiple shoulders on which to support the load of the liner within the outer casing. This outward expansion of the hanger element has occurred after it has been lowered beneath the enlargement in the bore of the outer casing as the liner is lowered from its Fig. C3 to its Fig. C4 position.

[0088] When the hanger has sprung outwardly to the position of Figure C4, continued lowering of the linger will move the enlargement C25 thereabout into the lower end of the hanger on which the teeth are formed, thus maintaining it in its outer hanging position, as shown in Fig. C4. A downwardly facing shoulder C51 is formed on the outer diameter of the liner above the outward enlargement C50 so as to land on the upper end of the hanger, as shown in Figure C4. The outward enlargement is moved into the inner diameter of the hanger, as shown in Figure C4, by virtue of a tapered shoulder C50B formed on its upper end slidable over an inwardly and downwardly tapered shoulder C50A surface on the liner.

[0089] As the hanger moves into landed position, enlargement C35 thereabout beneath its teeth fits closely within the recess C16 in the outer casing bore so as to limit outward expansion of the hanger element once it is moved into hanging position.

[0090] An inwardly enlarged portion C60 on the lower end of the hanger, beneath its outwardly enlarged portion C35 moves over the outer diameter of the lower end of the liner, thereby cooperating with the enlargement C50 to maintain the hanger element in its outer hanging position.

Running Tool

[0091] Referring back again to the running procedure, the annular packer element 150 (see Figure 1F) is disposed about a downwardly-enlarged upper cone 152 beneath the pusher sleeve 148. The packer element 150 is originally of a circumference in which its O.D. is reduced and thus spaced from the casing C. However, the packer element 150 is expandable so that it may be moved downwardly over the cone 152 to seal against the casing.

[0092] The packer element 150 is adapted to be set by means which includes spring-pressed lugs 328 which, when moved upwardly out of the tie back receptacle 130, will be forced to an expanded position, as shown in Figure 6A, to engage the top of the tie back receptacle. When weight is set down, the expanded lugs 328 transmit this downward force through to the pusher sleeve 148 and the packer element 150. A body lock ring 270 (see Figure 1F) is disposed between the tie back connector 130 and the pusher sleeve 148 and permits the packer element 150 to be forced downwardly over the upper cone 154 by lowering of the tie back connector. Upward movement of the set packer element is prevented.

[0093] The packer element 150 may be of a construction as described in U.S. Patent No. 4,757,860, comprising an inner metal body for sliding over the cone and annular flanges or ribs which extend outwardly from the body to engage the casing. Rings of resilient seating material may be mounted between such ribs. The seal bodies may be formed of a material having substantial elasticity to span the annulus between the liner hanger and the casing C.

Radial Set Packer

[0094] The present invention also relates to an improved radial set packer for sealing with a casing or other downhole cylindrical surface which is configured with a primary seal and a backup seal, and may be part of a downhole tool including a conveyance tubular and a conical wedge ring, and thus may be used for reliable sealing engagement between a liner hanger and a casing string.

[0095] Packer elements or packers which are radially set by axial movement of the packer element relative to a conical wedge ring have been used for sealing in subterranean well bores. A conveyance tubular is conventionally provided for positioning the packer element at the desired position within the well bore, and an actuator causes the packer element to move axially with respect to a conical wedge ring and thereby expand into sealing engagement with the cylindrical surface to be sealed.

[0096] U.S. Patents 4,757,860 (previously mentioned) and 5,076,356 disclose radial set packer elements which may be used in various applications, including a subsea wellhead. In a typical wellhead application, the packer element may need to expand in diameter approximately 0.030 inches in order to obtain a reliable seal with the polished bore. U.S. Patents 5,511,620 and 5,333,692 disclose packer elements intended for sealing between a liner hanger and a casing. More specifically, a conical member is moved axially with respect to the packer element to expand the packer element into engagement with a casing. That expansion may be significantly greater than the expansion of a packer element in a wellhead application due to the difference in diameter of the casing from the drift ID (smallest allowable ID for a particular size casing) to the maximum ID allowed by API for that size casing. The difference between this drift ID and the maximum ID for a particular size casing may thus be 0.300 inches or greater.

[0097] Several problems exist with the packer element disclosed in the '620 Patent. Because the seal element is stationary with respect to a movable conical element, the radially extending flanges or ribs of the seal element may not expand as desired Into portions of the non-uniform diameter casing string to obtain reliable metal-to-metal sealing engagement. Also, the packer element does not always form a reliable metal-to-metal seal with the conical wedge ring, and the conical wedge ring similarly does not form a reliable metal-to-metal seal with the tool mandrel. Also, the elastomeric sealing portions of the seal element are not allowed to thermally expand in response to high temperature downhole conditions, and thus exert uncontrollable forces on the spaced apart metal radial flanges or ribs.

[0098] Other problems with prior art packer elements concern poor sealing reliability under high pressure conditions. The metal ribs may not reliably seal with the cylindrical surface, and the elastomeric portion of the seal assembly may not reliably seal over extended time periods. Some packer elements function reasonably well when high pressure is applied to one side of the packer element, but do not perform well when high fluid pressure is applied to the other side of the packer element.

[0099] The disadvantages of the prior art are overcome by the present invention, and an improved packer element and a tool including the improved packer element is hereinafter disclosed for reliably sealing between the packer mandrel and a downhole cylindrical surface.

[0100] The radial set annular packer element according to the present invention is positioned downhole by a conveyance tubular. The packer element may be moved by a setting tool from a reduced diameter run-in position to a set and expanded diameter position, such that the packer element engages a casing, a polished bore receptacle, or other downhole cylindrical surface in a well. If the cylindrical surface is a casing or other member which may be irregularly shaped, the packer element is preferably moved axially relative to a conical wedge ring or cone during the setting operation. The packer element is particularly well suited for reliably sealing against high pressure either from above or below the element, and includes a primary elastomeric seal and a secondary elastomeric seal, and a primary metallic seal and a secondary metallic seal. The metal ribs of the packer element are angled so that the primary elastomeric seal is pressed against a rib angled toward the high pressure, and the secondary elastomeric seal is similarly pressed against a rib angled toward the high pressure. The secondary elastomeric seal body acts on the primary rib to prevent the primary rib from becoming perpendicular with respect to the sealing surface, and thereby enhances the reliability of the seal,

[0101] It is an object of the present invention to provide an improved packer element which may be used in downhole applications for reliably sealing with a cylindrical surface. It is a feature of the present invention that the packer element is particularly well suited for sealing between a liner hanger and a casing under conditions where the casing may grow considerably in response to thermal and/or pressure expansion during downhole operations.

[0102] It is a related object of the invention to provide a downhole tool including a conveyance tubular, a conical wedge ring and an annular seal assembly or packer element according to the present invention.

[0103] It is a feature of the present invention that each of the primary and the backup metallic ribs of the sealing element are angled at least 15° with respect to a plane perpendicular to a central axis of the sealing element.

[0104] Another feature of the invention is that axially spaced metal protrusion provide a reliable metal-to-metal seal between the packer element and the cone, and also preferably between the cone and the mandrel or body interior of the cone.

[0105] Still another feature of the invention is that the elastomeric seal bodies of the packer element include specifically designed volumetric voids so that, after the seal bodies engage the surface, the elastomeric seal bodies will be compressed until the ends of the ribs engage the sealing surface. At this stage, the now smaller voids in the seal bodies allow for thermal expansion of each seal body between the metal ribs to minimize undesirable stress force on the ribs.

<u>Seal Element</u>

[0106] Figure D1 depicts an annular packer element D10 according to the present invention positioned at the lower end of a pusher sleeve D12 at the lower end of a tie back receptacle prior to sealing engagement with a casing C. Conventional grooves or threads D28 or similar connectors may be used to interconnect the packer element to the tie back receptacle. Axial movement of the packer sleeve D12 and thus the packer element D10 in response to the packer setting operation pushes the packer element downward relative to the tapered cone D14 to expand the seal element into sealing engagement with the casing. The cone D14 is in turn supported on a liner hanger body D16. In an environment where the packer element is not the top liner hanger seal, the packer element D10 may be supported on the end of a seal actuator which replaces the pusher sleeve D12, and the liner hanger body D16 may be a packer mandrel or other conveyance tubular for positioning the packer element in the well. In the Figure D1 embodiment, the body D16 is thus part of the conveyance tubular which positions the packer element at a selected position within the well bore. The pusher sleeve of the tie back receptacle shown in Figure D1 represents a lower portion of an actuator sleeve which urges the packer element from a reduced diameter run-in position to an expanded diameter activated or sealed position. The actuator sleeve may thus apply a selected axial force to the packer element to set the packer. The actuator may be selectively activated by various mechanisms, including set down weight or other manipulation of the conveyance tubular, and may include axial movement of a piston in response to fluid pressure, either with or without dropping plugs or balls to increase fluid pressure. Further details with respect to the use of the packer element in a liner hanger application are disclosed in U.S. Provisional Application Serial No. 60/292,049 filed 18 May 2001.

[0107] The packer element as shown in Figure D1 is in its original configuration in which the OD is reduced prior to being sealed with the casing. Packer element D10 is expandable so that it is moved downwardly over the stationary cone D14 to seal against the casing, as discussed below and as shown in Figure D3. It is a feature of the invention that the packer element D10 be moved into reliable sealing engagement with the casing by a setting operation which includes moving the packer element D10 axially with respect to the packer cone D14, rather than moving the cone with respect to the stationary packer element. This setting operation forms a more reliable seal with the casing by allowing the ribs D20, during the setting operation, to flex or deform into the shape of the casing.

[0108] Referring to Figures D1 and D2, the packer element D10 comprises an inner metal body or base D18 for sliding over the conical wedge ring or cone D14 and annular flanges or ribs D20 which extend radially outwardly from the base D18 to engage the casing. The base D18 is relatively thin to facilitate radial expansion. The base D18 and the ribs D20 form a metal framework to support the rubber or other resilient and preferably elastomeric seal bodies. Rings of resilient seal bodies D22, D24 and D26 are provided between the ribs D20, and preferably the upper and lower sides of each seal body are in engagement with a respective rib. The body D18 and the ribs D20 are formed from material having sufficient ductility to expand into the annulus between the casing and the liner hanger. The metal portion of the packer element, namely the base D18 and the radially projecting ribs D20, is thus formed from material which is relatively soft compared to metals commonly associated with downhole tools. This allows the packer element to reliably expand into sealing engagement with the casing at a reduced setting load.

[0109] The radially projecting ribs D20 of the packer element are each substantially angled with respect to a plane perpendicular to a central axis of the packer element. More specifically, the centerline of each rib is angled in excess of 15°, and preferably about 30°, relative to the plane D38 perpendicular to the central axis of the packer element. Although the ribs may be slightly tapered to become thinner moving radially outward, the ribs preferably have a substantially uniform axial thickness. Rib D32 is shown in Figure D2 at an angle D33 between the rib centerline and the plane D38. This feature allows each of the ribs D20 to expand substantially as the diameter of the casing varies or "grows", whether in response to internal pressure and/or thermal expansion. Because of the ability of the angled ribs D20 to flex, reliable metal-to-metal contact is maintained between the ends of the ribs and the casing, as shown in Figure D3.

[0110] A particular feature of the invention is that the packer element D10 inherently forms both a primary seal with the casing and a secondary seal with the casing, with the secondary seal depending upon the direction of pressure. Also, the packer element may include both a primary and a backup elastomeric seal, and a primary and a backup metallic seal. Referring to Figure D3, it should be understood that the downward inclination of the ribs D30 and D32 is such that relatively high fluid pressure above the packer element may pass by these ribs and the annular elastomeric upper seal body D22, so that the interior seal body D24, which constitutes a majority of the elastomeric seal area, forms the primary elastomeric seal against fluid flow. The term "fluids" as used herein includes gas, liquids and combinations of gas and liquid. Seal body D24 preferably engages the ribs D32, D34 and the base D18, and substantially fills the annular void between these surfaces. When fluid pressure is above the seal element D10, the lower seal body D26 positioned between ribs D34 and D36 forms a backup secondary elastomeric seal in the event the primary elastomeric seal were to leak. Similarly, when high fluid pressure is below the packer element, high pressure fluid would likely flow past the ribs D36 and D34, so that seal body D24 is the primary seal element. Seal body D22 between the ribs D30 and D32 thus becomes the secondary elastomeric seal element. The primary elastomeric seal element is thus pressed in an axial direction (generally along the ventral axis of either the conveyance tubular body or the casing) in response to pressurized fluid, against an inclined rib which is angled toward the high pressure, and the secondary elastomeric seal element is captured between two ribs each angled toward the high pressure side, so that the secondary seal element is also pressed in an axial direction against a rib angled in the direction of the high pressure. Most importantly, the backup seal, whether that be seal body D22 or D26, is captured between two ribs and thus minimizes the likelihood that the axially innermost rib D32 or D34 will flex outward to come in line with the plane D38, i.e., perpendicular to the wall of the casing. The material of the seal body D22 or D26 thus acts as a biasing force which tends to retain the rib D32 or D34 at a desired angle, which then supports the primary seal body D24 and prevents the rib D32 or D34 from becoming perpendicular to the wall of the casing C. Should the ribs flex past the point of being perpendicular to the casing wall, the packing element likely will lose its sealing integrity with the casing. The radial ribs D20 are thus vertically spaced from one another and act independently with respect to upward and downward directed pressure forces.

[0111] Packer element D10 also includes multiple metal sealing surfaces, namely the ends of each of the ribs D20, to form annular metal-to-metal seals with the casing. More particularly, these angled ribs are configured to keep a constant metal-to-metal seal with the casing even though the packing element may be subjected to variable fluid pressure and temperature cycles. Under high pressure, the two ribs adjacent the high pressure may flex toward the base D18 and thus not maintain sealing integrity. A primary metal seal is nevertheless formed by one of the axially innermost ribs D32 or D34 on the downstream side of elastomeric packer body D24, and a backup metal-to-metal seal is formed by the axially outermost rib D30 or D36 spaced axially farthest from the high pressure. High fluid pressure forces both the primary and secondary backup ribs to reduce the angle D33, thereby forming a tighter sealed engagement with the casing. The redundant or backup elastomeric seal D22 or D26 exerts a biasing force which tends to prevent the primary metal seal D32 or 034 from moving past the position where it is perpendicular to the wall of the casing.

[0112] Referring again to Figure D2, each of the elastomeric seal bodies D22 or D24 and D26 is provided with a substantial void area D23, D25 and/or D27 to allow for compression of the elastomeric body and for thermal expansion so that, during both the final setting operation and during use downhole, the rubber-like material is not squeezed outwardly past the ends of the ribs, or squeezed to exert substantial forces on the ribs which will after the flexing of the ribs. Preferably the void area between the ends of the ribs and the base of the sealing element is such that at least about 5% to 10% thermal expansion of elastomeric material may occur. This 5% to 10% void area thus allow for thermal expansion of each elastomeric resilient seal, thereby avoiding the creation of additional forces to act on the ribs D20. Each of the elastomeric seal bodies thus preferably includes voids that allow each resilient seal body to compress between the metal ribs without over-stressing or buckling the ribs. These voids will thus be substantially filled due to compression of the resilient sealing material, and will become substantially filled, as shown in Figure 3, due to compression of the seal bodies and thermal expansion of the resilient seal bodies. The stress level on each of the elastomeric seals may therefore remain substantially constant with varying thermal cycles in the well bore.

[0113] As shown in Figure D3, the elastomeric seal bodies have been compressed to reduce the void area, leaving only a small void volume for additional thermal expansion. The void area is preferably designed to be from 5 to 10% of the volume of the resilient seal bodies once each seal body is in its compressed position with the ends of the ribs engaging the casing, but prior to thermal expansion.

[0114] Figure D3 depicts the packer element D10 according to the present invention in sealed engagement with the casing C, and at a temperature wherein the elastomeric material has already expanded to fill most of the void area discussed above. Figure D3 also shows the flexing or bending of these ribs from the run in position as shown in dashed lines to the sealing position as shown in the solid lines. The inclination of the ribs, i.e., angle D33 as shown in Figure D2, is thus increased during the packer setting operation. The ribs D30 and D32 at the upper end of the packer element D10 are angled downwardly, and the ribs D34 and D36 at the lower end of the packer element are angled upwardly. As explained above, the centerline of each rib is angled at least 15° with respect to the plane D38 perpendicular to the central axis of element 10 prior to setting, i.e. when of a reduced diameter as shown in Figure D1.

[0115] The base D18 of the packer seal includes a plurality of inwardly projecting protrusions D40. These annular protrusions or beads on the packer element provide a reliable metal-to-metal sealing engagement with the packer cone D14. These protrusions provide high stress points to form a reliable metal-to-metal seal. Similar protrusions D42 on the packer mandrel D16 provide metal-to-metal sealing engagement between the packer mandrel D16 and the packer cone D14. Accordingly, the seal of the present invention operates in conjunction with the packer cone to obtain a complete metal-to-metal seal between the packer mandrel and the packer cone, between the packer cone and the seal element, and between the seal element and the casing. The multiple seal protrusions or beads D40 form axially spaced metal-to-metal seals between the base D18 of the sealing element D10 and the tapered cone D14, while protrusions D42 seal between the cone D14 and the packer body or other conveyance tubular D16. These metal-to-metal seals are energized as the packer seal is set, and preferably include multiple redundant annular metal-to-metal seals. Alternately, one or both of the radially inner and intermediate metal-to-metal seals could be formed by annular protrusions on the packer cone for sealing with either or both the packer element base D18 and the packer mandrel D16.

[0116] The resilient elastomeric seals D48 on the ID of the seal bore D18 may be backup seals, since the spaced apart metal protrusions D40 form the metal-to-metal seal between the packing element and the cone once the packer element is fully set. Another elastomeric seal, such as a V packing D15, provides an elastomeric backup seal between the cone D14 and the body D16. These metal protrusions D40 on the ID of the element D10 are axially in line with (laterally substantially opposite) the area where the ribs D20 seal against the casing. The interface between the casing and the metal ribs D20 of the packing element D10 thus force the metal seal protrusions D40 into tight metal-to-metal sealing contact with the cone D14. The protrusions D42 on the body D16 are similarly axially in line with the element D10. The metal-to-metal seals between the packer element and the cone are preferably provided on the packer element, since its axial position relative to the cone when in the set position may vary with the well conditions.

[0117] With the desired setting force applied to the packer element D10, the packer element will be pushed down the ramp of a cone D14 so that the ribs D20 come into metal-to-metal engagement with the casing. Metal seal protrusions D40 and D42 between the packing element D10 and the cone D14 and between the body D16 and the cone D14 are in contact, but have not been energized. When the setting pressure is increased, the ribs on the packing element may be flexed inward to a position in solid lines in Figure D3. This high setting force will compress the seal bodies between the ribs and cause the outer diameter of each seal body into tight sealing engagement with the casing. This high setting force will also cause the metal protrusions D40 along the ID of the seal element D10 and the metal protrusions D42 along the OD of the mandrel D16 to form a reliable metal-to-metal seal with the cone D14. Under this load, these metal protrusions form high localized stress at the point the protrusions engage the cone to achieve a reliable metal-to-metal seal. The metal protrusions which provide the desired metal-to-metal seals between the body or mandrel D16 and the cone D14 could be provided on either the outer generally cylindrical surface of body D16 or the inner generally cylindrical surface of cone D14. A reliable fluid pressure tight barrier, which may be both a liquid barrier and a gas barrier, is thus formed with high reliability under various temperatures, pressures and seating longevity conditions, due to the combination of the elastomeric and metal seals. After the seating element comes into contact with the casing, the BOP presenter rams may be closed around the drill pipe (or other conveyance tubular) and fluid pressure may be applied to the annulus to pressure assist the setting of the packer element.

[0118] The sealing element of the present invention is well suited for use in a liner hanger for sealing between the packer mandrel of the liner hanger and the casing. The initial set down weight on the seal element D10 will thus force the seal element down the cone D14 and into contact with the casing C. Initially, the seal material which is radially outward of the ends of the ribs D20 will be compressed to occupy much of the void area in the seal bodies. Once the elastomeric bodies have been deformed so that the ends of the ribs engage the casing, the retaining void area may be from 5% to 10% of the volume of each seal body, assuming there has been no significant expansion of the seal bodies due to thermal expansion. If the seal bodies experience high thermal expansion prior to a setting operation, the void area will be reduced by compression of the seal bodies.

[0119] During well operations, the pressure may cause the casing to expand in diameter and, this expansion will cause the ribs to expand with the casing, so that the position of the ribs with respect to the expanded casing may return to the configuration as shown in dashed lines in Figure D3. The ability of the ribs to "grow" in diameter with the expanding casing keeps the ends of the ribs in reliable metal-to-metal contact with the casing as the well goes through pressure and temperature cycles. When pressure is released and the casing shrinks, the ribs may return to the solid line configuration as shown in Figure 3.

[0120] The seal element D10 of the present invention is thus ideally suited for applications in which high pressure may be applied from either direction to the seal element, since the seal element inherently provides both a primary seal and a secondary seal, with each elastomeric seal being supported in a direction to resist axial movement in response to the high pressure by a rib which is angled in the direction of the high pressure, and which allows fluxing to conform to the casing. The rib on each side of the primary seal body is supported by the secondary seal body, which biases the rib toward the high pressure.

[0121] In the case of a liner hanger, the liner hanger running tool conventionally includes the actuator which provides the compressive force to the packer element D10 to set the packer. In other applications where the seal element is used, an actuator may be used for applying the compressive force to move the seal from a run in or radially reduced position to a sealing or radially expanded position. The actuator may be hydraulically powered or may use mechanical setting operations. Thereafter, a retainer keeps the seal element in sealing contact with the casing, after the running tool is returned to the surface, by preventing or limiting axial movement of the packer element when fluid pressure is applied.

[0122] The sealing element of the present invention may be used in various applications in a well bore having a tubular disposed therein, wherein a packer mandrel or other conveyance tubular is positioned within the well bore to position the packer element at a selected location. The packer element is disposed about the conveyance tubular and includes a plurality of elastomeric seal bodies for sealing engagement with the well bore tubular, and a plurality of metal ribs which separate the elastomeric seal bodies, with the rib ends intended for metal-to-metal sealing engagement with the tubular. The packer element may be run into the well in a configuration similar to that shown in Figure D1 in which the sealing element has a reduced diameter, and the packer element deformed radially outward into sealing engagement with the well bore tubular as it moves relative to a conical wedge ring, until the packer element reaches the final set position, as shown in Figure D3. The radial set sealing element of the present invention may thus be used for various types of downhole tools. Additional back-up secondary metal ribs could be provided, as well as additional back-up elastomeric bodies engaging these additional ribs.

[0123] Various types of conveyance tubulars may be used for positioning the packer element at a selected location below the surface of the well. The substantially conical wedge ring or cone may have various constructions with a generally outer conical surface configured to radially expand the annular seal assembly or packer upon axial movement of the packer element relative to the wedge ring, due either to axial movement of the packer element relative to the stationary wedge ring or axial movement of the wedge ring relative to the stationary packer element. In a preferred embodiment, the seal assembly includes an upper elastomeric seal body, a primary elastomeric seal body, and a lower elastomeric seal body. While each of the upper and lower seal bodies ideally provide the backup elastomeric seal in the event the primary elastomeric seal were to leak, it is an important function of the upper seal body D22 and the lower seal body D26 to provide a desired biasing force against the respective rib D32 or D34, These elastomeric seal bodies thus function as biasing members between the axially outermost rib and the adjacent inner rib to exert a force which prevents the inner rib from flexing beyond a predetermined stage. For example, the lower seal body D26 engages both the inner rib D34 and the outer rib D36, and exerts an upward biasing force to prevent rib D34 from moving downward past a position where it is perpendicular to the wall of the casing. At the same time, the lower seal body D26 exerts a downward biasing force which tends to increase the downward flexing to the outer rib D36 when the inner rib D34 flexes downward in response to high pressure above the packer element.

[0124] In addition to the primary metal-to-metal seal, the secondary metal-to-metal seal, the primary elastomeric seal and the secondary elastomeric seal, additional sets of metal-to-metal and elastomeric seals could be provided in the packer element. Elastomeric bodies which are configured other than shown herein may thus be used for this purpose. Various types of plastic materials in various configurations may provide the desired biasing force, and ideally also a secondary resilient seal. Alternatively, a wave spring or other metallic material biasing member may be used instead of or in cooperation with the elastomeric bodies D22 and D26.

[0125] Preferably each of the metal ribs of the packer element as disclosed herein are annular members with the outermost surface of each rib, when in the run-in position, being substantial the same radial spacing from a central axis of the tool for reliable seating engagement with the surface to be sealed. In other embodiments, one or more of the ribs could include radial notches so that the rib would not form a complete annular metal-to-metal seal, which then could be provided by the elastomeric seal, although then the complete angular metal seal would not be obtained. Preferably a plurality of axially spaced protrusions are provided for metal-to-metal sealing engagement between the packer element and the cone, and between the cone and the conveyance tubular. In other applications, a single annular protrusion may be sufficient to form the desired metal-to-metal sealing function.

Ball Seats

[0126] Continuing further with a description of the overall system, the lower ball seat 246 (see Figure 1D) is mounted within the running tool bore by shear pins 248 opposite the pressure chamber 256. Sleeve 245 thus supports seat 246. The lower end of the ball seat has reduced thinner section or neck 258. Furthermore, one or more ports 260 formed in the running tool are positioned to be uncovered to permit fluid pressure in the running tool to be admitted to the pressure chamber 256 upon lowering of the seat 246. The ball 240 when released from the upper seat 232 will land onto the second seat 246, whereby pressure within the running tool above the ball will move the seat 246 downward upon shearing the pins 248 to open the ports 260 leading to the pressure chamber 256.

[0127] The ball 240 may thus pass through the first seat 232 for seating on the reduced diameter 258 of the second seat 246 so that additional pressure may be supplied through the ports 260 for raising the outer piston sleeve 252. This in turn permits split ring 264 having outer teeth gripping the liner hanger 110 to move into position opposite a reduced diameter lower end 268 of the sleeve 252 and thus out of gripping engagement with the liner hanger, whereby the running tool is released from the liner hanger.

[0128] At this stage, the operator will pressure up to pass the ball through seat 246, so that the drop in pressure will indicate that the ball 240 has passed through the ball seat 246, allowing circulation through the running string to continue, and the ball to be pumped downwardly into the ball diverter 280 (see Figure 1I). Fluids are then circulated through the tool awaiting cement displacement. The cement is then injected into the running tool and pumped downwardly, and the pump down plug 182 follows the cement and into the liner wiper plug 180 (see Figures 1J, 5A and 5B). This then forms a barrier to the previously displaced cement and the displacement fluid.

[0129] The lower end of the running tool mandrel 132 extends downwardly below the slip assembly and has an enlarged body 145 (see Figure 11) adapted to reciprocate within the liner 146. This enlarged body 145 has an upwardly facing shoulder 147 which may be raised into engagement with a downwardly facing shoulder to permit the running tool to be raised out of the set liner hanger, as will be described.

[0130] As previously described generally in connection with Figs. 1, 4A and 4B, to improvements in apparatus of this type in which the cementing operation requires the sequential lowering of balls and pump down plugs within the inner pipe, wherein in a preferred and illustrated embodiment, the inner pipe is a liner having an upper end installed within an outer casing by a column of cement pumped out the lower end of the liner into the annulus between it and the outer casing.

[0131] As above described, in a system of this type, a ball is dropped onto a seat in the bore of the liner to permit circulating fluid to be directed into a portion thereof for hydraulically actuating a part in the system external to the liner bore, and an opening on which the ball is seated may be circumferentially yieldable, upon application of higher circulating pressure, to cause the ball to pass therethrough and out the lower end of the linear. The ball may then be followed by a pump down plug to force the cement downwardly through the lower end of the liner and into the annulus between it and the outer casing.

[0132] In the system shown and described in the aforementioned provisional application, the ball is relatively large, and, in any case larger than the bore of the liner wiper plugs (LWP) into which the pump down plugs (PDP) are to be installed, Unless, the bore through the wiper plug is as small as possible, the inner diameter of the liner to be cemented in the outer hanger is necessarily enlarged to accommodate the wiper plugs which are carried about it. Consequently, it is the object of this invention to provide apparatus for such a system in which the balls may be substantially larger than the pump down plugs, and thus larger than the bore through the wiper plugs in which the pump down plugs are to be landed.

[0133] This and other objects are accomplished, by apparatus which includes the previously described diverter 280 comprising a tabular member such as a sub having an upper end connected to a well pipe for lowering into a casing in the well to permit it to be cemented therein, and having a bore with a relatively large diameter upper portion and a relatively smaller diameter lower portion. The larger portion enables one or more balls to be lowered therethrough, but the LWP in the smaller diameter portion prevents passage of the balls while permitting passage of the pump down plugs into the liner wiper plug.

[0134] For this purpose, a sub Installed beneath the larger portion has a pocket to one side of its bore into which the ball, or at least a portion of it, diverted to thereby permit the pump down plug to pass between the ball and the side of the sub opposite the pocket, whereby the pump down plug may continue downwardly to enter the liner wiper plug. The sub also includes a ramp extending across the bore of the sub and slanting downwardly toward the pocket so that, when the ball is dropped, it will land on the ramp and thus be guided into the slot. More particularly, the ramp has a U-shaped slot which is too narrow to pass a ball but is wide enough to pass a plug down between its closed end and the inner side of the diverted ball,

<u>Ball Diverter</u>

[0135] With reference now to the details of the above described drawings, each of Figs. E1, E2 and E4 shows, in vertical cross section, a tubular member E10 suspended within a liner L installed within an outer casing C within a wellbore, its purpose being to circulate cement downwardly through the lower portion of the tubular member and into the annulus between the liner and the casing to cement the liner within the casing. As also shown in Figs E4 and E5, a liner wiper plug LWP is suspended from the tubular member with a pump down plug is installed therein.

[0136] The ball diverter BD comprises a sub which is installed between the upper and lower portions of the tubular member, and has a pocket P formed in side of the sub to receive a portion of a ball B adapted to pass downwardly through the tubular member. A ramp R mounted on the sub has an upper face which is slanted downwardly from its upper end to its lower end to terminate opposite the pocket P. A slot S in the ramp is narrower than the ball, so that when the ball is dropped through the running tool and into the upper end of the tubular member of the cementing tool, it will be guided into the pocket.

[0137] As shown in Fig. A3, the opening between the inner end of the slot permits the lips of the pump down plug to flex inwardly so that the pump down plug is free to continue downwardly to a seated position in the liner wiper plug LWP, as shown in Fig. A4. That is, following dropping of the ball into the pocket, the pump down plug will, under the influence of downwardly directed circulating fluid, pass between the ball and closed end of the slot in the ramp. The pump down plug continues to be lowered until it lands in the liner wiper plug, as shown in Fig. A4, thus closing the lower end of the bore through the tubular member, all in a matter well known in the art.

[0138] Increased pressure of the circulating fluid shears the pin P holding the liner wiper plug in place to permit liner wiper plug to be moved downwardly in the liner, as shown in Fig. A5. Thus, the released plug assembly will continue to force the cement downwardly through the liner and then upwardly within the annulus between the liner and into the outer casing, whereby the liner may be cemented within the casing, all in the manner wall known in the art.

<u>Running Tool</u>

[0139] Again, continuing with the overall rights, Figure 2-8 illustrate movement of components of the tool 120 in the process of setting the liner. Once the liner is lowered to the desired depth, fluids are circulated through the well bore "bottoms up". After conditioning the well bore, the ball 240 is dropped from handling equipment at the surface and allowed either to free fall or be pumped at a desired rate onto the upper seat 232. Upon application of pressure to the seated ball, pins 222 between the seat and the liner hanger setting assembly are sheared to permit the ball and seat to move downwardly to a position uncovering ports 242 in the body of the slip setting assembly 140. The further application of fluid pressure will cause the surrounding piston sleeve 220 to travel upwardly. As a result, the tie back receptacle 130, the actuator slip slat 149 and slips 142 are pulled upward until the circumferentially spaced slips engage with the casing C. Thus, as shown in Figure 2A, the piston sleeve 220 of the slip setting assembly 140 surrounding the running tool mandrel 132 has been moved upwardly by the increase in pressure above the ball 240. The piston sleeve 220 is moved upwardly until the upper end 312 of the piston sleeve 220 engages and releases the split lock ring 244. This enables the tie back receptacle 130 to continue to be moved upwardly.

[0140] On the other hand, raising of the tie back receptacle 130 raises the cone 144A, slip arm 149 and slip 142A to the set position, as shown in Figure 2B. At this time, the load on the liner can be slacked off onto the slips, whereby the weight of the liner is "hung" in the casing. While holding pressure constant in the drill pipe to keep the slips in contact with the casing, the liner hanger thus may be slacked off onto the slips. To be certain that the entire liner load is slacked off onto the liner hanger assembly 110, additional pipe weight may be applied to check for hanger movement. Once it is determined that the slips have been hung, the fluid pressure can be reapplied to the seated ball 240 to a higher predetermined level, so that the ball may be pumped to the lower seat 246 in the liner hanger releasing assembly 250. With the ball so seated, a predetermined pressure may be applied to move the ball seat 246 and sleeve 245 downward to uncover the ports 260 in the liner hanger releasing assembly. Higher fluid pressure may then be applied to cause the piston sleeve 252 to move upwardly, thereby allowing the liner hanger releasing ring 264 to collapse within the reduced diameter lower end 268 of the sleeve 252, thereby disengaging the running tool from the liner hanger. If the hydraulic release is not operable to move the ring 264 to disengage the running tool, the operator may resort to a mechanical release mode. The function of the ball in releasing the running tool from the set liner hanger is discussed below.

[0141] The further increase in pressure on the ball 240 and the lower seat 246 will release the ball from the lower seat so that circulation through the running staring may continue while the ball 240 is pumped downwardly into the ball diverter 280. Fluids may then be circulated through the tool awaiting cement displacement. The cement and the displacement fluid are then injected into the running tool and pumped downwardly. When the cement has been pumped, the pump down plug which seals with the drill pipe is released from the surface handling equipment to land on a seat in the liner wiper plug, thereby forming a barrier between the previously displaced cement and the displacement fluid. A calculated amount of displacement fluid is required to pump to the drill pipe plug down to the lower liner wiper plug. The operator observes the pressure increase when the pump down plug 182 latches into the liner wiper plug 180. The pump-down plug 182 (see Figure 5A) thus follows the cement into the liner wiper plug 180. As the pump-down plug gets close to the running tool, the pump rate may be lowered so as to reduce the risk of malfunction between the latching and sealing of the lower wiper plug and the pump-down plug. This allows observation of the pump pressure increase when the pump-down plug 182 has landed in the lower wiper plug 180, as shown in Figure 5A.

[0142] It takes a calculated amount of displacement fluid to force the cement to the desired height in the annulus between the liner and casing. The drill string may be pressured to the predetermined level to shear the pins 186 (see Figure 5A) connecting the plug set to the running tool. With the liner wiper plug released as shown in Figure 5B, displacement fluids move the plug set down the liner 146 to the landing collar 370. The plug set thus forms a barrier between the cement and the displacement fluid, and keeps the displacement fluid from contaminating the cement fluids. A calculated amount of displacement fluid may be used to force the cement to desired height in the annulus between the liner and the casing.

[0143] The operator continues to pump displacement fluid until the liner wiper and pump down plug set latches into the landing collar 370 (see Figure 5C) located in a lower portion of the casing. When so landed, seals 372 about the plug set seal within the upper reduced bore of the landing collar 370, and slips 374 with toothed surfaces engage the opening in the landing collar to prevent upward movement of the landed plug by any downhole pressure. At this time, pressure in the running tool may be increased to a substantial level above circulating pressure to be sure that the wiper plug is properly landed and held down, and that the seals between the plug set and the landing collar are effected. The plug may then be tested by bleed-off pressure to insure that the flotation equipment below the landing collar 370 is holding.

<u>Plug Holder Sub</u>

[0144] As above mentioned, conventional liner hanger running tools include a plug holder sub adapted to support a liner wiper plug on the running tool during a cementing operation. The plug holder sub is conventionally latched to the running string, and the liner wiper plug is attached to the plug holder sub by a shear connection. Unfortunately, these shear connections frequently are prematurely weakened or are sheared either by running tool manipulation or by the momentum of the pump down plug landing and seating on the liner wiper plug.

[0145] Some manufacturers have included a plug holder sub that has a latching lug and a shifting sleeve. The plug cannot be released until the pump down plug shifts the sleeve to allow the latching lugs to relax and thereby allows the plug set to separate from the running tool. U.S. Patents 4,624,312 and 4,934,452 disclose plug holder subs which use a collet instead of a latching lug. U.S. Patent 5,036,922 discloses a running tool which employs a piston that is shifted in order for the plug set to be released.

[0146] While the above systems may prevent premature release of the plug set due to running tool movement or manipulation, they do not prevent premature release of the plug set due to the momentum of the pump down plug and the column of fluid behind that plug when it lands and seats on the liner wiper plug. In many applications, this lading or "hammering" force will cause the plug set to release so fast that the operator cannot detect the release and therefore cannot properly calculate the fluid displacements. This "hammering" effect of the pump down plug hitting the liner wiper plug and the effect of prematurely releasing the plug set may ruin a cementing job. The prior art has not addressed the problem of prematurely releasing the plug set due to this hammering effect of the pump down plug hitting the liner wiper plug.

As a consequence, the operator may not be able to calculate the fluid displacement after the pump down plug has sealed and latched into the liner wiper plug.

[0147] The disadvantages of the prior art are overcome by the present invention, and an improved downhole plug holder and method for supporting a liner wiper plug are hereinafter disclosed which increase the reliability of cementing operations.

[0148] The plug holder sub of the present invention may be used for positioning a wiper plug which may be released from a liner hanger running tool or the end of a tubular string during a cementing operation. The plug holder sub may be releasably positioned on the lower end of the liner hanger running tool, and is sized to pass a pump down plug, which lands in the liner wiper plug supported on the running tool by the plug holder sub. The liner wiper plug is connected to the plug holder sub in a manner which prevents premature release of the plug set from the running tool, either upon manipulation of the running tool or due to the hammering effect of the pump down plug entering and latching into the liner wiper plug. Once the pump down plug is sealingly seated and latched within the bore of the liner wiper plug, fluid pressure acts on a piston which is moved to unlock the plug set from the running tool so that the plug set is released and allowed to be pumped to the landing collar.

[0149] The piston that unlocks the plug set from the running tool acts on a fluid filled chamber which is vented to the annulus through an orifice. When the pump down plug is sealed within the bore of the liner wiper plug, increased fluid pressure acts on the piston. The type and volume of fluid vented, as well as the size of the orifice, determine the time it takes to move the piston to a plug release position. This time is important to allow the operator to determine the correct displacement of cement volumes for cementing the liner in the well.

[0150] The plug holder sub allows the running tool to be manipulated without any detrimental effects on the liner wiper plug. The pump down plug may be pumped at any desired speed to the liner wiper plug and sealed and latched. The hammering effect of landing the pump down plug on the liner wiper plug will not prematurely release the plug set. After the pump down plug has been seated and latched, the operator may increase pressure to the running tool, thereby confirming to the operator that the plug has been seated in the liner wiper plug. The operator may calculate the exact amount of displacement fluids it will take to cement the liner in the well. The fluid pressure may then be increased, causing the piston to start to move to the plug release position. The pump down plug and the liner wiper plug as a set will thus be released after a predetermined amount of time, which again is important to the operator being able to determine the correct displacement volumes for cementing the liner in the well.

[0151] It is an object of the present invention to provide a plug holder sub for releasing a liner wiper plug in response to high fluid pressure acting against a piston, which in turn expels fluid from a chamber through a metering jet.

[0152] It is a further object of the invention to provide an improved method of releasing a liner wiper plug in response to fluid pressure, such that fluid pressure moves a piston from a retaining position to a release position. The time it takes for high pressure to expel fluid through a metering jet is monitored to increase the reliability of property releasing the liner wiper plug during the cementing operation.

[0153] It is a feature of the present invention that a C-shaped retainer member may be used for attaching the liner wiper plug to a tubular body, wherein movement of a piston to a release position releases the C-shaped retainer to release the liner wiper plug.

[0154] It is a further feature of the invention that the C-shaped ring may have threads or other internal gripping members for gripping engagement with the liner wiper plug. A metering jet may also have external threads for threaded engagement with the tubular body.

[0155] it is an advantage of the present invention that the plug holder sub is highly reliable and is relatively inexpensive.

[0156] These and further objects, features, and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

[0157] Figure 1 depicts a plug holder sub F110 for supporting a conventional liner wiper plug. The sub f110 includes the body f112 secured to the lower end of the running tool mandrel. Before the running tool and liner is lowered in the well, the liner wiper plug engages locking ring F114, which is supported between body F112 and the lower body F116 by piston F134. Locking ring F114 includes grooves or threads F115 or other suitable members for grippingly engaging the liner wiper plug. Seal F120 on the lower body F116 seals the plug holder sub to the liner wiper plug. Threads F128 connect the body F112 to lower body F116. and seal F122 seals between these connected bodies.

[0158] The body F112 includes a passageway F128 which is open to the annulus about the running tool. An orifice jet F130 with a relatively sized orifice is positioned along this port, and preferably includes threads for engagement with threaded port F126. Fluid containing chamber F132 is pressurized by the piston F134, which includes an OD seal F136 and an ID seal F138.

[0159] When the pump down plug lands within the liner wiper plug, the increased pressure within the running tool acts on the piston F134, which in turn is forced upward to expel fluid from the chamber F132. The rate fluid exits the chamber will be determined by the characteristics of the fluid within the chamber F132, and the size of a selected orifice in the jet F130 positioned downstream from the chamber. The left side view of Figure F1 shows a pin F131 sealing off a weep port to the chamber F132. The pin F131 has a small port therein for slowly releasing pressurized fluid to the annulus. The pin F131 may be secured within the weep port by a swaging operation, and is another form of a metering jet. The right side illustrates a jet F130 for threading to the body F112.

[0160] A significant advantage of the plug holder sub according to the present invention is that the increase in fluid pressure is not the primary factor that determines the release of the plug set. The rate at which the piston moves up to expel fluid from the chamber is primarily a function of a particular jet size and the type of fluid in the chamber, Accordingly, the operator will see an increase in pressure when the pump down plug is landed on the liner wiper plug, and will then know, within selected limits, that a predetermined amount of time should elapse from that increase in pressure until the plug set is released. Once the piston F134 moves up to reduce or eliminate the volume within the chamber F132, the C-shaped locking ring F114 is free to move radially outward, thereby releasing the liner wiper plug and the pump down plug. The C-shaped locking ring F114 may be biased out but normally held radially in by the piston F134, or may be biased in and moved outward to release by the downward force on the liner wiper plug.

[0161] Plugs are conventionally run in a well in pairs, and the plug holder sub as shown in Figure F1 is suited for supporting one pair of liner wiper plugs. In some applications, one pair of plugs are preferably used before the cement fluid, and another set of wiper plugs are used after the cement fluid and before the displacing fluid. For this latter application, each of the plug sets may be separately released in response to an increase in fluid pressure, which moves a respective piston to expel fluid from the chamber and thereby release the plug set. One piston responsive to a low pressure fluid could thus be provided on the support sub, with that piston releasing the first plug set. At a higher fluid pressure, a second piston may move in response to fluid pressure to release the second plug set. Each piston may force fluid through a selective orifice in a jet. If desired, the second piston and/or both first and second piston may be shear pinned so that no movement occurs until a selected pressure level is obtained. If desired, the first plug set alternatively could isolate the port for the second plug set so pressure could not act on the second plug set till the first plug set was released.

[0162] Figure F2 depicts the piston F134 in its retaining position, with the C-shaped retaining member F114 held radially inward so that its threads engage the mating threads F152 on the liner wiper plug F154. The through passageway in liner wiper plug F154 is provided with a seat F156 for sealing with a conventional pump down plug, as discussed above. The liner wiper plug F154 conventionally includes at least one and preferably two cup shaped elastomeric sealing members F158 on an exterior thereof so that high fluid pressure behind the liner wiper plug forces the liner wipers outward into sealing engagement with the liner. An annular body F159 with o-rings F160 and latch ring F161 may be provided for sealing and latching the plug set with the landing collar.

[0163] The spacer and cement fluids may be mixed while circulating fluids for cement displacement. When the cement has been pumped, the pump down plug may be released from the surface, forming a barrier between the previously displaced cement and the displacement fluid. A calculated amount of displacement fluid may thus be used to pump the pump down plug to the liner wiper plug. As the pump down plug get close to the running tool, fluid pressure may be reduced, e.g. to about 500 psi, and this pressure will increase when the pump down plug lands in the liner wiper plug, as discussed above.

[0164] Once the pump down plug is latched into the liner wiper plug, the work string can be pressured up and after a selected period of time, the liner wiper plug and the pump down plug will be released from the plug holder sub. Increased fluid pressure thus moves a piston to release a look ring, which releases the liner wiper plug from the plug holder sub.

[0165] The piston within the plug holder sub preferably acts on a fluid with a known viscosity at the downhole temperature of the plug holder sub. Fluid flow through a predetermined size orifice will take a predetermined period of time to release the liner wiper plug. This time may be used by the operator to positively calculate displacement fluid volumes. A calculated amount of displacement fluid will thus force the cement to the desired height in the annulus between the liner and the casing. Fluid will thus be pumped until the liner wiper plug and the pump down plug set latches into the landing collar, at which time pressure may be increased to, e.g. 1000 psi, over circulating pressure to complete latching of plugs and check that the seals between the plugs and the landing collar are holding. Pressure may then be bleed off and checked for bleed back to ensure that the float equipment is holding pressure.

[0166] Various types of metering jets may be used for selectively detering fluid from the chamber F132. Significant restrictions can be formed within the passageway F128 to effectively constitute a metering jet. Fluid in the chamber F132 will be at a known viscosity for the downhole conditions, and with a selectively size metering jet the operator will know with reasonable accuracy the time it will take for the piston F134 to move from the retaining position to the release position.

[0167] Other forms of retainer members may be used for interconnecting the tubular body F116 with the liner wiper plug. A preferred retainer member has a C-shaped configuration with internal grooves or teeth for attaching to the liner wiper plug. The internal surface of the piston F134 thus prevents the retainer member from moving to the released position until the piston moves axially to its release position, as shown on the right side of Figure F1.

[0168] As discussed above, the liner wiper plug may be used at the lower end of the liner hanger running tool. The plug holder sub of the present invention may be used more generally at the lower end of any conveyance tubular, such as conveyance tubular F140 as generally shown in Figure F1. The conveyance tubular F140 may thus be used to both transmit fluid pressure to the interior of the plug holder sub, and also to position the plug holder sub at a selected location within the well. The plug holder sub of the present Invention may thus be used at the lower end of various types of tools, including a liner hanger running tool, or at the lower end of the tubular string used in a cementing operation, in order to reliably release the wiper plug from the plug holder sub during the cementing operation. The wiper plug once released may seal with the liner or with another downhole tubular.

Running Tool

[0169] Continuing again with a description of the overall system, conventional cementing equipment may be used beneath the diverter, including the above described plugset which forms a barrier to different fluids flowing down the liner. A pump down plug F182 as shown in Figure F5A may include upwardly facing cups 183 for cleaning the drill string, so that increased pressure in the running string when the plug 182 seals with the liner wiper plug 120 releases both plugs (the set) from the lower end of the liner hanger. The liner wiper plug 180 has similar cups 181, and lands on the collar 186 to be sealingly locked in place and close off the lower end of the casing.

[0170] The released running tool 120 may be picked up until the packer setting assembly 380 (see Figure 1C) is removed from the top of the tie back receptacle 130, whereby the spring pressed lugs 328 are raised to a position above the top of the tie back receptacle, at which time they expand outwardly. With the packer setting assembly 380 in its expanded position, weight can be slacked off by engaging the lugs 328 with the top of the tie back receptacle to cause the packer element 150 to begin its downward sealing sequence. This weight also activates a sealing ring 384 between the packer setting assembly 380 and the tie back receptacle to aid in further setting the packer element with annulus pressure assist. With the packer element 150 in engagement with the casing, rams on a BOP at the surface may be closed onto the drill pipe to form a pressure vessel between the rams and the expanded packer. The cross sectional area between the casing and the drill pipe is known and the load required to fully set the packer element 150 is known, so that the operator may apply pre-determined fluid pressure to the annulus to cause the tie back receptacle to move down applying a predetermined additional axial load to the packer element.

[0171] Downward movement of the pusher sleeve 148 to set the packer element 150 will disengage the internal threads 386 (see Figure 6B) of the pusher sleeve from the tie back receptacle 130. The pusher sleeve 148 thus moves radially outwardly as the pusher sleeve moves down the cone 152. The pusher sleeve 148 may be split along its circumference in such a manner that in its normal contracted position, its internal threads 386 would engage the external threads 131 on the tie back receptacle 130. Other types of pusher sleeves may be used.

[0172] The mandrel 132 of the released running tool 120 may then be raised to raise the cementing bushing 160 to cause the lugs 392 on the bushing to move In and unlock from the liner hanger 110. After pulling the lower end of the running tool to a predetermined position at the upper end of the liner, the operator may circulate fluid through the running tool to pump any excess cement to the surface. Circulation effectively reduces the amount of cement that will need to be drilled out before reentering the top of the liner, and enables the operator to check for fluid flow and/or fluid loss.

[0173] After the running tool is picked up to a pre-determined position above the liner top, the operator circulates through the drill string to pump any excess cement to the surface, thus reducing the amount of cement that will need to be drilled out before reentering the top of the liner. Figure 8A shows the released running tool 120 raised from the liner. Upon checking for fluid flow and/or fluid loss, the operator pulls the running tool out of the hole. Once the tool reaches the surface, the operator may check for damage to the running tool, wash fluids off the tool, and flush the tool I.D. before returning the tool to the shop. Figure 9C also shows what remains in the casing C, namely the set packer 150 and set slips 142.

[0174] The liner hanger releasing assembly 250 as shown in Figure 1D and 1E may be replaced with the releasing assembly shown in Figures 10 and 11. The liner hanger releasing assembly as shown in Figures 10 and 11 may still be disposed beneath the packer setting assembly 380 as described above or the packer setting assembly 52 described below, and includes an inner piston sleeve 340 sealably disposed about the running tool mandrel 132, and another piston sleeve 342 disposed about the inner piston sleeve. The piston sleeve 340 forms a pressure chamber similar to the sleeve 252 shown in Figure 1D for releasing the liner hanger. The liner hanger releasing assembly as shown in Figures 10 and 11 releases the lock ring 326 which is externally grooved for engaging the grooved inner diameter of the liner hanger 110 of the upper end of the liner 146. The lock ring 326 is held in locking position by the enlarged upper outer diameter of the piston sleeve 340 which, as shown in the Figure 10A, is in its lower position. At this time, the clutch 316 as shown in Figure 1D is pressed downwardly by springs 318 to engage the liner hanger 110, which is threaded for engagement with right-handed threads 324 on the running tool mandrel 132. The nut 322 carries lugs 326 which are pressed outwardly by springs 327 into vertical slots formed in the liner hanger 110 to prevent relative rotation between the mandrel 132 and the liner hanger.

[0175] Upon raising of the inner piston 340, the lock ring 326 is free to contract inwardly about the lower reduced outer diameter 268 of the piston sleeve 340 and thereby free the running tool to be raised after setting of the slips but prior to setting of the packer, thus permitting circulation of cement downwardly through the tool and upwardly within the annulus between the tool and casing.

[0176] In the event the lock ring 326 is not released for any reason, such as frictional engagement between the I.D. of the look ring 326 and the O.D. of piston 340 (see Figure 11A), the operator has the option of releasing the running tool mechanically, as shown in Figure 11. As shown in Figure 11C, lowering of the ball 240 to open the port 260 in the running tool mandrel will permit pressure fluid to pass through the port 262 in the inner piston 340 to act upon the outer piston 342 and cause the outer piston to be moved upwardly upon shearing of the pin 358 (see Figure 11A) between the inner and outer pistons. This permits the outer piston 342, which is connected to the clutch 316 by a shear pin 360, to raise the clutch 316 and to de-clutch it from the liner hanger.

[0177] Once the clutch 316 is disengaged, the operator may rotate the tool to the right so that with the right-hand threads between the threaded nut 322 and the running tool mandrel 132 lower the nut on the mandrel 132, as shown in Figure 11C. Once the threaded nut 322 is lowered, the running tool may be picked up the distance the nut 322 moved down, thereby releasing the lock ring 326 and thus disengaging the running tool from the liner hanger. As shown in the Figure 11D, the locking ring 326 has collapsed on the reduced O.D. 341 of the inner piston 340.

[0178] The running tool 120 may thus be lowered to engage its clutch with that of the liner hanger. The clutch 316 is pressed downwardly by the spring 318, so that the lower teeth 317 (see Figure 8C) at the upper end of liner hanger 110 are engaged with similar teeth at the lower end of clutch 316 to maintain rotary engagement between the running tool and the liner hanger. As shown in Figure 1D, the upper end 332 of the clutch 316 may be splined to the O.D. of the running tool mandrel 132 so as to permit relative axial movement with respect thereto under the urging of the spring 318. When the clutch 316 is engaged, rotation of the work string rotates the liner hanger. When the clutch is disengaged, rotation of the work string rotates the running tool mandrel 132 to move nut 322 with respect to thread 324, as described below.

[0179] Figures 11A-C accordingly illustrates a liner hanger release assembly which enables the operator to release mechanically by right-hand rotation, in the event he is unable to release hydraulically. As shown in Figure 11A and 11B, the running tool mandrel 132 is surrounded by the pair of inner and outer sleeve pistons 340 and 342. The inner piston 340 has a shoulder 272 for engaging shoulder 274 of the running tool mandrel 132. Intermediate seal rings above and below ports 260 are uncovered upon lowering of the ball 240 on the ball seat 246 to the lower position, as shown in Figure 11C. Outer sleeve piston 342 surrounds the inner piston 340 and, while in the position as shown in Figure 11A, is supported on the inner piston 340 by engaging an outer shoulder 348 on the inner piston with the generally opposite shoulder on the outer piston 342. More particularly, this shoulder 348 is generally aligned with the port 262 in the inner sleeve 340 and intermediate the upper and lower seal rings 346 between the inner and outer sleeves. A ring 350 forms a stop shoulder at the upper end of the inner piston 340 to limit upward movement of the outer piston 342 with respect to the inner piston. The inner piston 340 is stopped in a upward direction by a downwardly facing shoulder 344 on the running tool.

[0180] In the initial position of the assembly as shown in Figure 11A, prior to lowering of the lower ball seat 246 and opening of the port 260 from the bore of the running tool, the lock ring 326 is held in a locked position between an enlarged diameter portion of the inner piston 340 and the inner diameter of the liner hanger 110. The nut 322 as shown in Figure 11B is positioned below reduced diameter portion 341 of the inner piston 340, with the internal threads 352 engaged with the threads 324 about the running tool mandrel 132. As in the case of the previously described embodiment, the threaded nut 322 is prevented from rotation relative to the liner hanger assembly by spring pressed lugs 326 in vertical slots in the liner hanger 110. If the running tool is not hydraulically released by opening of the ports 260 to raise the inner piston 340 and release the lock ring 326, the running tool may be mechanically released by a second hydraulic release operation, as discussed above.

[0181] If the operator wishes to rotate the liner while cementing, higher fluid pressure is then applied to the outer piston 342 to shear pins 360 between the outer piston 342 and clutch 316, at which time the spring 318 will re-engage the clutch. The operator may then rotate the running tool mandrel 132, thereby rotating the liner hanger. Additional fluid pressure may then be applied to the ball 240 to force it through the reduced thinner diameter of the seat 246.

<u>Figure 12 Packoff Bushing</u>

[0182] Referring now to Figure 12A, a preferred embodiment of a packoff bushing 10 is depicted for seating between a radially outward liner running adapter of the liner hanger and a radially inward running tool mandrel. The packoff bushing 10 is axially captured on the running tool mandrel or tubular body 12. The compact design of the packoff bushing and its limited axial movement on the running tool body 12 facilitates re-stabbing the packoff bushing into the liner hanger, as explained below. The upper end 14 of body 12 includes threads 16 and seal 18 for sealed engagement with the lower end of the liner hanger releasing assembly of the running tool. The lower end 20 of the body 12 includes similar threads 22 for interconnection with a sleeve which extends downward to a ball diverter. The body or sub 12 is thus part of the mandrel of the running tool, and a slick joint is not required.

[0183] As shown in Figure 12A, an internal seal 24 and an external seal 28 are provided on the locking piston 26. Seal 24, which may be a V-packing seal, thus seals between the locking piston 26 and the body 12 and seal 28, which may also be a V-packing seal, seals between the piston 26 and the running adapter of the liner hanger

48. Retainer 30 is threadably connected to the piston 26 for holding the seals 24 and 28 in place.

[0184] Retaining member 32 is threadably connected to top cap 34 so that the one-piece C-ring 36 is positioned between the top cap 34 and the piston 26. Retaining member 32 includes a shoulder 38 for engaging shoulder 40 on the body 12. The lower flange portion 33 of the retaining member 32 and the upper end 27 of the piston 26 are each splined, so that the spline fingers are circumferentially interlaced about the packoff bushing. Flange portions 33 thus capture the lock ring 36 axially when the piston 26 is forced upward. The lock ring 36 is a unitary C-shaped ring having a circumference in excess of 200°, and normally less than about 350°, and is intended for engaging and axially locking to the liner hanger. A preferred lock ring 36 may have a circumference of from 300° to 340°, thereby providing substantially full circumferential contact with the liner hanger while allowing for radial expansion and contraction of the lock ring. The relaxed diameter of the lock ring 36 is substantially as shown in Figure 12A. The packing retainer 30 is normally spaced axially a slight distance above the stop surface 44 on the body 12 for locking and unlocking the bushing.

[0185] When fluid is pumped downward through the liner hanger running tool, the lower end of the piston 26 is exposed to high pressure, which moves the piston 26 away from stop surface 44, as shown in Figure 12A, so that the lock surface 46 on the end of the piston 26 retains the C-ring 36 radially outward and into locking engagement with the liner hanger to axially lock the packoff bushing to the liner hanger. The lock ring 36 thus prevents the packoff bushing from moving axially when pressure is increased during the cementing operation, while the seals 24 and 28 maintain fluid integrity between the running tool and the liner hanger.

[0186] Since the top cap 34 is axially secured to the body 12, the load shoulder 44 on the top cap 34 provides a means for transmitting forces downward to the liner hanger during the running-in and cementing operation. Shoulder 44 would thus engage shoulder 45 on the running adapter 48 of the liner hanger when a set down weight is applied to the liner hanger so that the liner hanger is "hung off". A bearing 46 may be provided to allow the running tool body 12 to rotate relative to a set packoff bushing during an emergency releasing operation. The packoff bushing may thus be reliably maintained in the locked position, with the piston 26 up and the C-ring 36 expanded, as shown in Figure 12A, when fluid pressure is applied to the packoff bushing. Those skilled in the art should appreciate that engagement shoulders 38 and 40 allow the packoff bushing assembly 10 to be retrieved with the running tool to the surface after the cementing operations. Retrievable packoff bushing 10 as shown in Figure 12A thus replaces the bushing shown in Figure 1.

[0187] Use of the C-ring 36 rather than circumferentially spaced dogs allows high cementing pressure forces to be applied to the packoff bushing without "pumping out" the packoff bushing. As shown in Figure 12A, an annular groove 47 in then running adapter 48 of the liner hanger receives the lock ring 36 to securely lock the packoff bushing to the liner hanger when fluid pressure is applied to the piston 26. Without fluid pressure, the C-ring 36 thus retracts radially inward toward the retaining member 32 when the lock ring 36 engages the top surface of the groove 47 as the bushing is pulled out of the liner hanger. When the bushing is re-stabbed into the liner hanger, the C-ring 36 is retracted radially Inward, e.g., when the lock ring 36 engages load shoulder 45 on the liner hanger. During upward movement of the running tool relative to the liner hanger, the C-ring 36 thus may move radially inward when engaged, and may also move radially inward when the packoff bushing is re-stabbed back into the liner hanger. The C-ring design significantly increases reliability of the tool according to the present invention, and reduces both the complexity and the costs of prior art tools which use multiple lugs or dogs. Figure 12B illustrates the splined members 27 of the piston 26 and the splined members 33 of the retaining member 32, and the C shape of the lock ring 36. External slots 37 circumferentially spaced about the C-ring 36 facilitate expansion and contraction of the C-ring.

[0188] The liner hanger running tool with the packoff bushing disclosed herein may be used on various types of liner hanger operations. The packoff bushing may be used with or without a packer setting assembly and a packer element for sealing between the liner hanger and the casing. Although the packoff bushing as disposed herein is positioned axially between the liner hanger releasing assembly and the slip setting assembly, the packoff bushing could be provided at other locations in the liner hanger running tool.

<u>Figure 13 Packer Setting Assembly</u>

[0189] Figure 13 illustrates a preferred embodiment of a packer setting assembly 52, which will allow activation and packoff of the liner top packer. The packer setting assembly is provided on the sleeve shaped body or sub 54 which is part of the mandrel of the running tool, and includes lower threads 55 for engagement with a lower sub of the mandrel. The packer setting assembly 52 includes a housing 56 carrying a V packing seal 58. Other conventional elastomeric seals may replace the V packing 58. A flow slot 53 in the body 54 ensures fluid communication with the splines or ribs 57 on the body 54, so that the housing 56 moves axially along these splines without trapping fluid pressure. Packing retainer 60 and snap ring 62 hold the V packing in place. A packer setting or force transmitting C-ring 64 is positioned on the housing 56, and includes an internal sleeve portion 66. A C-shaped trip ring or lockout ring 70 is positioned between the lock sleeve 68 and retainer cap 72. Lock sleeve 68 engages the sleeve portion 66 to retain the C-ring 64 in the compressed position as shown in Figure 13, so that when released the C-ring 64 will snap out. A housing extension 74 is threadably secured to housing 56, and bearing 80 allows the body 54 to rotate relative to housing 56. Bearing sleeve 78 is connected to the sub 54 by shear member 82. Sleeve portion 84 of the bearing sleeve 78 engages the body 54 as shown in Figure 13, although sealing between the body 54 and the bearing sleeve 78 is not required. Packing members 86 on the body 54 are discussed below.

[0190] The first time the packer setting assembly is moved out of the polished bore receptacle 90 (which is the same as the receptacle, 130 discussed in the Fig. 1-9 running tool), trip ring 70, which was positioned within the polished bore receptacle, will snap to a radially outward position, as shown in Figure 13, due to the natural biasing of the C-shaped trip ring. When the packer setting assembly is subsequently reinserted into the polished bore receptacle, the trip ring 70 will engage the top of the polished bore receptacle 90 as shown in Figure 13, and the packer setting C-ring 64 is positioned within the polished bore receptacle. When set down force is applied, housing 56 will move downward relative to lock sleeve 68, and the trip ring 70 will move radially inward due to camming action. The entire packer setting assembly may thus be lowered to bottom out on a lower portion of the running adapter prior to initiating the cementing operation. The next time the packer setting assembly is raised out of the polished bore receptacle, the radially outward biasing force of the C-ring 64 will cause the C-ring to engage the top of the polished bore receptacle of the liner hanger. More particularly, the shoulder 65 will engage the top of the polished bore receptacle 90, since the natural or released diameter of the C-ring 64 approximates the outer diameter of the receptacle 90. The flat surface 65 on the C-ring 64 thus engages the top surface of the tie back receptacle 90. In this position, the tapered surface 73 at the lower end of retainer cap 72 engages the mating tapered surface 63 of the upper end of C-ring 64, and the setting weight thus results in a radially outward force applied to the C-ring 64 to effectively lack the C-ring in the weight-transfer position, so that the C-ring will not prematurely snap radially inward before the packer is set. Once the C-ring 64 is set against the liner hanger, the body 54 may be moved downward relative to the housing 56, thereby shearing members 82.

[0191] The packer setting assembly 52 has high reliability since a substantial downward set weight may be transmitted through the C-ring 64 to the tie back receptacle, and since the mechanical setting pressure is assisted by fluid pressure between the ID of the casing and the OD of the running tool or drill pipe. After members 82 shear and body 54 moves downward relative to housing 56, the radially inward surface of projection 88 on the housing 56 is then supported on the larger diameter surface 90 of the sub 54, with packing members 86 sealing with the housing 56. A collar or similar stop on the body 54 engages the top of bearing sleeve 78 to limit downward travel of the mandrel. Seal 58 remains sealed to the tie back receptacle. After the packer setting assembly 52 is set, the increase in pressure in the annulus between the casing and the running tool allows the housing 56 to act as a piston which is forced downward in response to the annulus pressure, thereby providing increased downward force to reliably set the liner hanger packer when the packer is forced radially outward as it is pushed down the packer setting cone.

[0192] A complete running procedure for running, setting, and releasing the liner hanger system according to the present invention will now be discussed. The setting tool is conventionally attached to the lower end of a work string, typically a drill pipe, and is releasably connected to a liner hanger, which is attached to the top of the liner. The work string lowers the liner into the borehole into a position above the lower end of the previously set casing or liner. With the liner at a desired depth, well bore fluids are circulated "bottoms up" to clean the hole. A setting ball may initially be dropped from a cementing manifold at the surface. The ball may either free fall or may be pumped to the liner hanger slip setting assembly, where the ball will rest on the expandable ball seat. Fluid pressure may then be increased to a selected value, e.g. 500 psi, which exerts a force on the shear screws acting between the ball seat and the mandrel of the slip setting assembly. When this force surpasses the design limits, the screws will shear to release the ball and seat to a position that uncovers hydraulic ports in the mandrel. Continued pumping of fluid will then force the ball through the seat, and allow the ball to be pumped to the second ball seat within the releasing tool.

[0193] Fluid pressure is then increased to shear screws between the piston and the mandrel of the liner hanger setting assembly. The piston, which was exposed to pressure within the running string when the ball was first released, is responsive to fluid pressure and travels upward, thereby forcing the slips to release and come into contact with the casing. The liner load may then be slacked off onto the set slips. Once the slips are supporting the weight of the liner, the liner is "hung off".

[0194] With the liner load slacked off onto the hanger slips, additional slack off or "set down weight" may be applied to the hanger to check for any hanger movement. The set down weight will be transmitted through the running tool to the liner hanger, which is supported by the liner hanger slips. This set down weight may, for example, be transmitted through the running tool mandrel to the packoff bushing and then from the load shoulder on the packoff bushing to the liner hanger. A ball may then be landed, and the ball seat moved to expose fluid ports. Pressure may then be increased to a selected value, e.g. 1200 psi, which is transmitted through ports in the mandrel of the liner hanger releasing assembly. This increased pressure shears screws on the primary piston, thereby moving the piston to allow the liner hanger release ring to collapse and disengage the running ring from the liner hangers. At this stage, the liner hanger running tool is free from the liner hanger. Since the clutch that keys the running tool to the liner hanger is shear pinned to the releasing piston, it moves from the clutched position to an unclutched position as the piston moves up to release the running ring. The running tool is preferably released by the increase in fluid pressure acting on the primary piston. If the running tool is still engaged to the liner hanger after pressuring up on the primary releasing piston, the operator may continue to pressure the drill sting to the maximum allowable pressure checking for release in small pressure increments up to the shear pressure of the secondary piston. If the primary piston does not release the running tool from the liner hanger, continued pressure will shear the secondary piston from the primary piston and the secondary piston will move axially up to disengage the clutch of the running tool from the clutch on the liner hanger. With the clutch disengaged, the running tool may be rotated 5-6 turns to the right to disengage the running tool from the liner hanger.

[0195] The operator at this stage may pick up the running string and note the loss of liner weight on a rig weight indicator, thereby indicating that the running tool is released from the liner hanger. This pick up operation will also disengage the packoff bushing from the liner hanger running adapter or tie back receptacle. As previously indicated, the packoff bushing is designed to be re-stabbable so that the operator may pull the running tool and the packoff bushing upward as desired to check that the running tool is released from the liner hanger. After it is confirmed that the running tool is released, the packoff bushing will be restabbed when the running tool is slacked back off into the liner hanger. When there is pressure below the packoff bushing, the bushing is securely locked to the liner hanger.

[0196] A selected fluid pressure, e.g. 2500 psi, may then be used to shear the secondary piston from the clutch to allow the clutch to re-engage the liner hanger. Once the liner hanger running tool is released from the liner, pressure may then be applied to the ball and seat. At a predetermined pressure, e.g. 3000 psi, the ball will pass through the port isolation ball seat, expanding the diameter of the seat. The ball is forced through the seat to permanently deforming the ball seat. The drop in pressure and re-gaining fluid circulation will then indicate that the ball has successfully passed through the ball seat. The ball is then allowed to free fall or be pumped to the ball diverter.

[0197] The spacer and cement fluids may be mixed while circulating fluids for cement displacement. When the cement has been pumped, the pump down plug may be released from the surface, forming a barrier between the previously displaced cement and the displacement fluid. A calculated amount of displacement fluid may thus be used to pump the pump down plug to the liner wiper plug. As the pump down plug get close to the running tool, fluid pressure may be reduced, e.g. to about 500 psi, and this pressure will increase when the pump down plug latches in the liner wiper plug. Once the pump down plug is latched into the liner wiper plug, the work string can be pressured up and after a selected period of time, the liner wiper plug and the pump down plug will be released from the plug holder sub. Increased fluid pressure thus moves a piston to release a ring, which releases the liner wiper plug from the plug holder sub. The piston within the plug holder sub acts on a fluid with a known viscosity, and fluid flow through a predetermined size orifice will take a predetermined period of time to release the liner wiper plug. This time may be used by the operator to positively calculate displacement fluid volumes. A calculated amount of displacement fluid will thus force the cement to the desired height in the annulus between the liner and the casing. Fluid will thus be pumped until the liner wiper plug and the pump down plug set latches into the landing collar, at which time pressure may be increased to, e.g. 1000 psi, over circulating pressure to complete latching of plugs and check that the seals between the plugs and the landing collar are holding. Pressure may then be bleed off and checked for bleed back to ensure that the float equipment is holding pressure.

[0198] It should be remembered that the packer setting assembly incorporates an unlocking feature that allows the packer setting assembly to be pulled out of the liner hanger tie back receptacle one time without unlocking the packer setting ring. Upon re-stabbing the assembly into the tie back receptacle, the packer setting ring becomes armed and is ready to expand the second time the packer setting assembly is pulled out of the tie back receptacle. Accordingly, the running tool may be picked up until the packer setting assembly is removed from the tie back receptacle, which allows the trip ring to expand and engage the top of the tie back receptacle. Stacking off on the running string collapses the trip ring so that it may reenter the tie back receptacle, and moves a locking sleeve out of contact with packer setting ring. Since the C-shaped packer setting ring is compressed but is now released from the locking sleeve, the packer setting assembly is ready to be activated the next time it is pulled from the tie back receptacle. Accordingly, the running tool may be picked up sufficiently to expose the packer setting assembly, then set down weight used to set the packer element.

[0199] Once the packer setting ring is in its expanded position, drill pipe weight may be slacked off on top of the tie back receptacle. This downward force through the packer setting assembly and to the tie back receptacle Initiates the packer setting sequence. This action will shear screws and allow the setting load to be transmitted to the packing element. As a load increases, the packer element will expand in OD as it moves down the cone, thereby pushing the expanding packer element out into engagement with the casing.

[0200] With the packer element in engagement with the casing, the rig rams may be closed around the drill pipe, so that a pressure vessel is formed between the casing and the running tool and between the packer element and the seals of the ram at the surface. Knowing how much load is required to properly set the packer element, a known fluid pressure can be applied to the annulus to cause the tie back receptacle to move down, thereby applying a greater and known load to the packer element. A desired setting load to the packer element may thus be applied through a combination of set down weight and fluid pressure.

[0201] After pulling the setting tool to a predetermined position above the top of the liner, fluid may be circulated through the drill string to circulate any excess cement to the surface, thereby reducing the need for drill out. Once the excess cement has been circulated out of the well, the operator may pull the setting tool from the well. Once at the surface, the tool may be checked for damage and serviced.

[0202] The tools as discussed above function as an assembly for a specific application, i.e., for the running and releasing of the liner hanger, the cementing of the liner into the wellbore and the setting of the packer element. One could run a liner hanger without a packer element and therefore the running tool would not require the packer setting assembly. Also, a packer element could be run into a wellbore without a liner hanger slip mechanism and therefore the slip releasing assembly would not be required in the running tool. Various combinations of the disclosed tools could be put together to run a variety of downhole tools.

[0203] While preferred embodiments of the present invention have been illustrated in detail, it is apparent that modifications and adaptations of the preferred embodiments will occur to those skilled in the art. However, it is to be expressly understood that such modifications and adaptations are within the spirit and scope of the present invention as set forth in the following claims.

[0204] The invention will now be summarised in the following numbered clauses :

1. A tool for suspending from a running string to position a liner hanger in a casing within a wellbore, suspending a liner from the liner hanger and retrieving portions of the tool, comprising:

the tool mandrel supported from the running string;
a slip setting assembly about the mandrel for setting slips to engage the casing and suspend the liner hanger from the casing; and
a releasing assembly for releasing from the set liner hanger portions of the tool to be retrieved to the surface, the releasing assembly including a connecting member for engaging the tool with the liner hanger, a first piston hydraulically moveable in response to fluid pressure within the tool mandrel from a lock position to a release position for releasing the connecting member, a clutch for rotationally connecting the tool mandrel with the liner hanger, and a second piston moveable in response to fluid pressure within the tool mandrel for disengaging the clutch, such that right-hand rotation of the running string moves the nut downward along the mandrel so that the running string may then be picked up to disengage the tool from the liner hanger.

2. The tool as defined in Clause 1, further comprising:

a piston shear member for interconnecting the first piston and the second piston, such that the second piston may be disconnected from the first piston in response to fluid pressure within the tool mandrel.

3. The tool as defined in Clause 1, further comprising:

a clutch shear member for interconnecting the second piston and the clutch, such that shearing the clutch shear member reengages the clutch With the liner hanger two permit rotation of the set liner hanger with the running string.

4. The tool as defined in Clause 1, further comprising:

a port in the tool mandrel for fluid communication with the first piston; and
a sleeve for blocking the port, such that the increase in fluid pressure when a ball lands on a seat shifts the sleeve downward to open the port.

5. The tool as defined in Clause 1, wherein the engaging member is a radially collapsible C-ring.
6. The tool as defined in Clause 5, wherein the C-ring includes external threads for engagement with internal threads on the liner hanger to secure the tool to the liner hanger,
7. The tool as defined in Clause 1, further comprising:

a plurality of dogs carried by the nut for fitting within slots in the liner hanger to rotationally lock the nut to the liner hanger.

8. The tool as defined in Clause 1, further comprising:

a flow-through port in the first piston, such that fluid pressure within the mandrel passes through the flow-through port to act upon the second piston.

9. The tool as defined in Clause 1, further comprising:

a stop on the first piston for limiting travel of the second piston.

10. The tool as defined in Clause 1, wherein the first piston is a radially inner piston for sealing with the tool mandrel, and the second piston is a radially outer piston for sealing with the inner piston.
11. A tool for suspending from a running string to position a liner hanger is a casing within a wellbore,

suspending a liner from the liner hanger in place and retrieving portions of the tool, comprising:

a tool mandrel supported from the running string;
a slip setting assembly about the mandrel for setting slips to engage the casing and suspend the liner hanger from the casing;
a releasing assembly about the tool mandrel for releasing the liner hanger from the portions of the tool to be retrieved to the surface; and
a packoff bushing for sealing between the liner hanger and the tool mandrel, including a radially moveable locking member and a fluid pressure responsive piston moveable in response to fluid pressure within the tool mandrel between a release position whereby the packoff bushing may be removed from the liner hanger and reinserted into the liner hanger, and a lock position for retaining the locking member in a groove in the liner hanger to lock the packoff bushing to the liner hanger.

12. The tool as defined in Clause 1, wherein the radially moveable locking member comprises a C-shaped lock ring.
13. The tool as defined in Clause 12, wherein the C-shaped lock ring includes radially external slots for facilitating expansion and contraction of the lock ring.
14. The tool as defined in Clause 12, wherein the C-shaped lock ring has a circumference from 200°-350°.
15. The tool as define in Clause 12, wherein the lock ring retracts when engaging a shoulder on the liner hanger, thereby allowing the lock ring to be reinserted into the liner hanger after being raised above the liner hanger.
16. The tool as defined as Clause 11, wherein the piston is axially moveable with respect to the tool mandrel to move the locking member to the lock position in response to fluid pressure within the tool mandrel.
17. The tool as defined in Clause 11, wherein the packoff bushing comprises:

a radially internal seal for sealing between the piston and the mandrel; and
a radially external seal for sealing between the piston and the liner hanger.

18. The tool as defined in Clause 11, wherein the packoff bushing includes a radially outer shoulder for engaging a radially inner shoulder on the liner hanger for applying set down weight to the liner hanger.
19. The tool as defined in Clause 11, wherein the packoff bushing includes a radially inner shoulder, and the tool mandrel includes a radially outer shoulder, such that the engagement of the inner shoulder and outer shoulder allow the packoff bushing to be retrieved with the retrieving portions of the tool.
20. The tool as defined in Clause 11, further comprising:

a packer setting assembly about the tool mandrel for setting a packer to seal between the casing and the liner hanger.

21. A packer setting assembly for setting a radial set packer element, the packer setting assembly applying a force on one of the packer element and a cone to move the packer element relative to the cone, the packer setting assembly comprising:

a radially expandable force transmitting C-ring, the force transmitting G-ring when expanded acting to engage a setting sleeve for applying a set-down weight through the setting sleeve to set the radial set packer element.

22. The packer setting assembly as defined in Clause 21, further comprising:

a lockout mechanism for preventing the force transmitting C-ring from moving to the expanded position.

23. The packer setting assembly as defined in Clause 22, wherein the lockout mechanism includes a lockout C-ring for radially expanding to engage the top of the liner and thereby disengage the lockout mechanism.
24. The packer setting assembly as defined in Clause 22, further comprising:

the lockout mechanism moves from an expanded position to a retracted position due to a camming surface on a housing of the packer setting assembly, thereby releasing the force transmitting C-ring.

25. The packer setting assembly as defined in Clause 22, wherein the lockout mechanism moves axially to release the force transmitting C-ring.
26. The packer setting assembly as defined in Clause 21, further comprising:

a lock-out mechanism for allowing the force transmitting C-ring to be raised out of the top of a liner hanger one time without moving the force transmitting C-ring to the expanded position, such that the next time the force transmitting C-ring is moved out of the liner hanger, the force transmitting C-ring expands to its expanded position for engagement with the liner hanger.

27. The packer setting assembly as defined in

Clause 21, further comprising:

a packer setting housing;
an I.D. seal for sealing between a packer mandrel and the packer setting housing; and
an O.D. seal for sealing with between the setting sleeve and the packer setting housing, such that fluid pressure may be used to assist in applying a setting force through to the setting sleeve to the packer element.

28. The packer setting assembly as defined in Clause 21, further comprising:

a packer setting housing about a mandrel; and
a bearing for facilitating rotation of the mandrel relative to the housing.

29. The packer setting assembly as defined in Clause 21, wherein the radial set packer element includes a metal radially inward base and one or more radially outer seal bodies.
30. The packer setting assembly as defined in Clause 21, wherein the setting sleeve acts on the packer element of a liner hanger to seal between the liner hanger and a casing.
31. A method of releasing a running tool while supported on a running string from a liner hanger in a casing within a wellbore, the liner hanger being secured to a casing by a slip assembly to suspend the liner hanger from the casing, the method comprising:

providing a releasing assembly about a tool mandrel, the releasing assembly including a connecting member or engaging the running string with the liner hanger, a first piston hydraulically moveable in response to fluid pressure within the tool mandrel from a lock position to a release position for releasing the connecting member, a clutch for rotationally connecting the tool mandrel with the liner hanger, and a second piston moveable in response to fluid pressure within the tool mandrel for disengaging the clutch; and
pressurizing the running string to move the first piston to the release position for releasing the running string.

32. The method as defined in Clause 31, further comprising:

pressurizing the running string to move the second piston to disengage the clutch;
rotating the running string to move a nut downward along the tool mandrel; and
thereafter picking up the running string to disengage the running tool from the liner hanger.

33. The method as defined in Clause 31, further comprising:

shearably interconnecting the first piston and the second piston, such that the second piston may be disconnected from the first piston in response to fluid pressure within the tool mandrel.

34. The method as defined in Clause 31, further comprising:

shearably interconnecting the second piston and the clutch such that shearing the clutch shear member re-engages the clutch to permit rotation of the liner hanger with the running string.

35. The method as defined in Clause 31, further comprising:

providing a port in the tool mandrel for fluid communication with the first piston; and
blocking the port with a sleeve, such that the increase in fluid pressure when a ball lands on a seat shifts the sleeve downward to open the port.

36. The method as defined in Clause 31, wherein the engaging member is formed to be a radially collapsible C-ring.
37. The method as defined in Clause 31, further comprising:

providing a plurality of dogs carried by the nut for fitting within slots in the liner hanger to rotationally lock the nut to the liner hanger.

38. The method as defined in Clause 31, further comprising:

providing a flow-through port in the first piston, such that fluid pressure within the tool mandrel passes through the flow-through port to act upon the second piston.

39. The method as defined in Clause 31, further comprising:

providing a stop on the first piston for limiting travel of the second piston.

40. The method as defined in Clause 31, wherein the first piston is a radially inner piston for sealing with the tool mandrel, and the second piston is a radially outer piston for sealing with the inner piston.
41. A method of sealing between a liner hanger suspended in a casing within a wellbore and supporting a tool mandrel from a running string, the method

comprising:

providing a packoff bushing for seating between the liner hanger and the tool mandrel, the packoff bushing including a radially moveable locking member and a fluid pressure responsive piston; moving the piston in response to fluid pressure within the tool mandrel between a release position whereby the packoff bushing may be removed from the liner hanger and reinserted into the liner hanger, and a lock position for retaining the locking member in a groove in the liner hanger to lock the packoff bushing to the liner hanger.

42. The method as defined in Clause 41, further comprising:

forming the radially moveable locking member to have a C-shaped lock ring configuration.

43. The method as define in Clause 41, wherein the lock ring retracts when engaging a shoulder on the liner hanger, thereby allowing the lock ring to be reinserted into the liner hanger after being raised above the liner hanger.
44. The method as defined as Clause 41, wherein the piston is axially moveable with respect to the tool mandrel to move the locking member to the lock position in response to fluid pressure within the tool mandrel.
45. The method as defined in Clause 41, further comprising:

providing a radially internal seal for sealing between the piston and the mandrel; and
providing a radially external seal for sealing between the piston and the liner hanger.

46. The method as defined in Clause 41, further comprising:

providing a radially outer shoulder on the packoff bushing for engaging a radially inner shoulder on the liner hanger when the locking member is aligned with the groove in the liner hanger for applying set down weight through the radially outer shoulder to the liner hanger.

47. The method as defined in Clause 41, further comprising:

providing a radially inner shoulder on the packoff bushing;
providing a radially outer shoulder on the tool mandrel; and
engaging of the inner shoulder and outer shoulder to retrieve the packoff bushing to the surface.

48. The method as defined in Clause 41, further comprising:

providing a packer setting assembly about the tool mandrel for setting a packer to seal between the casing and the liner hanger.

49. A method of setting a radial set packer element by applying a force on one of the packer element and a cone to move the packer element relative to the cone, the method comprising:

providing a radially expandable force transmitting C-ring;
expanding the force transmitting C-ring to engage a setting sleeve; and
applying a set-down weight through the setting sleeve to set the radial set packer element.

50. The method as defined in Clause 49, further comprising:

providing a lockout mechanism for preventing the force transmitting C-ring from moving to the expanded position.

51. The method as defined in Clause 50, further comprising:

engaging the lock out mechanism with the top of the liner hanger to releases the force transmitting C-ring.

52. The packer setting assembly as defined in Clause 51, further comprising:

providing a C-ring lockout mechanism;
moving the G-ring lockout mechanism from an expanded position to a retracted position by applying set down weight to the C-ring lockout mechanism due to a camming surface on a housing of the packer setting assembly, thereby releasing the force transmitting C ring.

53. The method as defined in Clause 50, wherein the lockout mechanism moves axially to release the force transmitting C-ring.
54. The method as defined in Clause 49, further comprising:

allowing the force transmitting C-ring to be raised out of the top of a liner hanger one time without moving the force transmitting C-ring to the expanded position, such that the next time the force transmitting C-ring is moved out of the liner hanger, the force transmitting C-ring expands to its expanded position for engagement with the liner hanger.

55. The method as defined in Clause 50, further comprising:

providing a packer setting housing;
providing an I.D. seal for sealing between a packer mandrel and the packer setting housing; and
providing an O.D. seal for sealing with between the setting sleeve and the packer setting housing, such that fluid pressure assists in applying a setting force to the setting sleeve.

56. The method as defined in Clause 49, wherein the radial set packer element includes a metal radially inward base and one or more radially outer seal bodies.

57. A retrievable hydraulically operated tool for running in a wellbore to perform a downhole tool activation, the tool comprising:

a running tool tubular body for suspending in the wellbore from a conveyance tubular, such that fluids may be circulated through a bore in the conveyance tubular and in the tubular body, the tubular body including a fluid inlet port from the bore in the tubular body;
a fluid pressure responsive member in fluid communication with the fluid inlet port and moveable relative to the tubular body from an initial position to an activated position in response to fluid pressure within the tubular body;
a port closure member moveable with respect to the tubular body from a port isolation position to an open port position, the port closure member in the port isolation position blocking fluid communication from the bore in the tubular body, and permitting fluid communication from the bore in the tubular body through the fluid inlet port when in the open port position;
a seat supported on the port closure member, such that an increase in fluid pressure to the fluid inlet port when a plug lands on the seat shifts the port closure member from the port isolation position to the open port position in response to fluid pressure above the landed plug; and
a plug release mechanism for releasing the plug after the port closure member has moved to the open port position.

58. The retrievable tool as defined in Clause 57, wherein the port closure member comprises a sleeve axially moveable within the bore of the tubular body.

59. The retrievable tool as defined in Clause 57, wherein the fluid pressure responsive member includes a piston moveable from the initial position to the activated position in response to fluid pressure.

60. The retrievable tool as defined in Clause 59, wherein the piston moves axially upward from the initial position to the actuated position in response to fluid pressure.

61. The retrievable tool as defined in Clause 53, wherein the plug is a ball.

62. The retrievable tool as defined in Clause 61, wherein the ball lands on the seat to substantially seal off the bore through the tubular body.

63. The retrievable tool as defined in Clause 57, wherein the port closure member is retained in the port isolation position by a shear member.

64. The retrievable tool as defined in Clause 57, wherein the seat permanently deforms in response to increased fluid pressure to pass the plug through the seat.

65. A retrievable liner hanger running tool for running in a wellbore to perform a downhole tool actuation on a liner hanger, the running tool comprising:

a running tool tubular body for suspending in the wellbore from a conveyance tubular, such that fluid may be circulated through a bore in the conveyance tubular and in the tubular body, the tubular body including a fluid inlet port from the bore in the tubular body;
a piston axially moveable with respect to the tubular body and in fluid communication with the fluid inlet port, the piston being moveable from an initial position to an activated position in response to fluid pressure within the tubular body, axial movement of the piston to the activated position causing one of (a) axial movement of a slip to set the liner hanger, (b) movement of a release mechanism to release the liner hanger from the running tool, and (c) relative movement between a cone and a seal to seal between the liner hanger and surrounding casing;
a sleeve axially movement with respect to the tubular body from a port isolation position to an open port position, the sleeve in the port isolation position blocking fluid communication from the bore in the tubular body, and permitting fluid communication from the bore in the tubular through the fluid inlet port when in the open port position;
a seat supported on the port closure member, such that an increase in fluid to the fluid inlet port pressure when a ball lands on the seat shifts the port closure member from the port isolation position to the open port position in response to fluid pressure above the landed ball; and
a plug release mechanism for releasing the bell after the port closure member has moved to the open port position;

66. The running tool as defined in Clause 65, wherein the piston moves axially upward from the initial position to the actuated piston in response to fluid pres-

sure,

67. The running tool as defined in Clause 65, wherein the ball lands on the seat to substantial seal off the bore through the tubular body.

68. The running tool as defined in Clause 65, wherein the sleeve is retained in the port isolation position by a shear member.

69. The relative tool as defined in Clause 65, wherein the seat permanently deforms in response to increased fluid pressure to pass the ball through the seat.

70. A method of hydraulically operating a tool for running in a wellbore to perform a downhole tool activation, the method comprising:

suspending a running tool tubular body in the wellbore from a conveyance tubular;
providing a fluid inlet port from the bore in the tubular body;
providing a fluid pressure responsive member in fluid communication with the fluid inlet port and moveable relative to the tubular body from an initial position to an activated position in response to fluid pressure;
providing a port closure member moveable with respect to the tubular body from a port isolation position to an open port position, the port closure member in the port isolation position blocking fluid communication from the bore in the tubular body, and permitting fluid communication from the bore in the tubular through the fluid inlet port when in the open port position;
supporting a seat on the port closure member;
landing a plug on the seat to shift the part closure member from the port isolation position to the open port position in response to fluid pressure above the landed plug;
performing the downhole tool activation in response to movement of the fluid pressure responsive member to the activated position; and
releasing the plug after the port closure member has moved to the open port position.

71. The method as defined in Clause 70, wherein the fluid pressure responsive member includes a piston moveable from the initial position to the activated position in response to fluid pressure.

72. The method as defined in Clause 71, wherein the piston moves axially upward from the initial position to the actuated position in response to fluid pressure.

73. The method as defined in Clause 70, wherein the plug is a ball which lands on the seat to substantially seal off the bore through the tubular body.

74. The retrievable method as defined in Clause 70, further comprising:

retaining the port closure member in the port isolation position by a shear member.

75. The method as defined in Clause 70, wherein the seat permanently deforms in response to increased fluid pressure to pass the plug through the seat.

76. The method as defined in Clause 70, wherein movement of the fluid pressure responsive member causes one of (a) axial movement of a slip to set the liner hanger, (b) movement of a release mechanism to release the liner hanger from the running tool, and (c) relative movement between a cone and a seal to seal between the liner hanger and surrounding casing.

77. The method as defined in Clause 70, wherein the plug is released after the downhole tool has been activated in response to movement of the fluid pressure responsive member to the activated position.

78. A ball and plug dropping head adapted to be installed above the upper end of the liner for use in sequentially dropping one or more balls and plugs into a liner of a liner hanger system, comprising:

a housing having an inlet adapted to be fluidly connected in line with the lower end of a top drive, an outlet generally aligned with the inlet and adapted to be connected to the upper end of a running tool, generally in line with, and passages extending downwardly within the housing at circumferentially spaced locations,
each passage having an upper end opening to the side of the inlet and a lower end connecting with the outlet,
lateral passages in the housing each connecting the inlet with a passage,
a plug removably mounted in the upper end of each passage to permit a ball or plug to be installed therein, and
valves mounted in the housing each for opening and closing a passage beneath the lateral passage connecting thereto so as to support ball or plug when closed and permit the ball or plug to pass therethrough, and circulating fluid to pass downwardly therethrough when a ball or plug is not in the passage.

79. As in clause 78, wherein each valve is removably mounted in a side opening in the housing to permit it to be installed and removed from outside of the housing.

80. A liner hanger system, comprising

a joint of casing adapted to be connected as part of an outer casing installed within a wellbore,
a liner adapted to be lowered within the outer casing,
the bore of said casing joint having vertically spaced, upwardly facing landing surfaces

formed on an intermediate portion thereof, and a lower annular recess separated from the lower landing surface by a lower annular restriction,
the said liner including a tubular body having a recess formed thereabout with an annular groove formed in its lower end,
a hanger comprising a circumferentially expandible and contractible C-ring disposed within and closely about the hanger recess when in the retracted portions,
said ring having teeth formed thereabout for landing on the landing surfaces of the casing joint when in its expanded portion, and a lower end fitting within the groove when in its retracted portion to permit the liner to be lowered through the outer casing,
said ring being expandable, upon relative vertical movement with respect to the liner, so as to release its lower end from the groove and thereby permit the ring to expand outwardly against the outer casing,
whereby, upon continued relative movement of the liner and ring, the teeth will move into a position in which they expand outwardly into landed positions on the landing surfaces to permit the liner to be suspended therefrom,
said liner having a downwardly facing shoulder for landing on the upper end of the expanded ring and an outward enlargement beneath the shoulder to fit within the upper end of the ring so as to hold the ring expanded.

81. As Clause 80, including

a tie bar guidably reciprocable within the liner recess radially inwardly of the ring and having its upper end connected to a part surrounding and vertically moveable with respect to the liner, said tie bar and ring having radially extending parts which connect the tie bar to the ring to raise the ring out of the groove and, when the ring is so raised, are released from one other to permit the liner to be lowered with respect to the ring,

82. As in Clause 81, wherein
the liner recess has a vertical slot to receive the tie bar and a stop surface on its lower end to be engaged with the lower end of this tie bar prior to its being raised to lift the lower end of the ring from the groove in liner recess.
83. As in Clause 80, wherein
the bore of the casing joint also has an upper annular recess separated from the upper landing surface by an upper annular restriction.
84. As in Clause 80, wherein
the liner also has a lower outward enlargement thereabout above the groove for disposal within the lower end of the expanded ring.
85. As in Clause 80, wherein
the bore of the casing joint has a polished bore above the landing surface.
86. Well apparatus comprising

an elongate member having an outwardly facing frusto conical surface and adapted to be lowered into and suspended within a wellbore, and
a slip comprising a circumferentially expandible and contractible c-ring having slip teeth about its outer side and a frusto conical surface on its inner side disposed about the frusto conical surface of the member so that the c-ring may be moved vertically between a contracted position in which the teeth are spaced from the wellbore and an expanded portion in which the teeth engage the wellbore,
the member also having a recess to receive an end of the c-ring to retain the c-ring contracted about the member, as it is lowered, whereby, upon removal of the one end from the recess, the c-ring is free to expand toward its fully expanded position to cause its slip teeth to grip the wellbore, so that the weight of the member may be hung from the casing upon relative vertical movement of the conical surfaces of the c-ring and member.

87. As in Clause 86, wherein
the frusto conical surface of the member extends downwardly and inwardly and the frusto conical surface of the c-ring is slidable upwardly over the surface of the member as the member is lowered to cause its teeth to move outwardly to engage the wellbore.
88. Well apparatus as defined in Clause 86, including a part carried by the member for guided reciprocation with respect thereto and engageable with the end of the c-ring or in order to remove the end of the c-ring from the recess and thus release it for expansion.
89. As in Clause 88, wherein
the part for releasing the c-slip comprises a tie bar extending guidably within the member, with the c-ring and the tie bar have interfitting parts, when the end of the c-ring is in the recess, so as to permit the c-slip to be removed from the recess by the tie bar and then released therefrom to permit the c-ring to expand into engagement with the bore of the casing.
90. A tool for use in a subterranean well to seal with a generally cylindrical interior surface of a tubular or another downhole tool, the tool comprising:

a conveyance tubular for positioning the tool at a selected location below the surface of the well;
an annular seal assembly disposed about the conveyance tubular, the seal assembly having a reduced diameter run-in position and an expanded seating position;

a wedge ring having a substantial conical outer surface configured to radially expand the annular seal assembly upon axial movement of the annular seal assembly relative to the wedge ring such that the seal assembly is expanded from its run-in position to its expanded sealing position wherein the seal assembly is in sealing engagement with the generally cylindrical interior surface; and

the annular seal assembly including a metal framework having a radially inward annular base and a plurality of metal ribs each extending radially outward from the base, the metal framework including an upper downwardly angled primary seal metal rib for sealing pressure below the seal assembly, a lower upwardly angled primary seal metal rib for sealing pressure above the seal assembly, a primary elastomeric seal in a cavity radially outward from the base and axially between the upper primary seal metal rib and the lower primary seal metal rib, an upper downwardly angled secondary seal metal rib spaced axially above the upper primary seal metal rib, and a lower upwardly angled secondary seal metal rib spaced axially below the lower primary seal metal rib.

91. The downhole tool as defined in Clause 90, further comprising:

an upper biasing member between the upper primary seal metal rib and the upper secondary seal metal rib for exerting a downward biasing force on the upper primary seal metal rib in response to high fluid pressure below the seal assembly, and a lower biasing member spaced between the lower primary seal metal rib and the lower secondary seal metal rib for exerting an upward force on the lower primary seal metal rib in response to high fluid pressure above the seal assembly.

92. The downhole tool as defined in Clause 90, wherein an outer surface of each of the upper primary seal metal rib, the lower primary seal metal rib, the upper secondary seal metal rib, and the lower secondary metal rib is configured for forming an annular metal-to-metal seal with a generally cylindrical interior surface.

93. The downhole tool as defined in Clause 90, wherein said conveyance tubular supports the wedge ring generally stationary while the seal assembly moves axially with respect to the stationary wedge ring.

94. The downhole tool as defined in Clause 90, wherein the conveyance tubular supports the seal assembly generally stationary while the wedge ring moves axially with respect to the stationary seal assembly.

95. The downhole tool as defined in Clause 90, wherein the seal assembly seals with an interior surface of a downhole tubular.

96. The downhole tool as defined in Clause 90, wherein the primary elastomeric seal includes a void area when the primary elastomeric seal is moved into sealing engagement with the cylindrical surface, such that the primary elastomeric seal may thermally expand to fill at least part of the void area in response to elevated downhole temperatures.

97. The downhole tool as defined in Clause 90, wherein each of the downwardly angled primary seal metal rib and the upwardly angled primary seal metal rib is inclined while in the run-in position at an angle of at least 15° with respect to a plane perpendicular to a central axis of the cylindrical interior surface.

98. The downhole tool as defined in Clause 97, wherein each of the downwardly angled secondary metal rib and the upwardly angled secondary metal rib is inclined while in the run-in position at an angle of at least 15° with respect to a plane perpendicular to a central axis of the cylindrical interior surface.

99. The downhole tool as defined in Clause 90, further comprising:

one or more axially spaced protrusions on a radially inner surface of the annular base of the metal framework each for metal-to-metal sealing engagement with the conical outer surface of the wedge ring.

100. The downhole tool as defined in Clause 99, further comprising:

one or more annular elastomeric sealing members for sealing between the base of the metal framework and the conical outer surface of the wedge ring.

101. The downhole tool as defined in Clause 99, further comprising:

one or more annular metal protrusions on one of an outer surface of a conveyance tubular and an inner surface of the wedge ring to form a metal-to-metal seal between the wedge ring and the conveyance tubular.

102. The downhole tool as defined in Clause 101, further comprising:

one or more annular elastomeric sealing members carried by one of the conical wedge ring and the conveyance tubular for forming an elastomeric seal between the conveyance tubular and the wedge ring.

103. A tool for use in a subterranean well to seal with a generally cylindrical interior surface of a tubular or another downhole tool, the tool comprising:

a wedge ring having a substantially conical outer surface configured to radially expand the annular seal assembly upon axial movement of the annular seal assembly relative to the wedge ring such that the seal assembly is expanded from its run-in position to its expanded sealing position wherein the seal assembly is in sealing engagement with the generally cylindrical interior surface; and
an annular seal assembly having a reduced diameter run-in position and an expanded sealing position, the seal assembly including a metal framework having a radially inward annular base and a plurality of metal ribs each extending radially outward from the base, the metal framework including an upper downwardly angled primary seal metal rib for sealing pressure below the seal assembly, a lower upwardly angled primary seal metal rib for sealing pressure above the seal assembly, a primary elastomeric seal in a cavity radially outward from the base and axially between the upper primary seal metal rib and the lower primary seal metal rib, an upper downwardly angled secondary seal metal rib spaced axially above the upper primary seal metal rib, and a lower upwardly angled secondary seal metal rib spaced axially below the lower primary seal metal rib.

104. The downhole tool as defined in Clause 103, further comprising:

an upper secondary elastomeric seal between the upper primary seal metal rib and the upper secondary seal metal rib, and a lower secondary elastomeric seal spaced between the lower primary seal metal rib and the lower secondary seal metal rib.

105. A downhole tool as defined in Clause 103, wherein an outer surface of each of the upper primary seal metal rib, the lower primary seal metal rib, the upper secondary seal metal rib, and the lower secondary metal rib is configured for forming an annular metal-to-metal seal with a generally cylindrical interior surface.

106. The downhole tool as defined in Clause 103, wherein each of the downwardly angled primary seal metal rib, the upwardly angled primary seal metal rib, the downwardly angled secondary seal metal rib and the upwardly angled secondary seal metal rib is inclined while in the run-in position at an angle of at least 15° with respect to a plane perpendicular to a central axis of the cylindrical interior surface.

107. A method of forming a downhole seal with a generally cylindrical interior surface of a tubular or another downhole tool, the method comprising:

providing an annular seal assembly disposed about a conveyance tubular, the seal assembly having a reduced diameter run-in position and an expanded position, the seal assembly including a metal framework having a radially inward annular base and a plurality of metal ribs each extending radially outward from the base, the metal framework including an upper downwardly angled primary seal metal rib for sealing pressure below the seal assembly, a lower upwardly angled primary seal metal rib for sealing pressure above the seal assembly, a primary elastomeric seal in a cavity radially outward from the base and axially between the upper primary seal metal rib and the lower primary seal metal rib, an upper downwardly angled secondary seal metal rib spaced axially above the upper primary seal metal rib, and a lower upwardly angled secondary seal metal rib spaced axially below the lower primary seal metal rib;
providing a wedge ring having a substantial conical outer surface; and
axially moving the annular seal assembly relative to the wedge ring such that the seal assembly is expanded from its run-in position to its expanded position wherein the seal assembly is in sealing engagement with the generally cylindrical interior surface.

108. The method as defined in Clause 107, further comprising:

providing an upper biasing member between the upper primary seal metal rib and the upper secondary seal metal rib for exerting a downward biasing force on the upper primary seal metal rib in response to high fluid pressure below the seal assembly; and
providing a lower biasing member spaced between the lower primary seal metal rib and the lower secondary seal metal rib for exerting an upward force on the lower primary seal metal rib in response to high fluid pressure above the seal assembly.

109. The method as defined in Clause 108, wherein an outer surface of each of the upper primary seal metal rib, the lower primary seal metal rib, the upper secondary seal metal rib, and the lower secondary metal rib is configured for forming an annular metal-to-metal seal with a generally cylindrical interior surface.

110. The method as defined in Clause 108, wherein the wedge ring is generally stationary while the seal

assembly moves axially with respect to the stationary wedge ring.

111. The method as defined in Clause 110, wherein a set down weight transmitted to the seal assembly through the conveyance tubular moves the seal assembly axially with respect to the stationary wedge ring.

112. The method as defined in Clause 108, further comprising:

providing one or more axially spaced protrusions on a radially inner surface of the annular base of the metal framework each for metal-to-metal sealing engagement with the conical outer surface of the wedge ring.

113. The method as defined in Clause 112, further comprising:

providing one or more annular elastomeric sealing members for sealing between the base of the metal framework and the conical outer surface of the wedge ring.

114. The method tool as defined in Clause 108, further comprising:

providing one or more annular metal protrusions on one of an outer surface of the conveyance tubular and an inner surface of the wedge ring to form a metal-to-metal seal between the wedge ring and the conveyance tubular.

115. For use with a downhole cementing tool, comprising

a tubular member having an upper end connected to a well pipe for lowering into a well bore to permit it to be cemented therein, and having a bore with a relatively large diameter upper portion enabling one or more balls and pump down plugs to be lowered therein and a smaller lower portion including a liner wiper plug whose bore is smaller than the balls but permits passage of the pump down plugs therethrough,
a diverter including a sub forming a part of the tubular member intermediate the upper and lower portions and having a side pocket to one side of the bore to receive a ball prior to passage of a pump down plug therethrough, and
a ramp extending diagonally across the sub and slanted downwardly to guide the ball into the side pocket and having a U-shaped opening facing the pocket to prevent passage of the ball, but permit a plug to pass between the ball and pocket into the liner wiper plug.

116. A plug holder sub for being supported on a conveyance tubular for temporarily supporting a wiper plug and for releasing the wiper plug in response to an increase in fluid pressure within the conveyance tubular, the plug holder sub comprising:

a generally tubular body adapted for connection with the conveyance tubular and having a throughbore in fluid communication with the conveyance tubular;
a retainer member for attaching the wiper plug to the tubular body, the retainer member movable from a retaining position to a release position for releasing the wiper plug from the tubular body;
a piston movable within the tubular body in response to fluid pressure within the throughbore from a retaining position for preventing the releasing member from moving to the release position, the piston acting against a fluid within a chamber within the tubular body when moving to the release position; and
a metering jet along a fluid flow path from the fluid chamber to an annulus about the tubular body, such that fluid pressure within the throughbore restrains movement of the piston to the release position until fluid is forced through the metering jet, thereby preventing release of the liner wiper plug until the piston moves to the release position.

117. The plug holder as defined in Clause 116, wherein the wiper plug includes an internal seat, such that a pump down plug landed on the wiper plug allows for the increase in fluid pressure within the tubular body.

118. The plug holder as defined in Clause 116, wherein the retainer member is a C-shape ring which is radially expanded when the piston is in the release position to release the wiper plug.

119. The plug holder as defined in Clause 116, wherein the C-shaped ring has internal gripping members for gripping engagement with the wiper plug.

120. The plug holder sub as defined in Clause 116, wherein the piston moves axially from the retaining position to the release position.

121. The plug holder sub as defined in Clause 120, wherein a radially interior surface of the piston engages the retainer member to prevent the retainer member from moving to the release position, and axial movement of the piston releases the retainer member to the release position.

122. The plug holder sub as defined in Clause 116, wherein the metered jet has external threads for threaded engagement with the tubular body.

123. The plug holder sub as defined in Clause 116, wherein the metering jet is secured to the tubular body by a swage connection.

124. A plug holder sub for being supported on a conveyance tubular for temporarily supporting a wiper plug and for releasing the wiper plug in response to an increase in fluid pressure within the conveyance tubular, the plug holder sub comprising:

a generally tubular body adapted for connection with the conveyance tubular and having a throughbore in fluid communication with the conveyance tubular;
a retainer member for attaching the liner wiper plug to the tubular body, the retainer member movable from a retaining position to a release position for releasing the wiper plug from the tubular body;
a piston axially movable within the tubular body in response to fluid pressure within the throughbore from a retaining position for preventing the releasing member from moving to the release position, a radially interior surface of the piston engaging the retainer member to prevent the retainer member from moving to the release position, and axial movement of the piston releases the retainer member to the release position, thepiston acting against a fluid within a chamber within the tubular body when moving to the release position; and
a metering jet along a fluid flow path from the fluid chamber to an annulus about the tubular body, such that fluid pressure within the throughbore restrains movement of the piston to the release position until fluid is forced through the metering jet, thereby preventing release of the liner wiper plug until the piston moves to the release position.

125. The plug holder sub as defined in Clause 124, wherein the plug holder sub is positioned on a lower end of a liner hanger running tool, and the wiper plug is a liner wiper plug.
126. The plug holder as defined in Clause 125, wherein the liner wiper plug includes an internal seat, such that a pump down plug landed on the liner wiper plug allows for the increase in fluid pressure within the tubular body.
127. The plug holder sub as defined in Clause 124, wherein the fluid in the chamber has a known viscosity.
128. The plug holder as defined in Clause 124, herein the retainer member is a C-shape ring which is radially expanded when the piston is in the release position to release the wiper plug, and the C-shaped ring has internal gripping members for gripping engagement with the liner wiper plug.
129. A method of supporting a liner wiper plug on a conveyance tubular and for releasing the liner wiper plug in response to an increase in fluid pressure within the conveyance tubular, the method comprising:

providing a generally tubular body adapted for connection with the conveyance tubular and having a throughbore in fluid communication with the conveyance tubular;
providing a retainer member for attaching the liner wiper plug to the tubular body, the retainer member movable from a retaining position to a releases position for releasing the liner wiper plug from the tubular body;
moving a piston within the tubular body in response to fluid pressure within the throughbore from a retaining position for preventing the releasing member from moving to the release position, the piston acting against a fluid within a chamber within the tubular body when moving to the release position;
metering discharge of fluid along a fluid flow path from the fluid chamber to an annulus about the tubular body, such that fluid pressure within the throughbore restrains movement of the piston to the release position until fluid is forced through a metering jet, thereby preventing release of the liner wiper plug until the piston moves to the release position;
allowing the retainer member to move to the release position when the piston is in the release position, thereby releasing the liner wiper plug from the tubular body; and
monitoring a drop in fluid pressure in response to the release of the liner wiper plug.

130. The method as defined in clause 129, wherein the retainer member includes providing a C-shape ring which is radially expanded when the piston is in the release position to release the liner wiper plug.
131. The method as defined in clause 130, further comprising:

providing internal gripping members on the C-shaped ring for gripping engagement with the liner wiper plug.

132. The method as defined in Clause 129, wherein a piston moves axially from the retaining position to the release position.
133. The method as defined in Clause 129, wherein the piston moves axially from the retaining position to the release position.
134. The method as defined in Clause 133, wherein a radially interior surface of the piston engages the retainer member to prevent the retainer member from moving to the release position, and axial movement of the piston releases the retainer member to the release position.
135. The method as defined in Clause 129, further comprising:

providing an infernal seat on the liner wiper plug, such that a pump down plug landed on the liner wiper plug allows for the increase in fluid pressure within the tubular body.

Claims

1. A tool for use in a subterranean well to seal with a generally cylindrical interior surface of a tubular or another downhole tool, the tool comprising:

a conveyance tubular for positioning the tool at a selected location below the surface of the well;
an annular seal assembly disposed about the conveyance tubular, the seal assembly having a reduced diameter run-in position and an expanded sealing position;
a wedge ring having a substantially conical outer surface configured to radially expand the annual seal assembly upon axial movement of the annular seal assembly relative to the wedge ring such that the seal assembly is expanded from its run-in position to its expanded sealing position wherein the seal assembly is in sealing engagement with the generally cylindrical interior surface; and
the annular seal assembly including a metal framework having a radially inward annular base and a plurality of metal ribs each extending radially outward from the base, the metal framework including an upper downwardly angled primary seal metal rib for sealing pressure below the seal assembly, a lower upwardly angled primary seal metal rib for sealing pressure above the seal assembly, a primary elastomeric seal in a cavity readially outward from the base and axially between the upper primary seal metal rib and the lower primary seal metal rib, an upper downwardly angled secondary seal metal rib spaced axially above the upper primary seal metal rib, and a lower upwardly angled secondary seal metal rib spaced axially below the lower primary seal metal rib.

2. A tool for suspending from a running string to position a liner hanger in a casing within a wellbore, suspending a liner from the liner hanger and retrieving portions of the tool, comprising:

The tool mandrel supported from the running string;
a slip setting assembly about the mandrel for setting slips to engage the casing and suspend the liner hanger from the casing; and
a releasing assembly for releasing from the set liner hanger portions of the too to be retrieved to the surface, the releasing assembly including a connecting member for engaging the tool with the liner hanger, a first piston hydraulically moveable in response to fluid pressure within the tool mandrel from a lock position to a release position for releasing the connecting member, a clutch for rotationally connecting the tool mandrel with the liner hanger, and a second piston movable in response to fluid pressure within the tool mandrel for disengaging the clutch, such that right-hand rotation of the running string moves the nut downward along the mandrel so that the running string may then be picked up to disengage the tool from the liner hanger.

3. The tool as defined in claim 2, further comprising:

a piston shear member for interconnecting the first piston and the second piston, such that the second piston may be disconnected from the first piston in response to fluid pressure within the tool mandrel.

4. A method of releasing a running tool while supported on a running string from a liner hanger in a casing within a wellbore, the liner hanger being secured to a casing by a slip assembly to suspend the liner hanger from the casing, the method comprising:

providing a releasing assembly about a tool mandrel, the releasing assembly including a connecting member for engaging the running string with the liner hanger, a first piston hydraulically moveable in response to fluid pressure within the tool mandrel from a lock position to a release position for releasing the connecting member, a clutch for rotationally connecting the tool mandrel with the liner hanger, and a second piston moveable in response to fluid pressure within the tool mandrel for disengaging the clutch; and
pressurizing the running string to move the first piston to the release position for releasing the running string.

5. The method as defined in claim 4, further comprising;

pressurizing the running string to move the second piston to disengage the clutch;
rotating the running string to move a nut downward along the tool mandrel; and thereafter picking p the running string to disengage the running tool from the liner hanger.

6. For use with a downhole cementing tool, comprising a tubular member having an upper end connected to a well pipe for lowering into a well bore to permit it to be cemented therein, and having a bore with a relatively large diameter upper portion enabling one or more balls and pump down plugs to be lowered therein and a smaller lower portion including a liner wiper plug whose bore is smaller than the balls but permits passage of the pump down plugs therethrough,

a diverter including a sub forming a part of the tubular member intermediate the upper and lower portions and having a side pocket to one side of the bore to receive a ball prior to passage of a pump down plug therethrough, and
a ramp extending diagonally across the sub and slanted downwardly to guide the ball into the side pocket and having a U-shaped opening facing the pocket to prevent passage of the ball, but permit a plug to pass between the ball and pocket into the liner wiper plug.

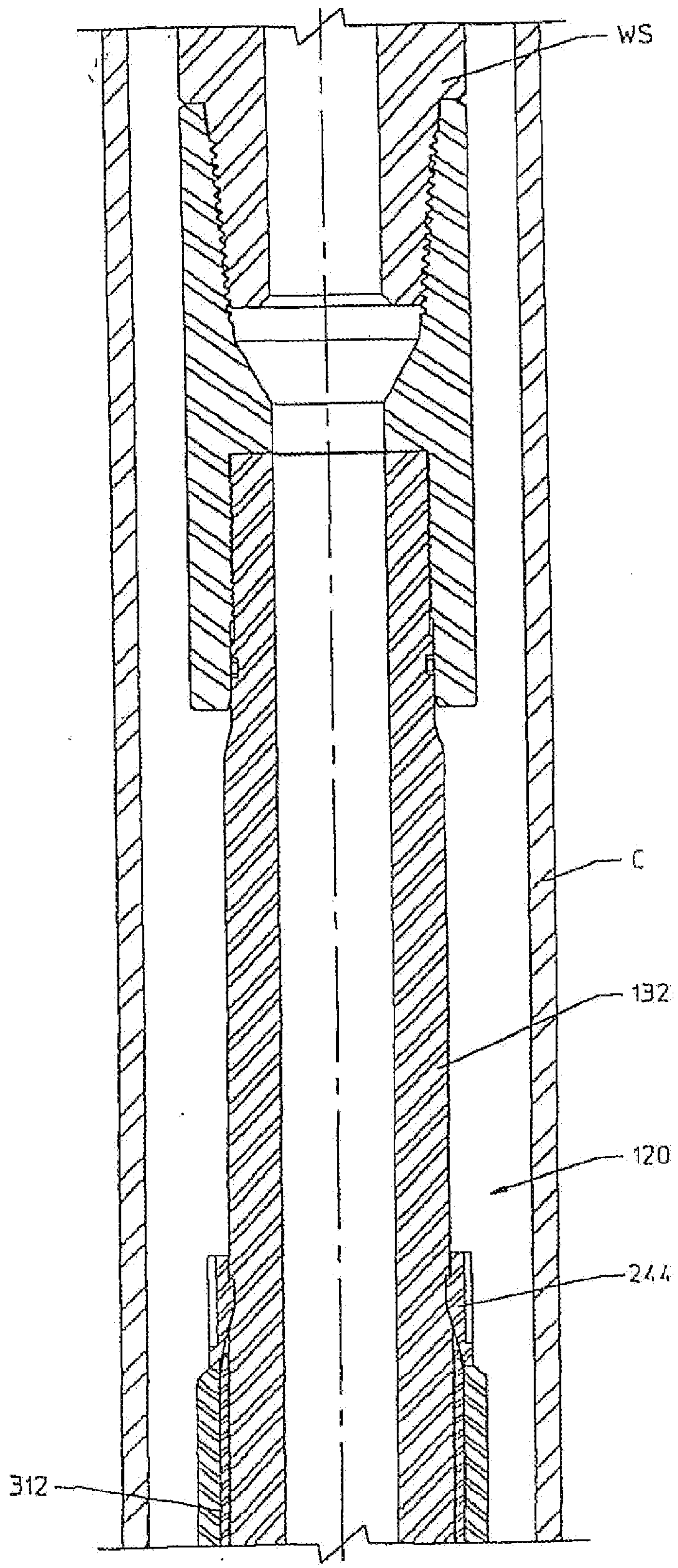


FIGURE 1A

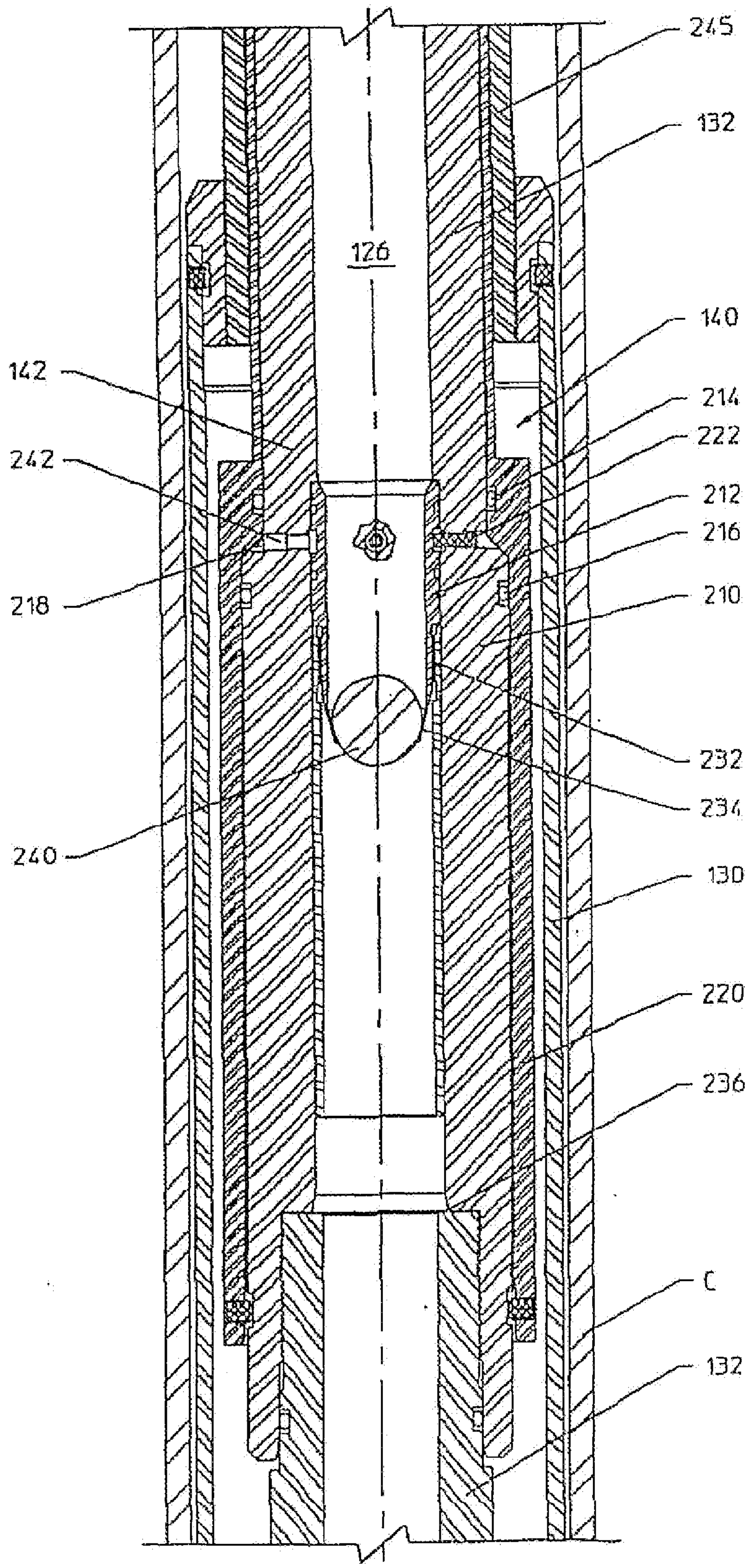

245
132
126
140
142
214
222
242
212
216
218
210
232
234
240
130
220
236
C
132

FIGURE 1B

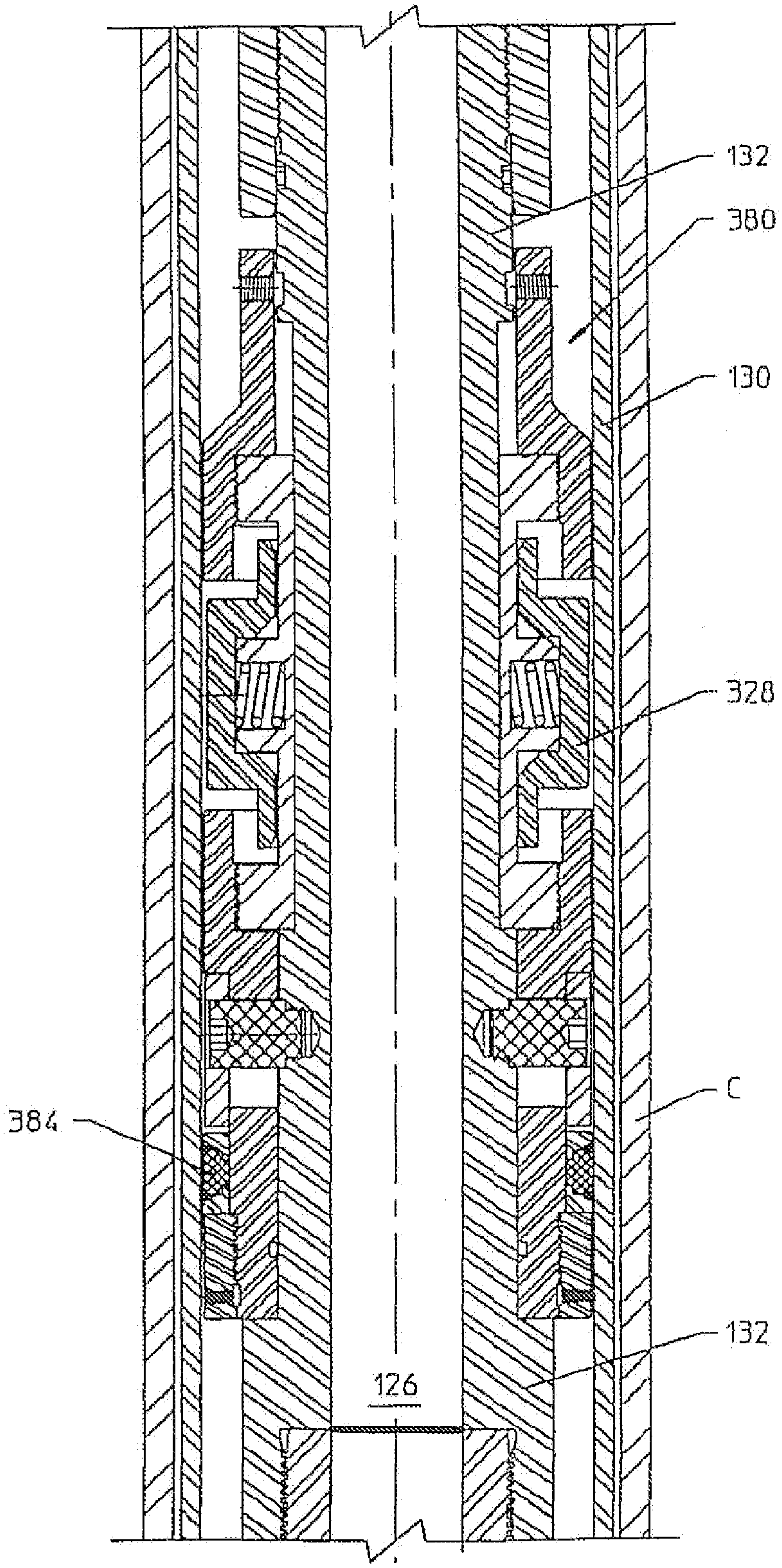


FIGURE 1C

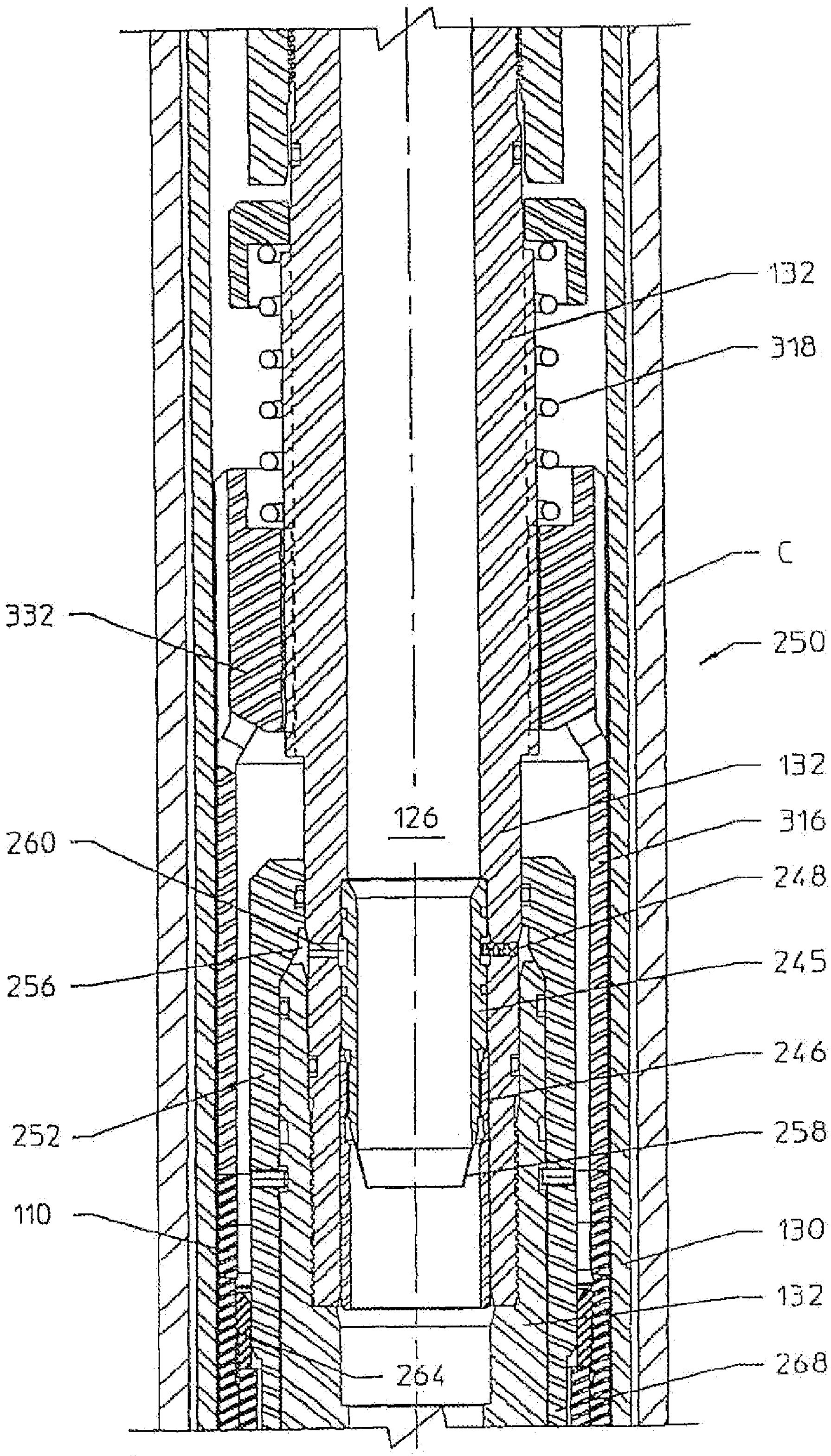

132
318
C
332
250
132
126
316
260
248
256
245
246
252
258
110
130
132
264
268

FIGURE 1D

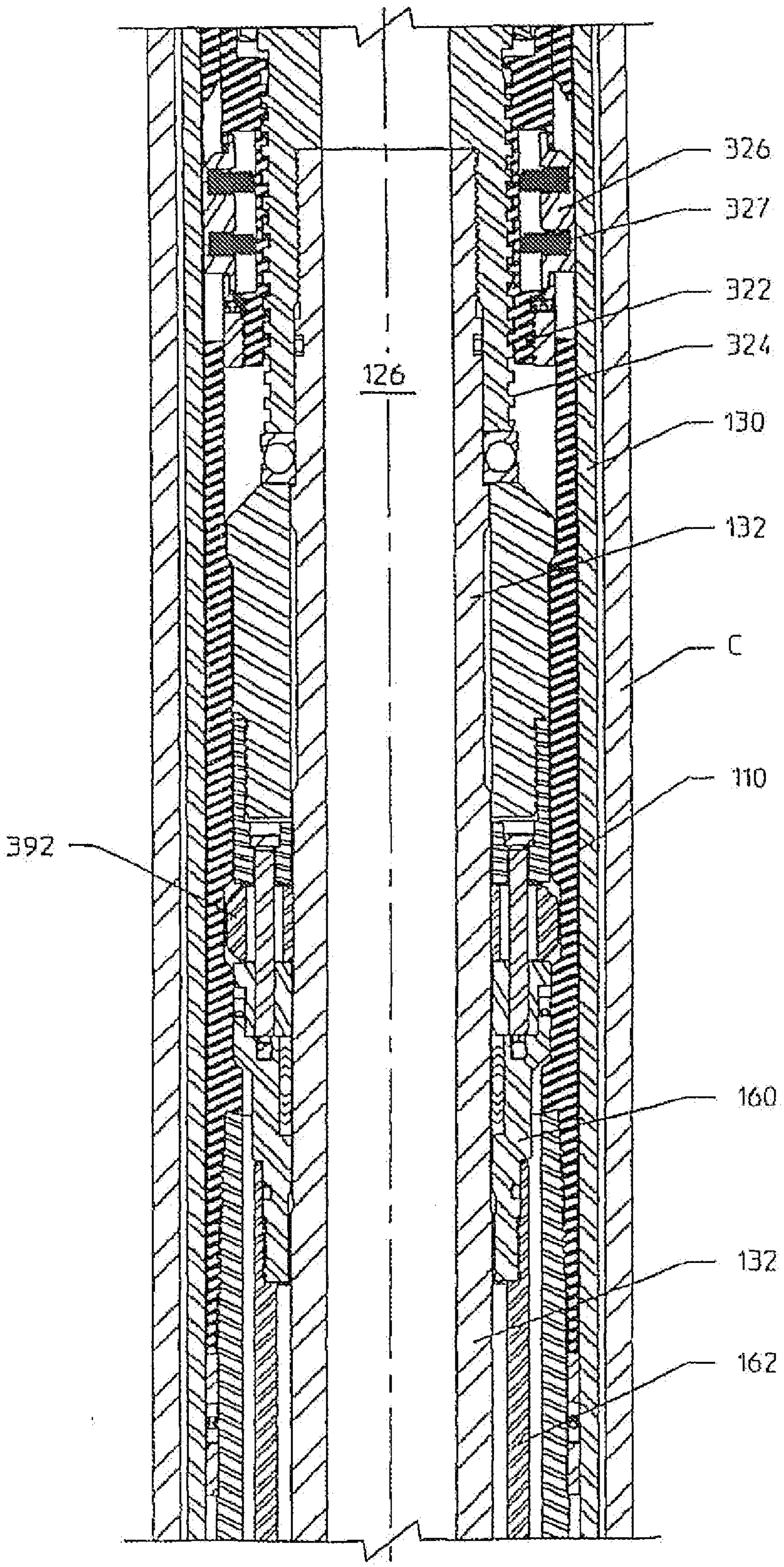


FIGURE 1E

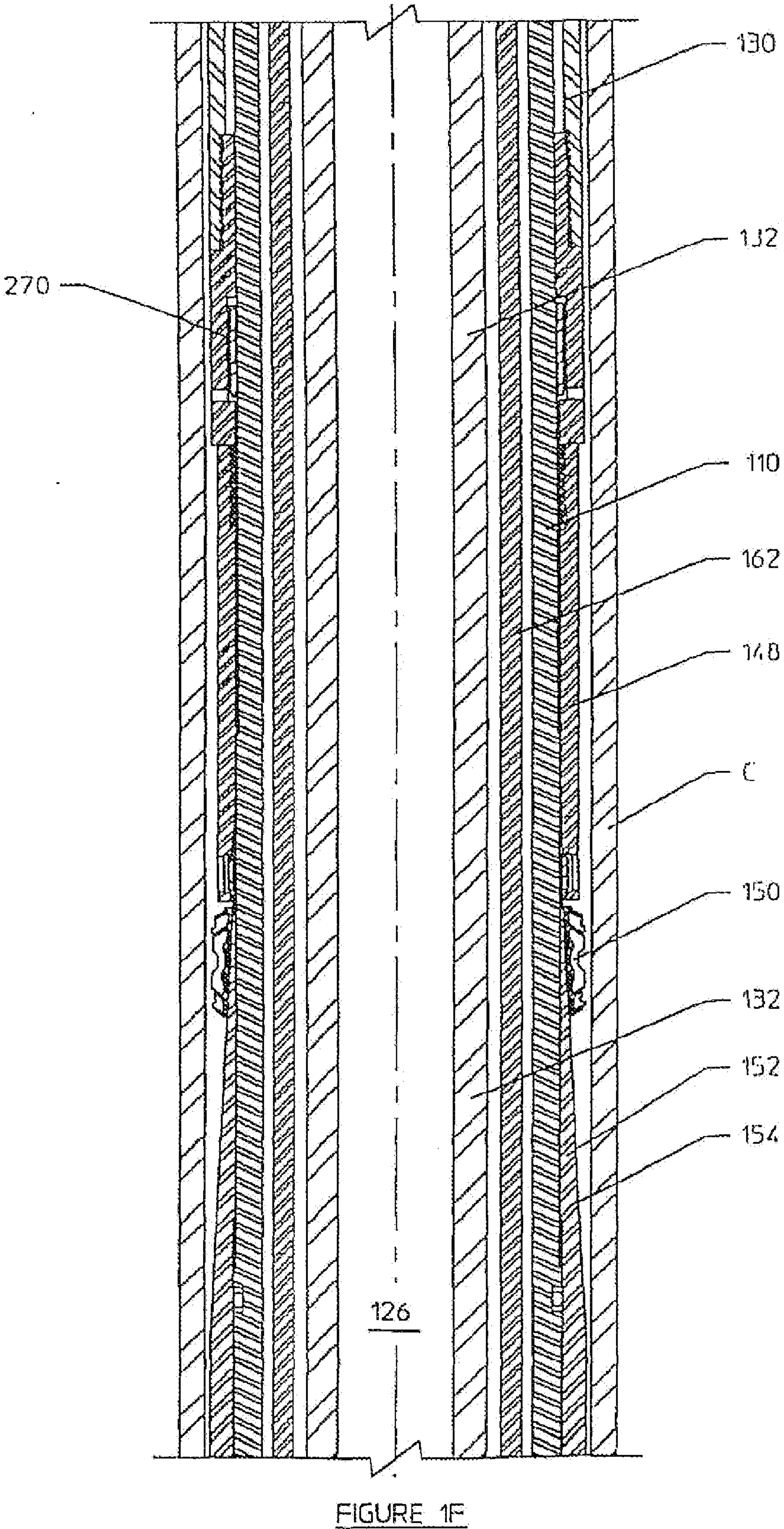


FIGURE 1F

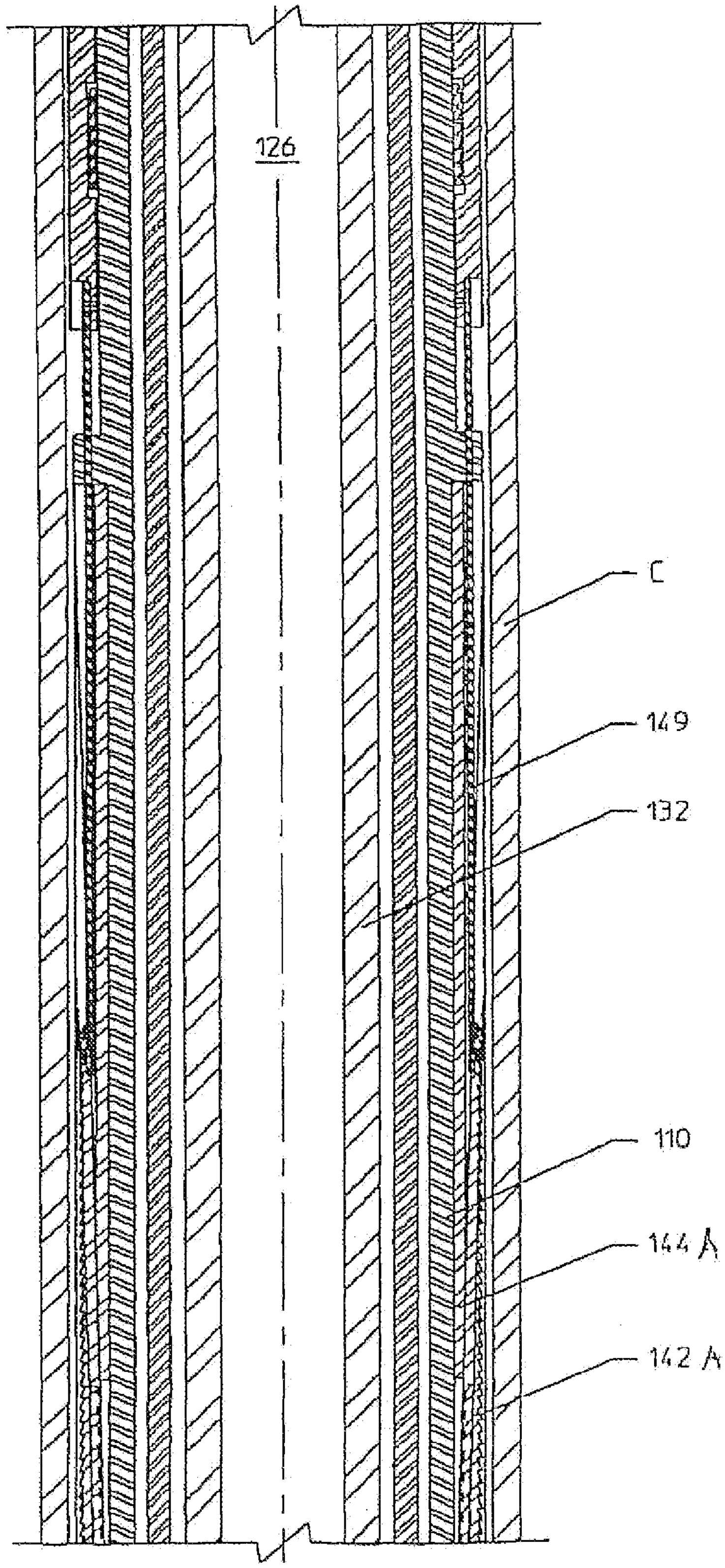


FIGURE 1G

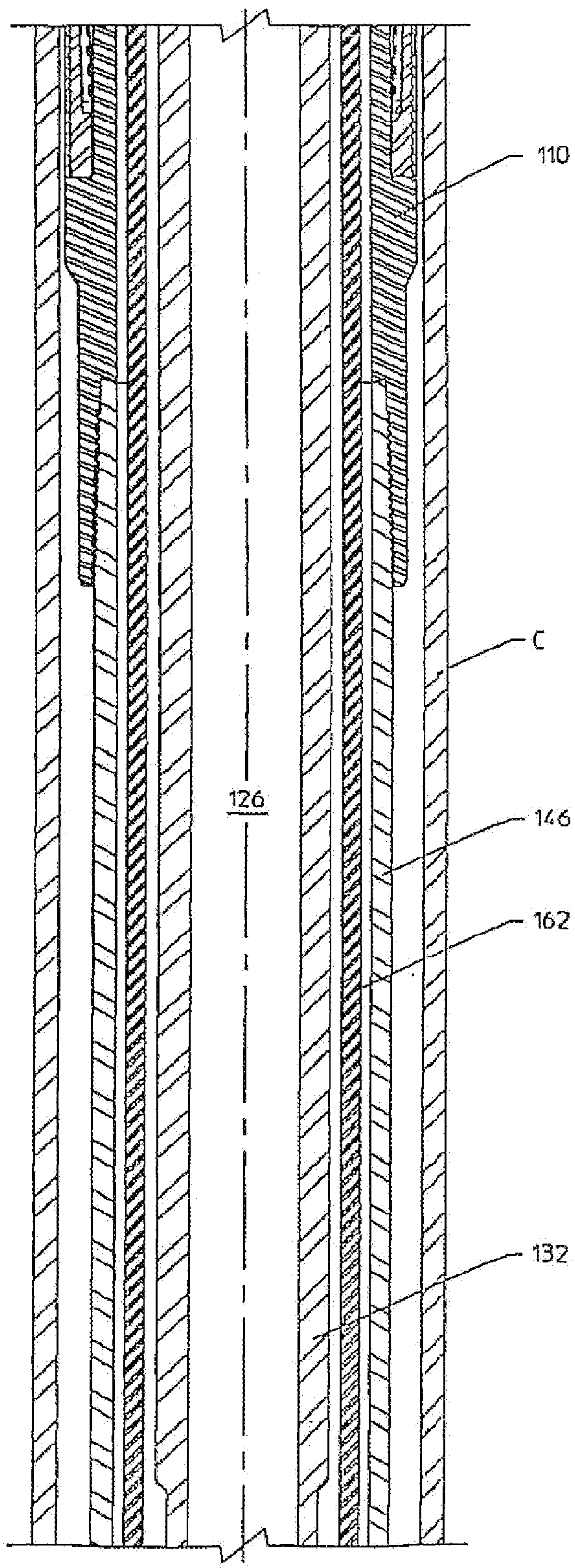


FIGURE 1H

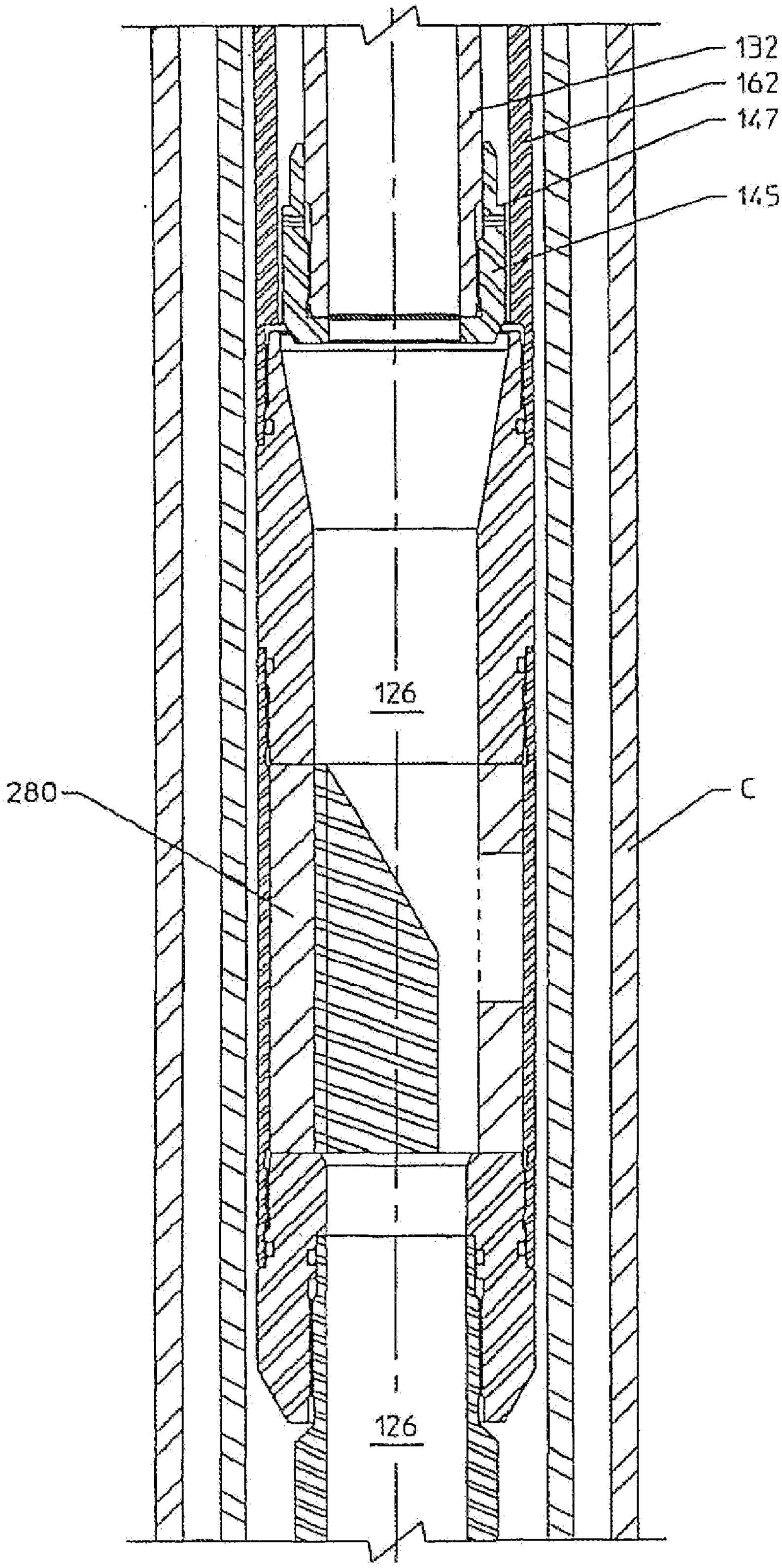


FIGURE 1L

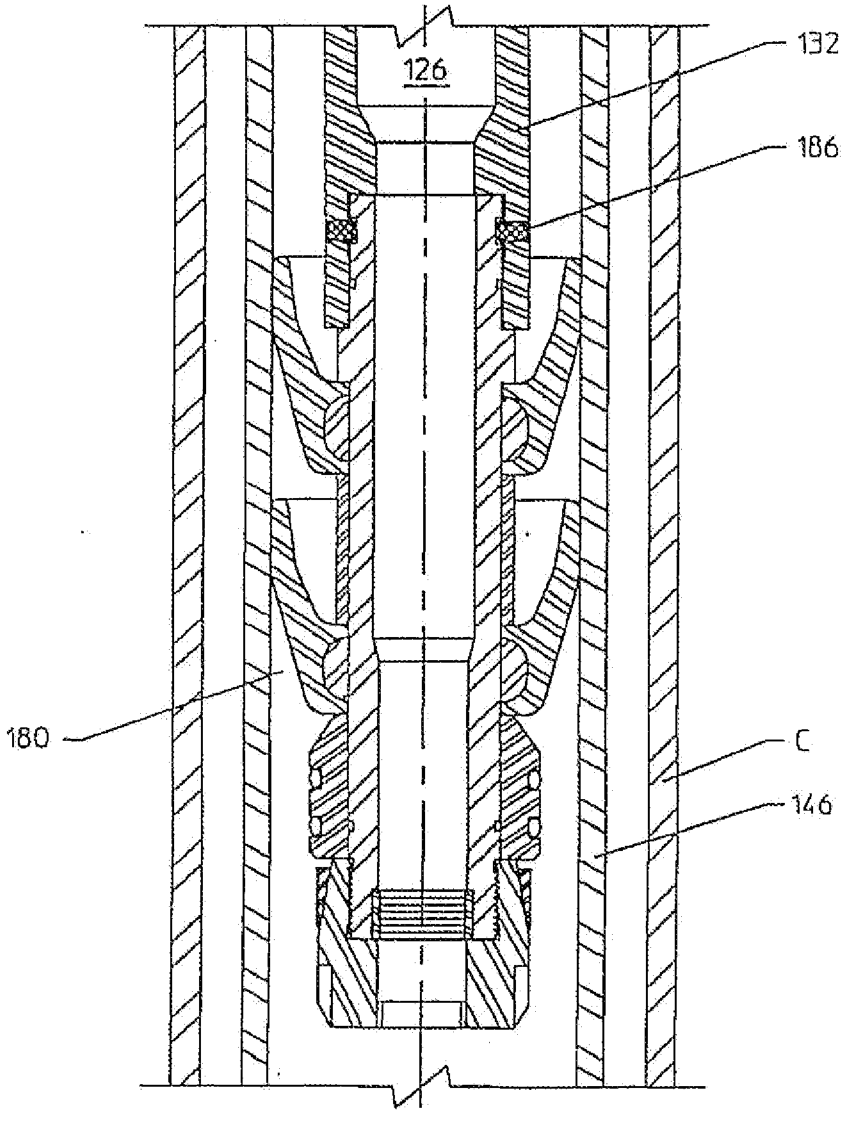


FIGURE 1J

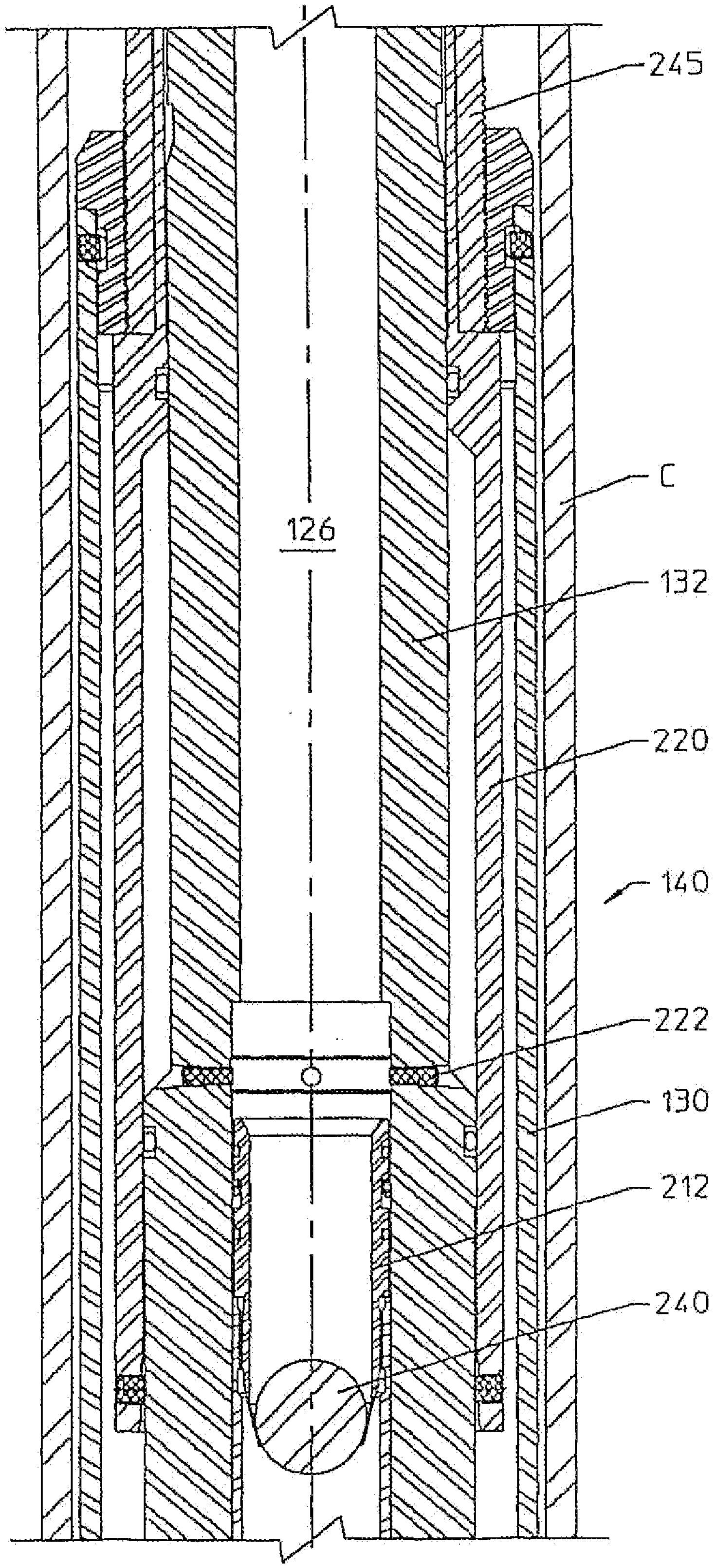


FIGURE 2A

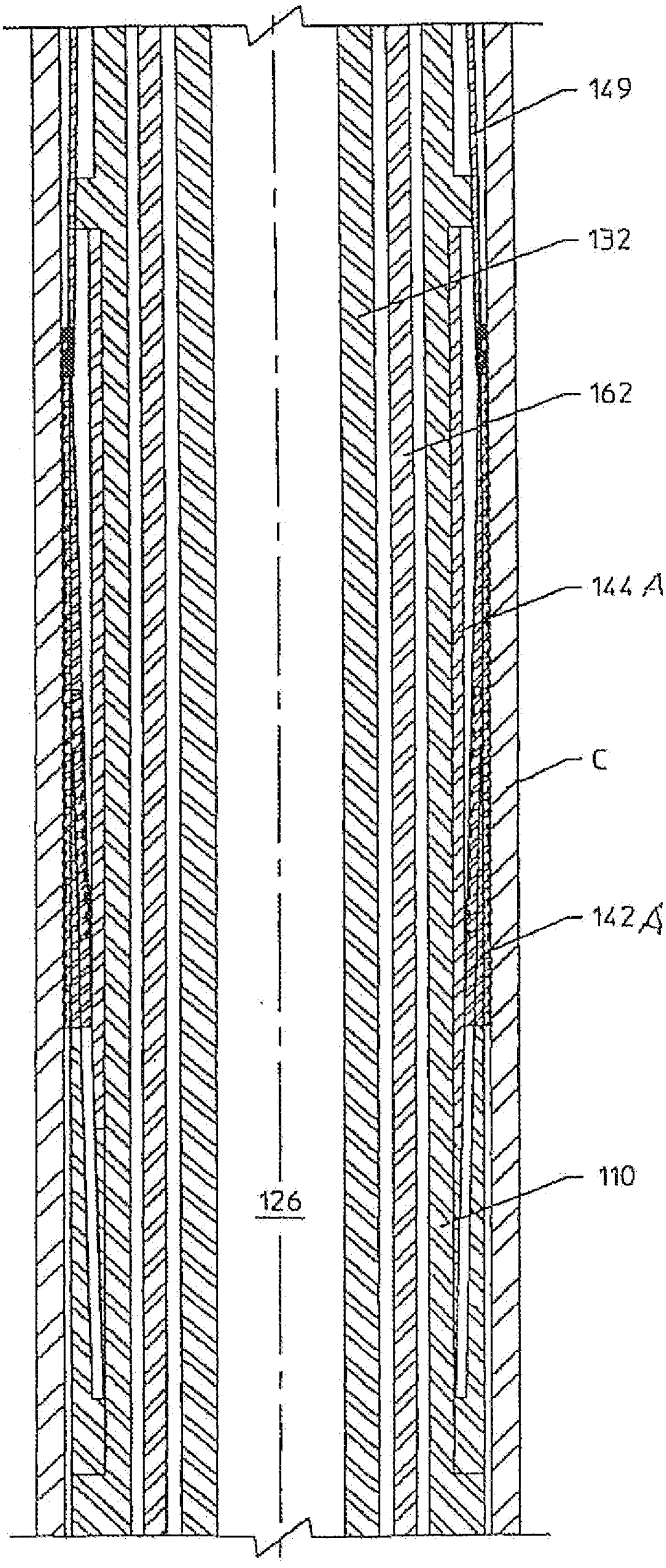


FIGURE 2B

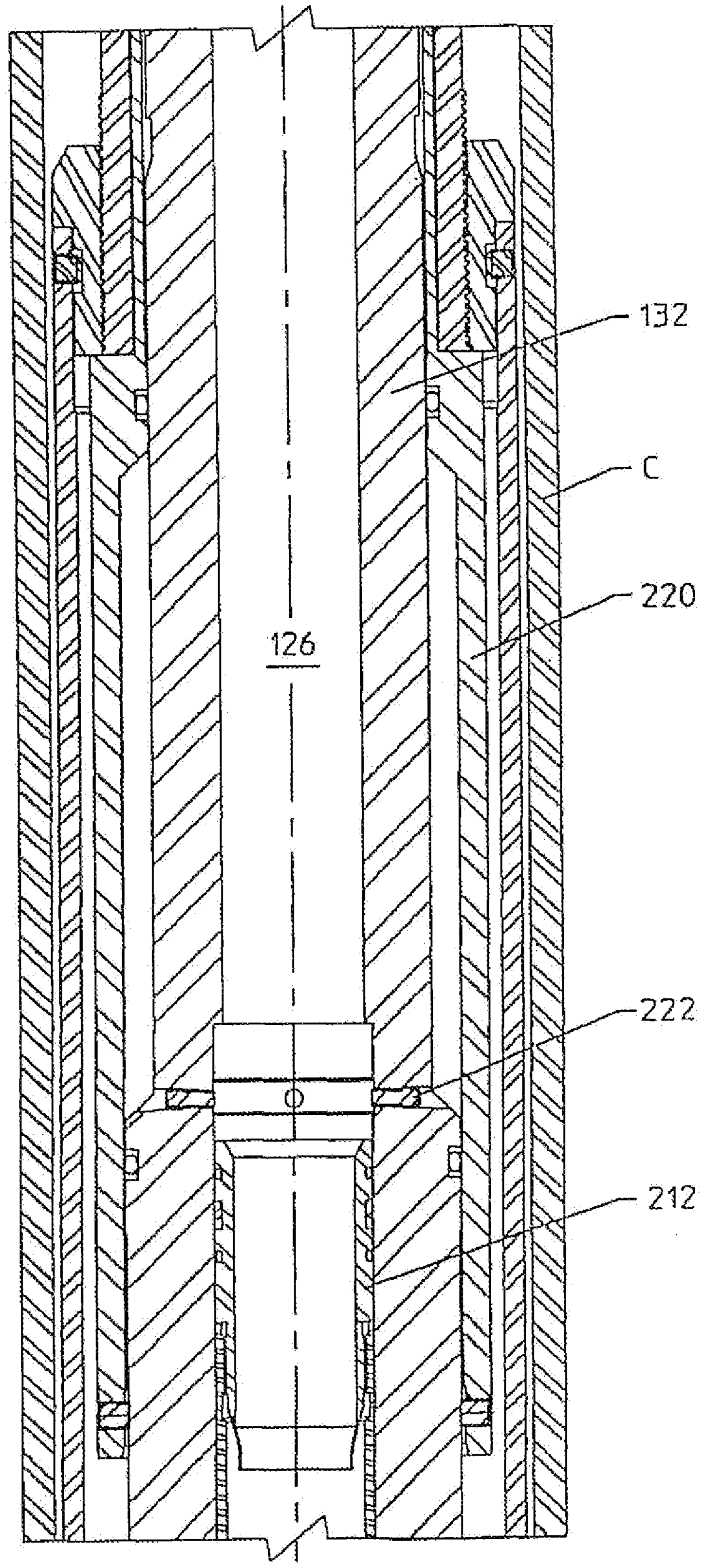


FIGURE 3A

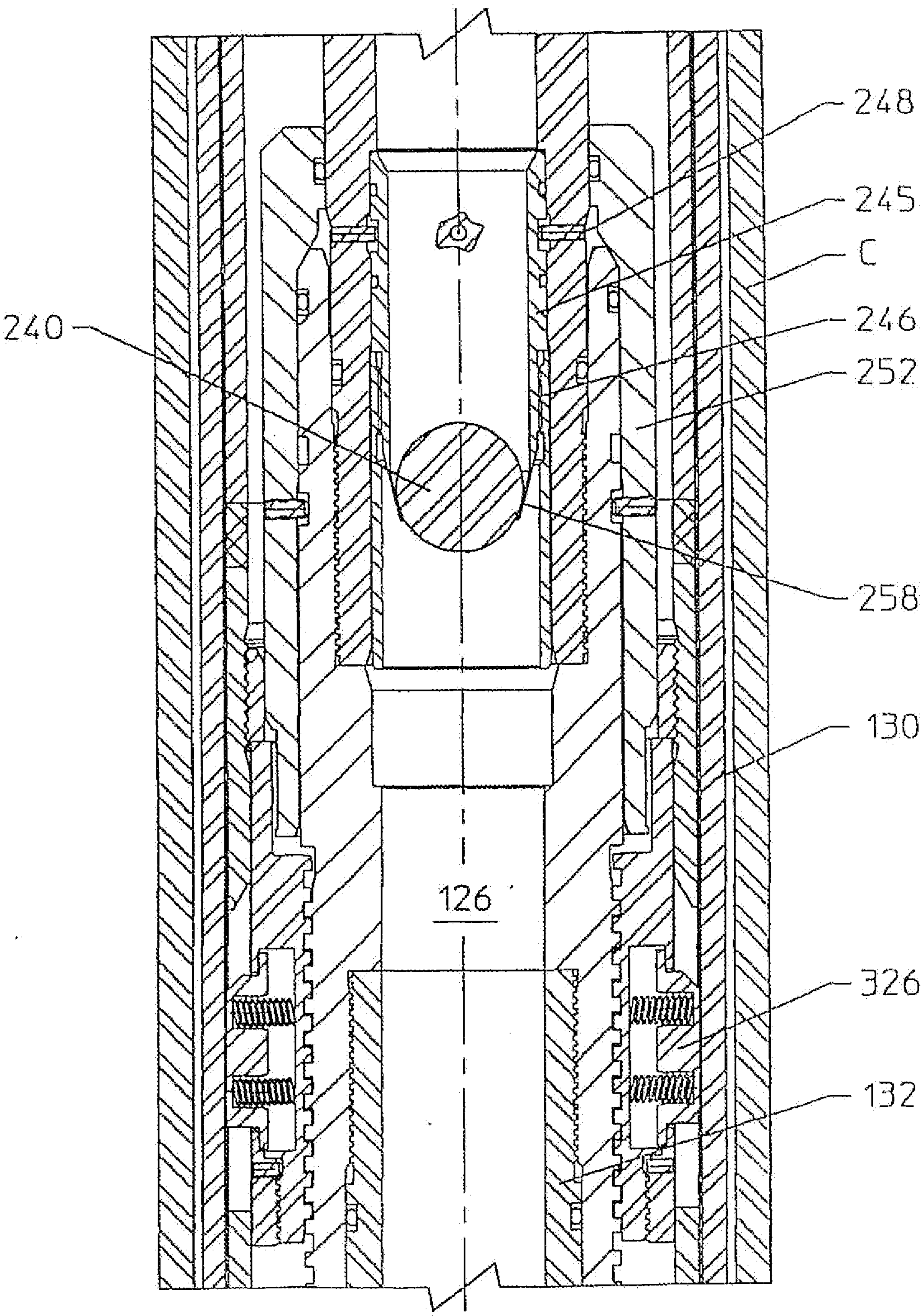


FIGURE 3B

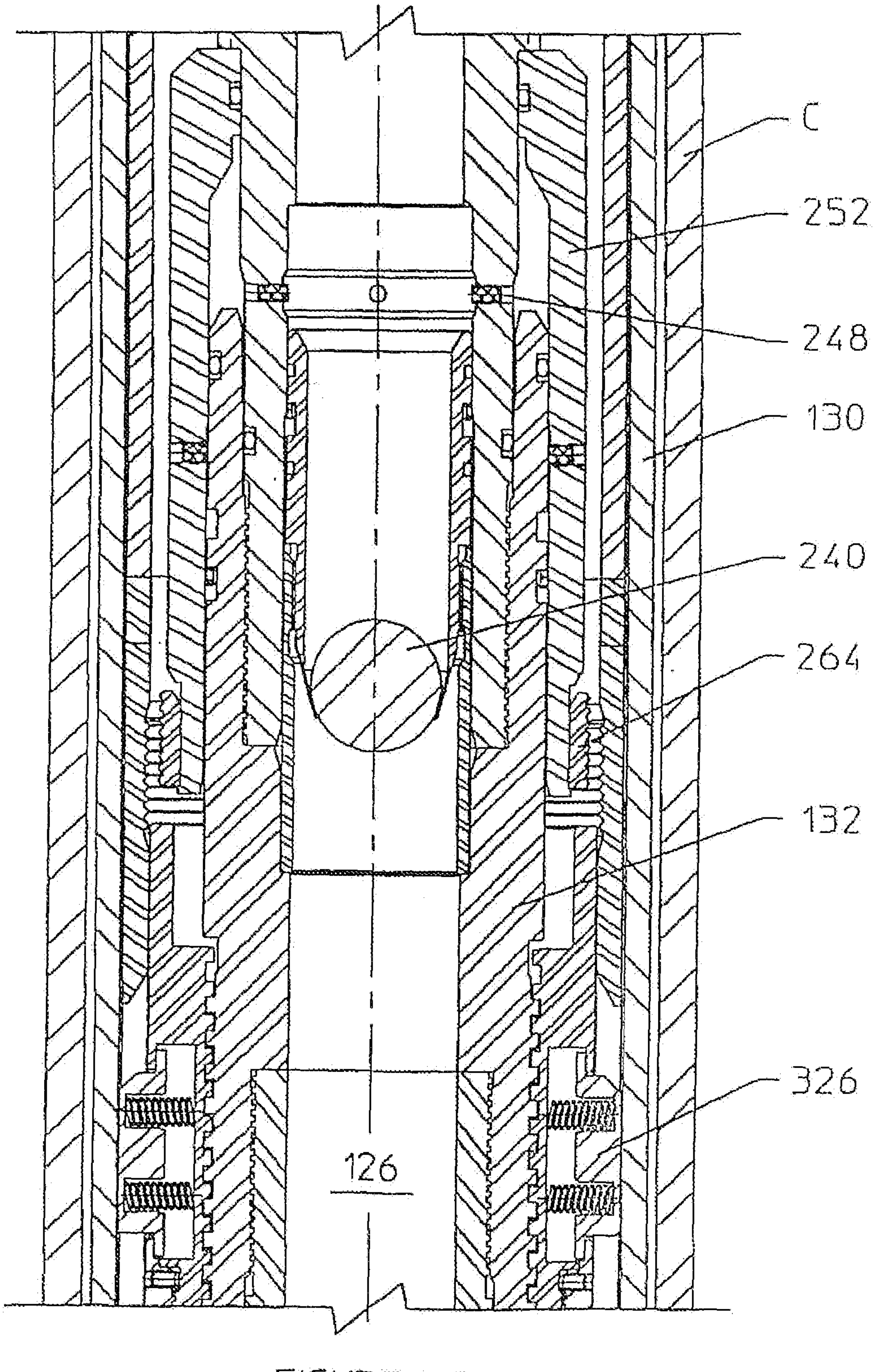


FIGURE 3C

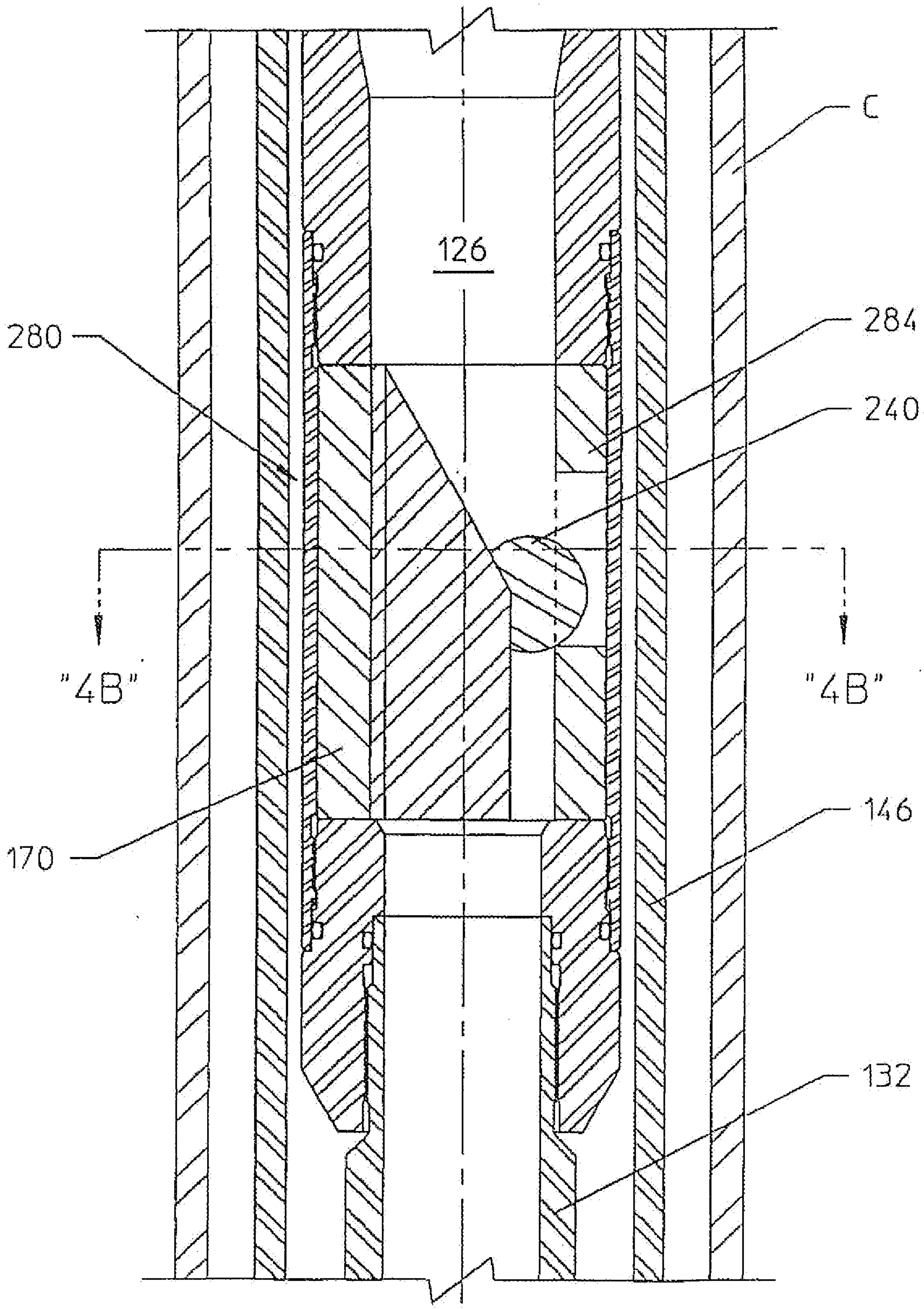


FIGURE 4A

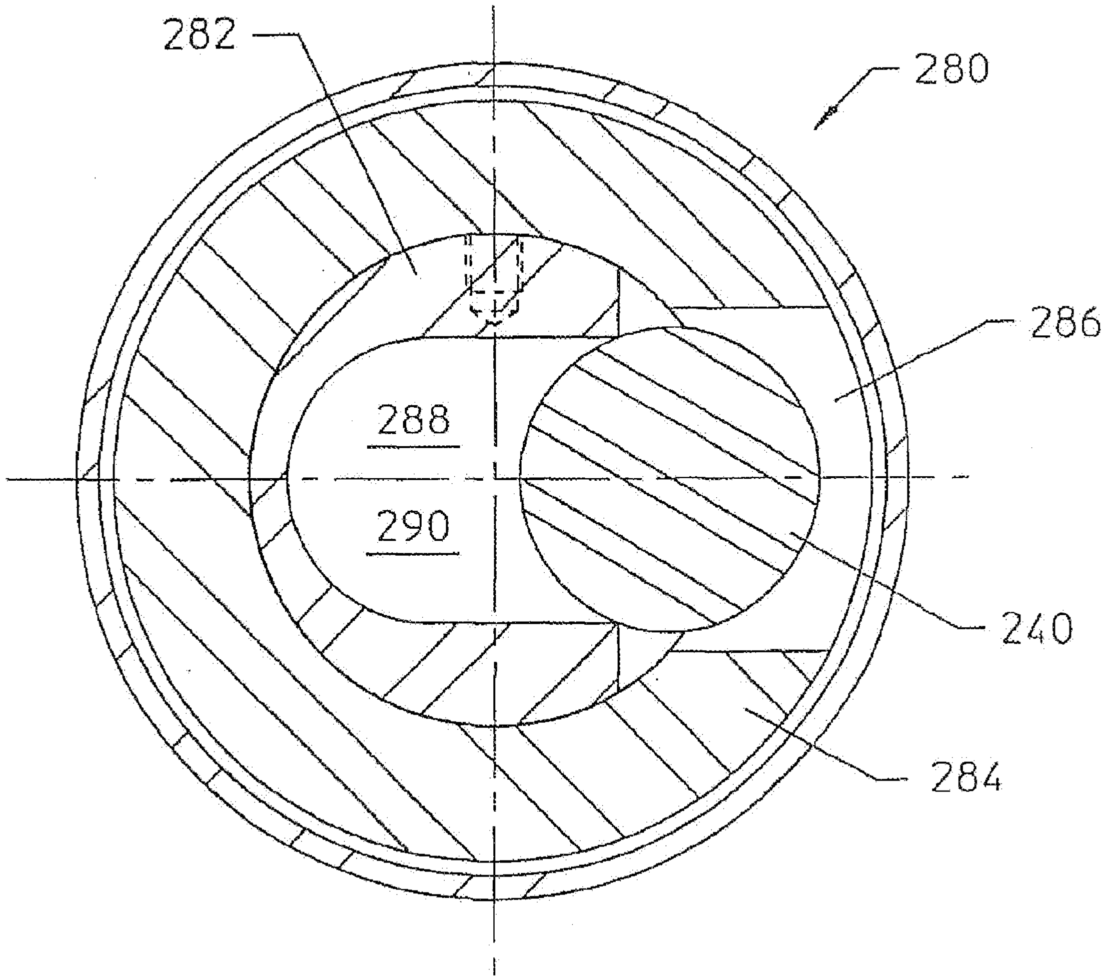


FIGURE 4B

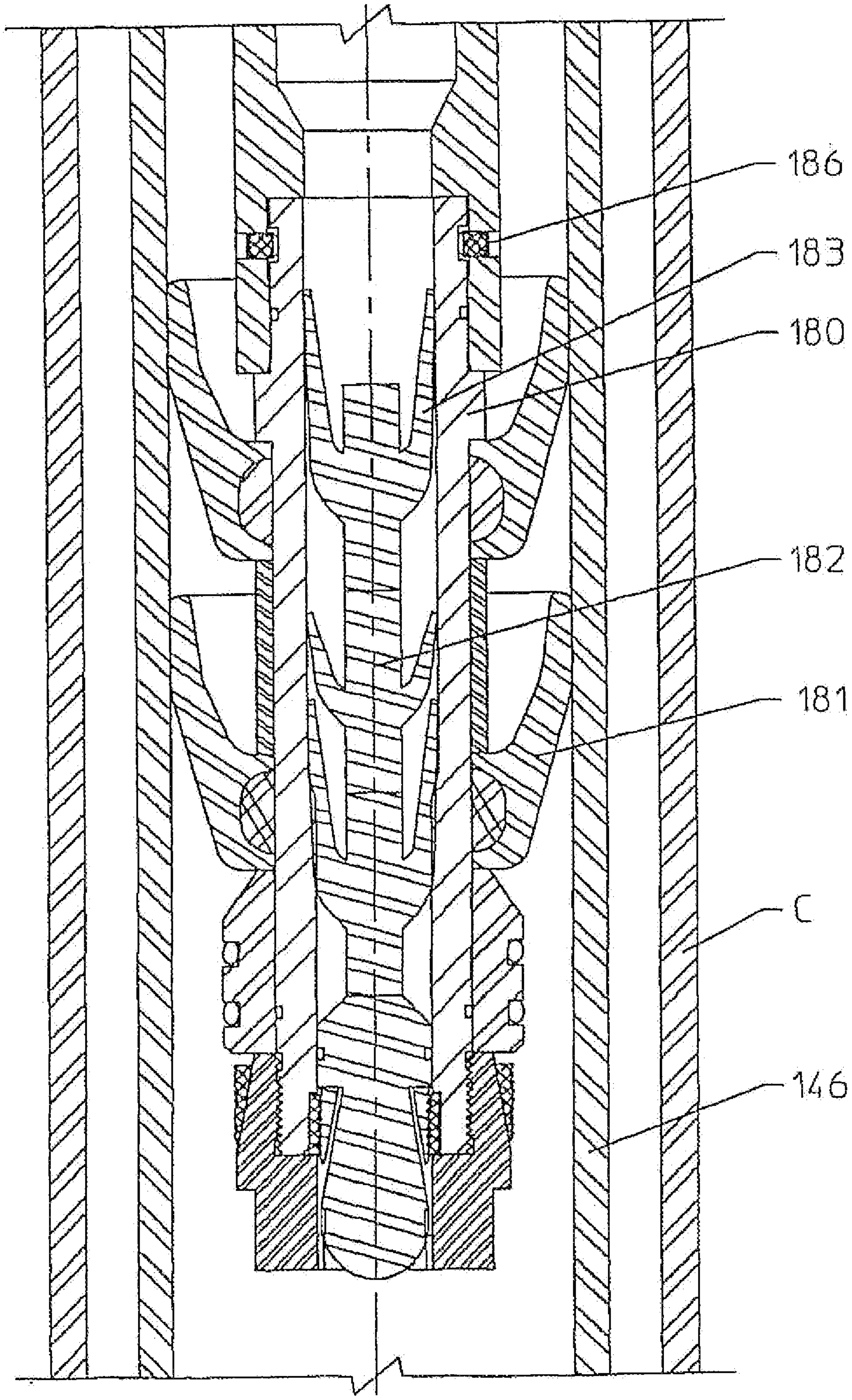


FIGURE 5A

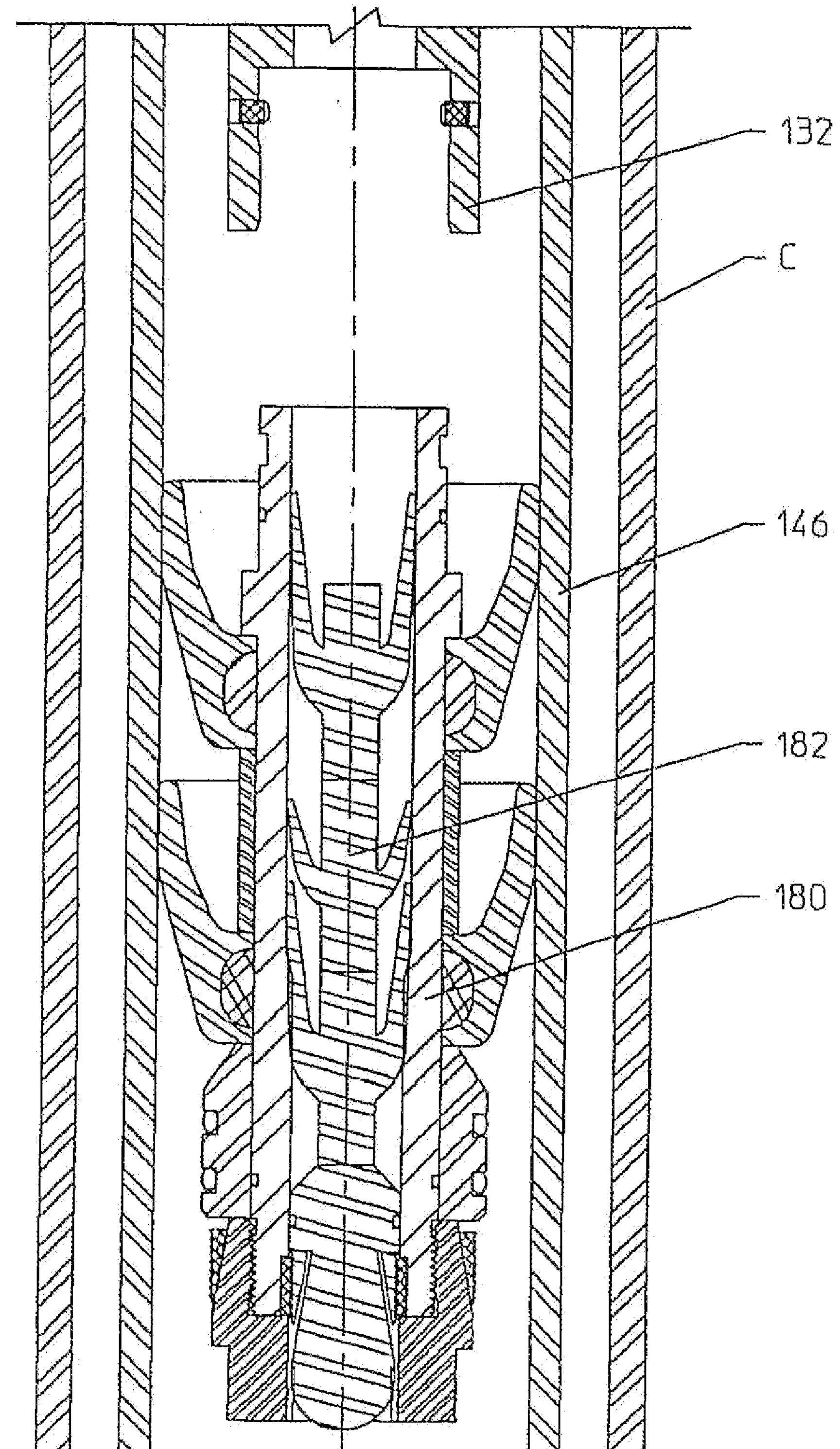


FIGURE 5B

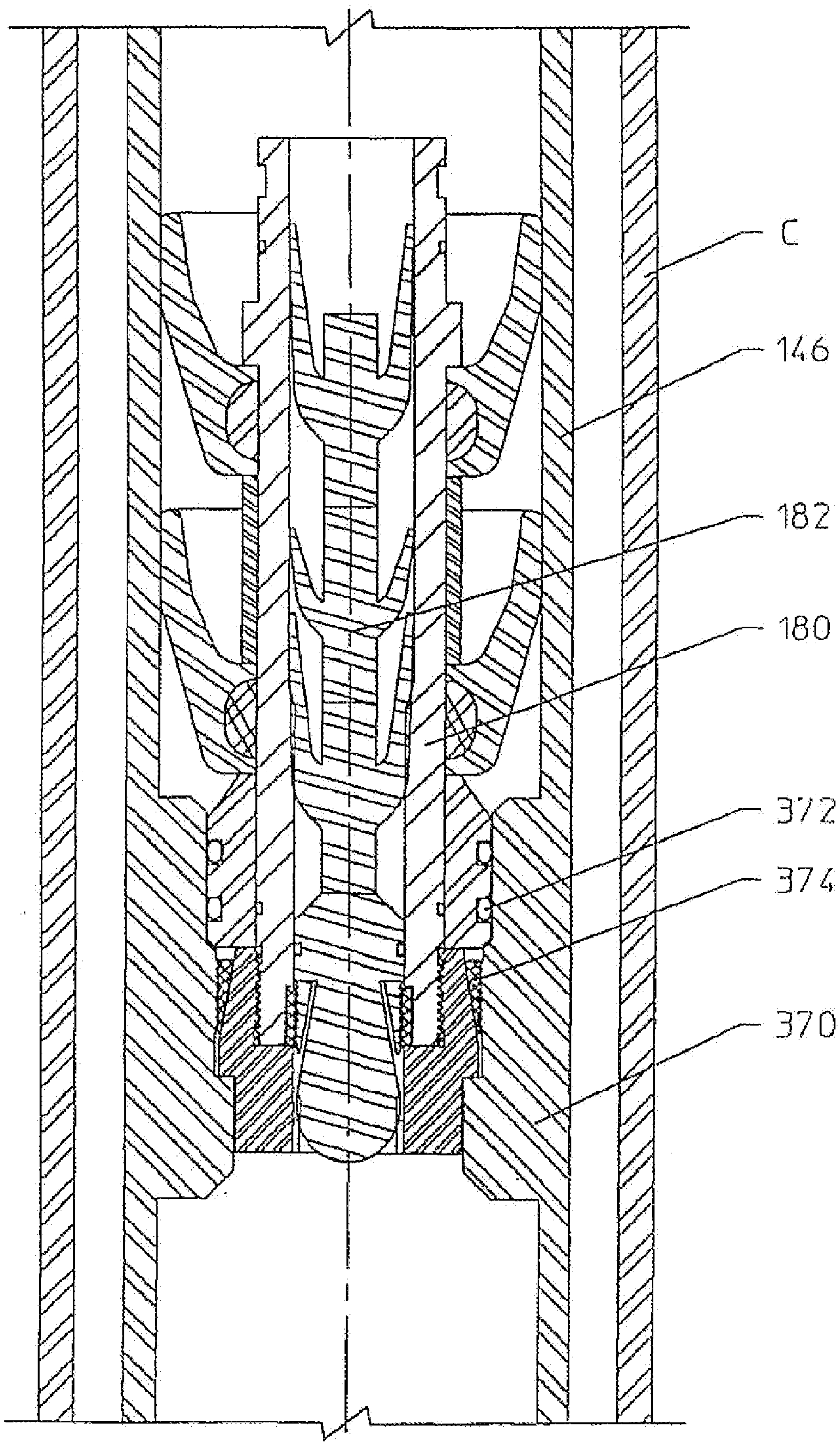


FIGURE 5C

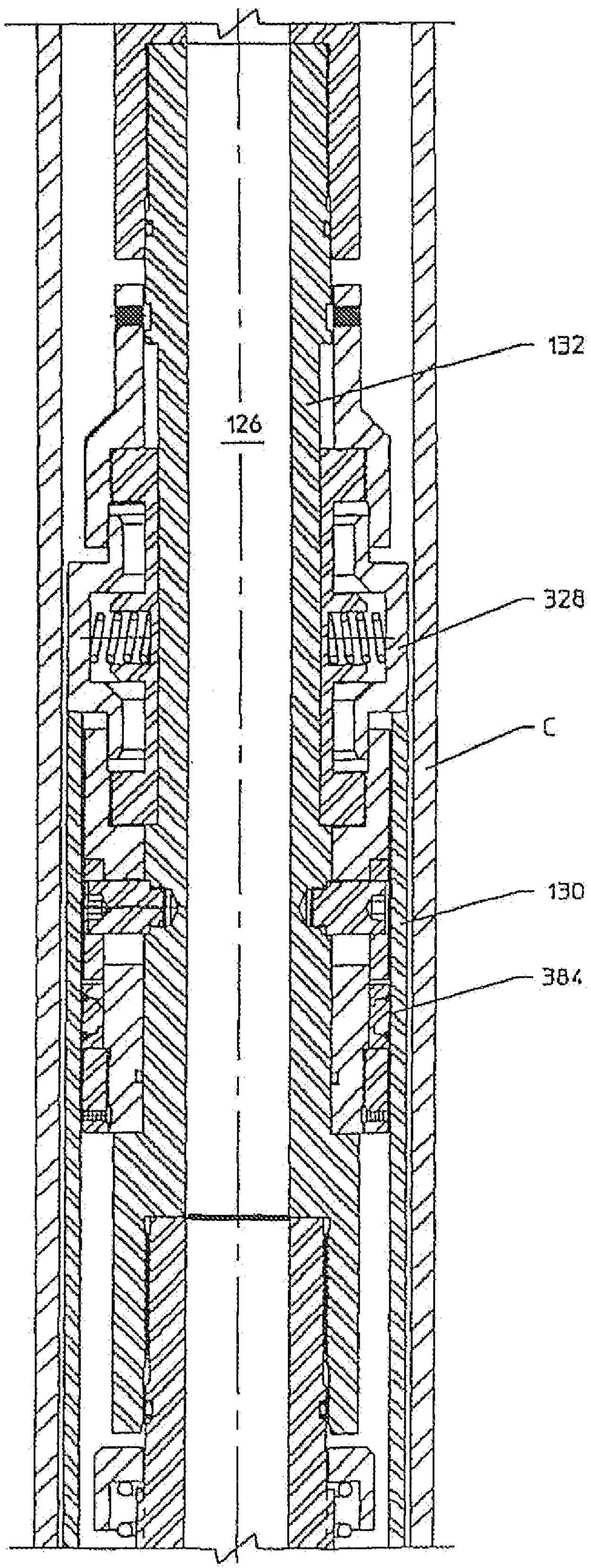


FIGURE 6A

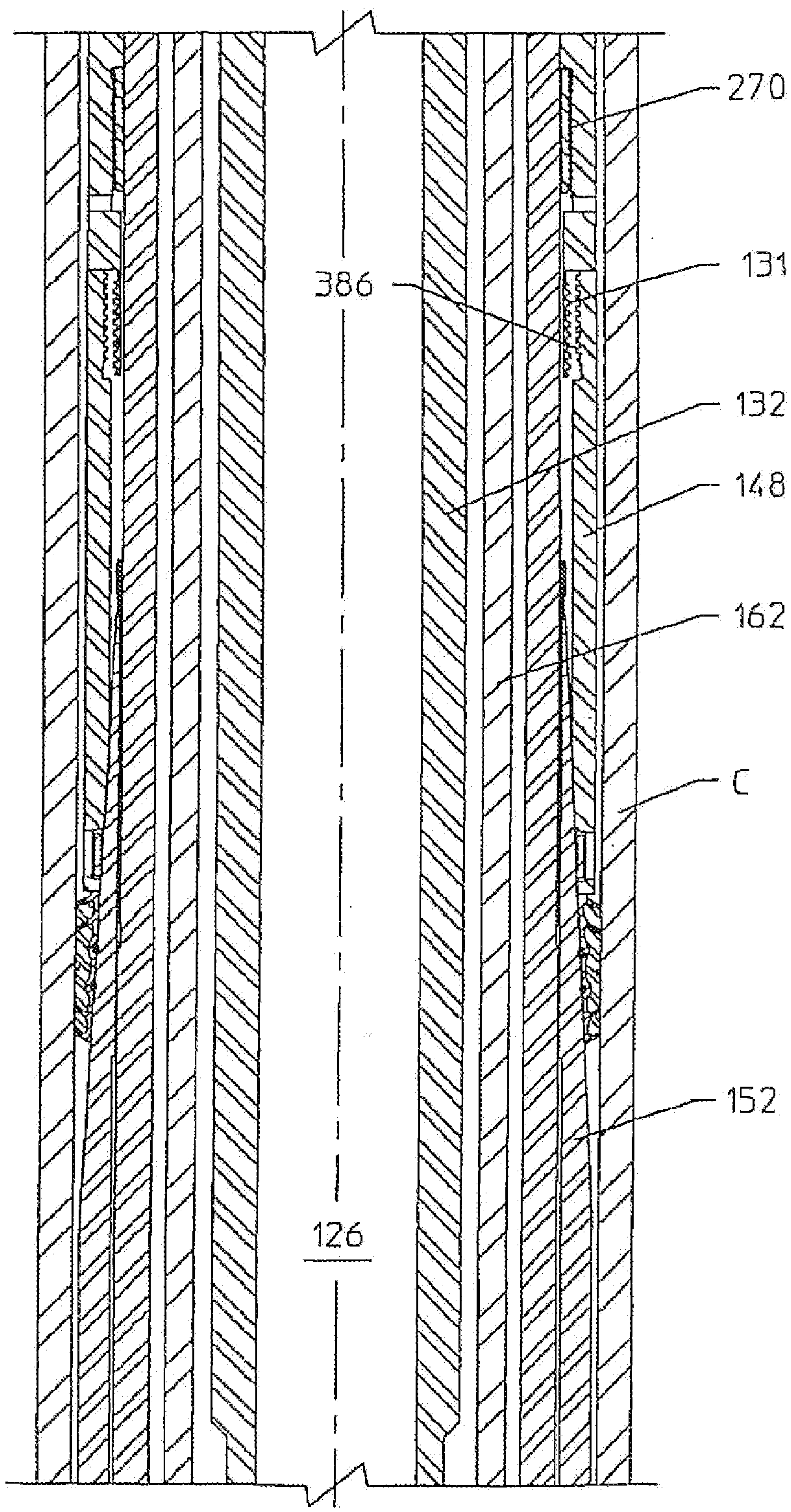


FIGURE 6B

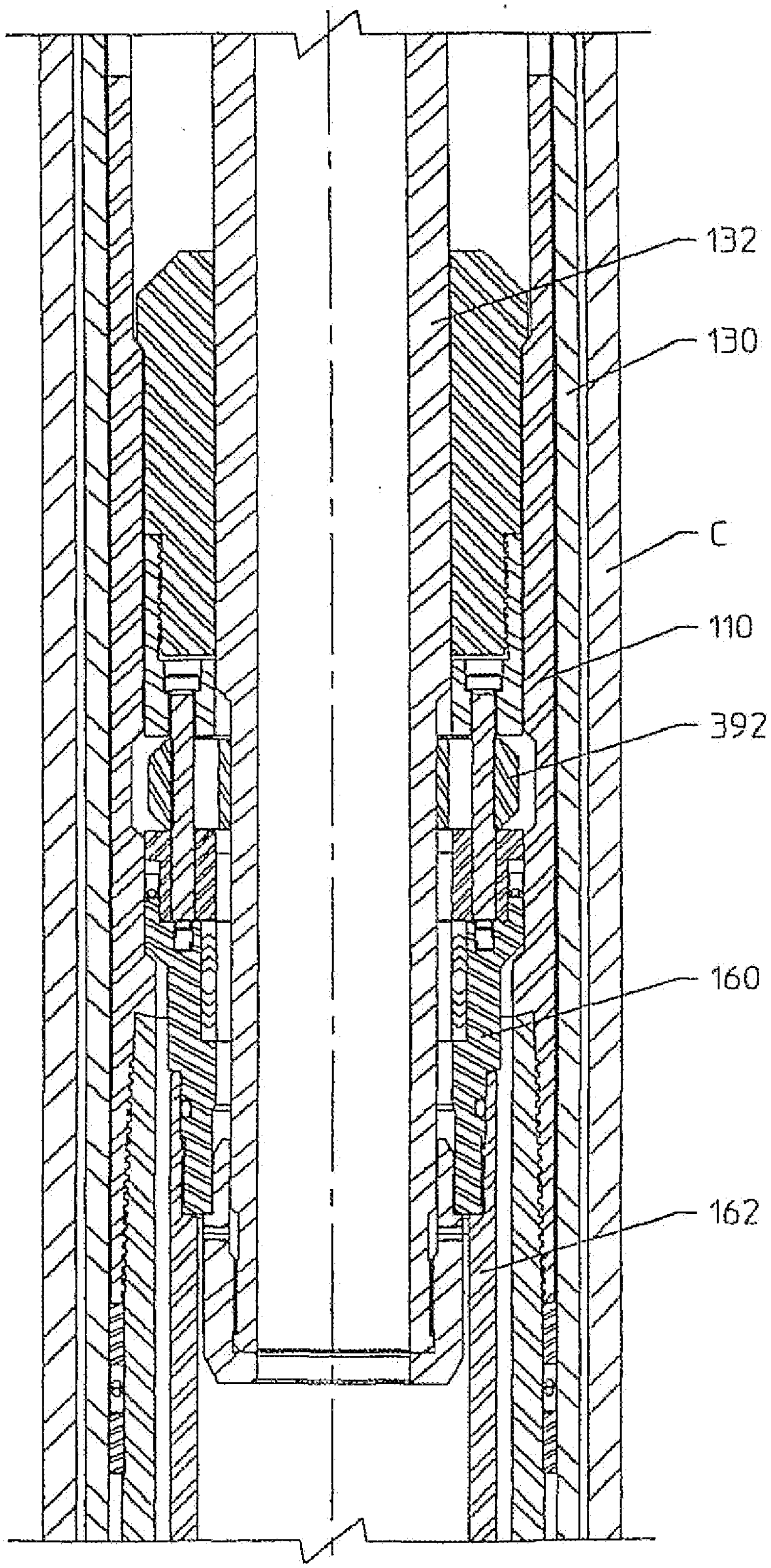


FIGURE 7A

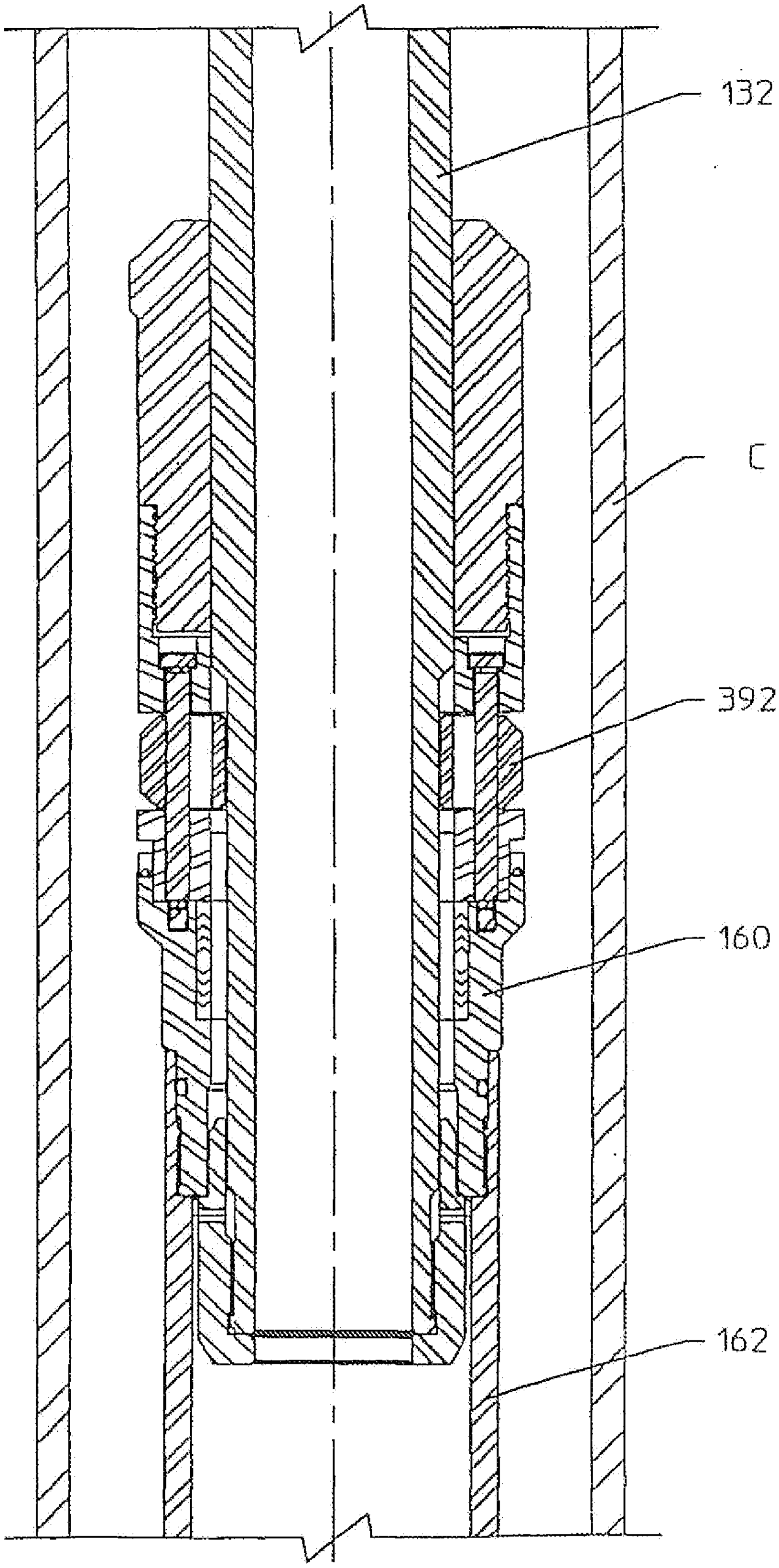


FIGURE 8A

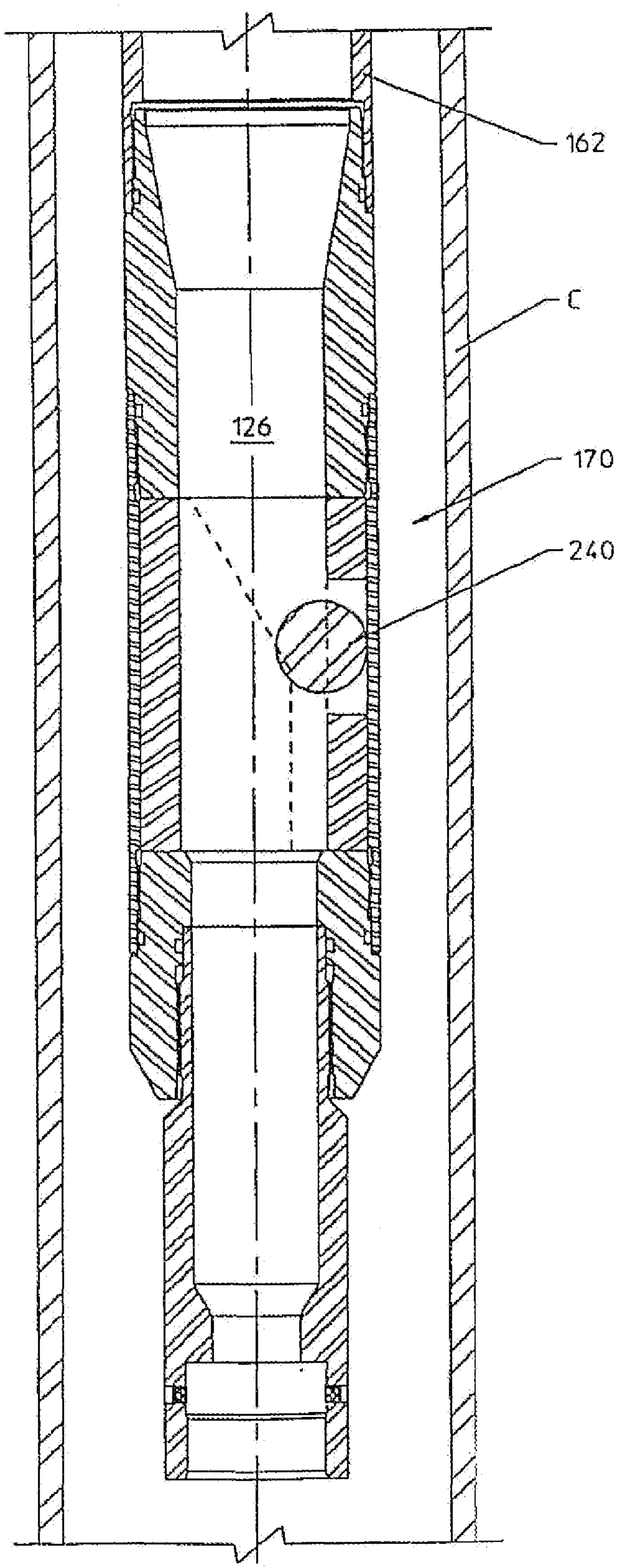


FIGURE 8B

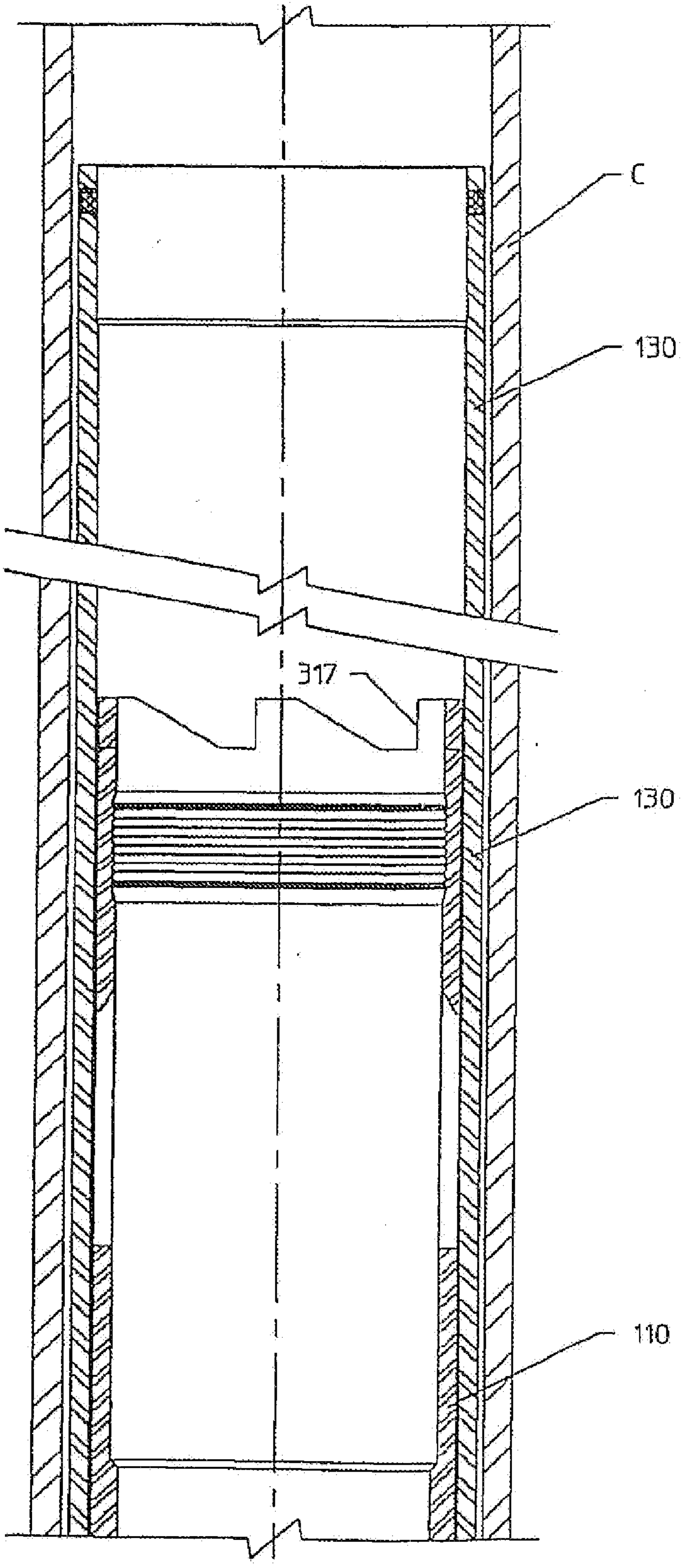


FIGURE 8C

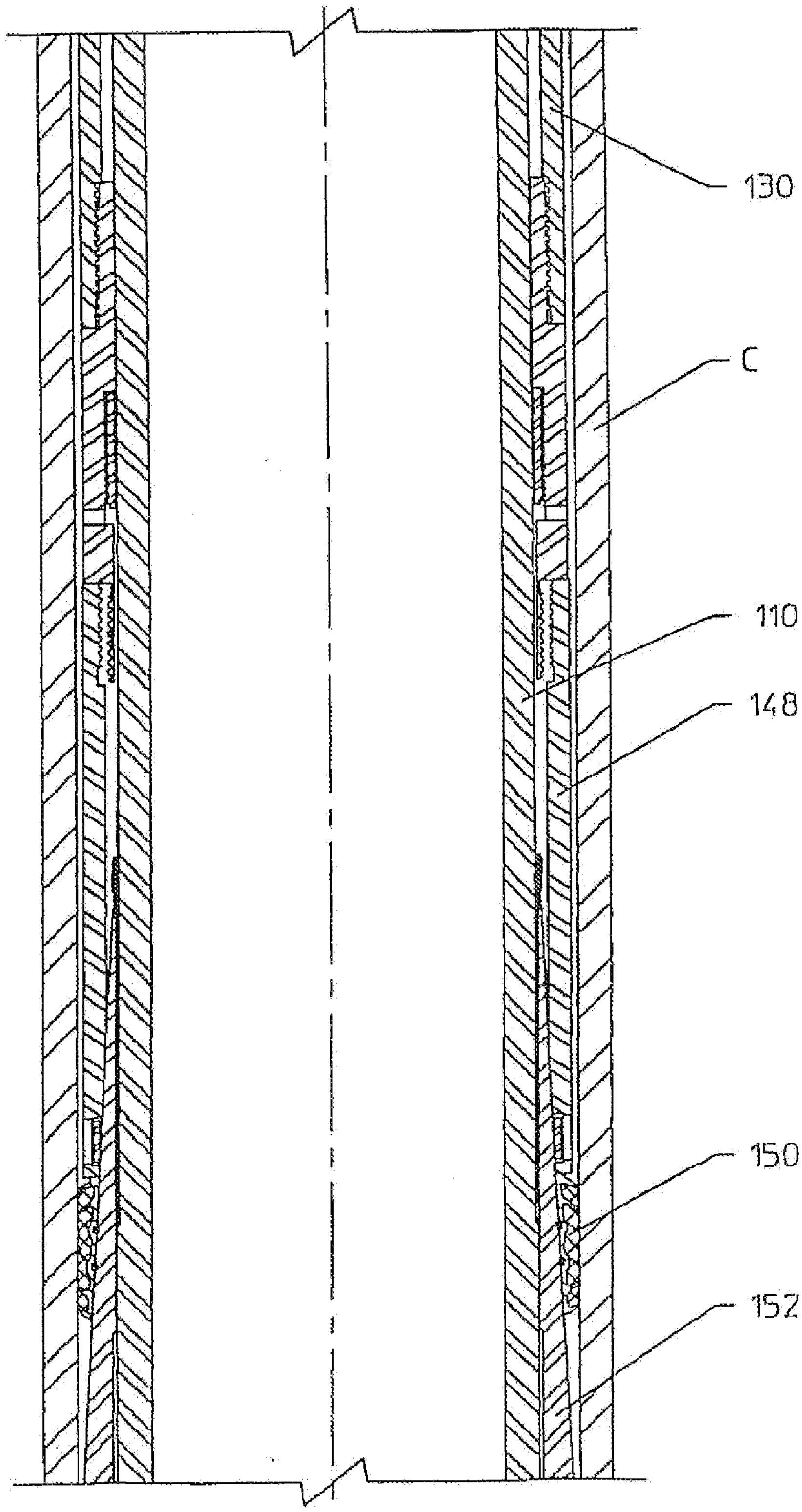


FIGURE 8D

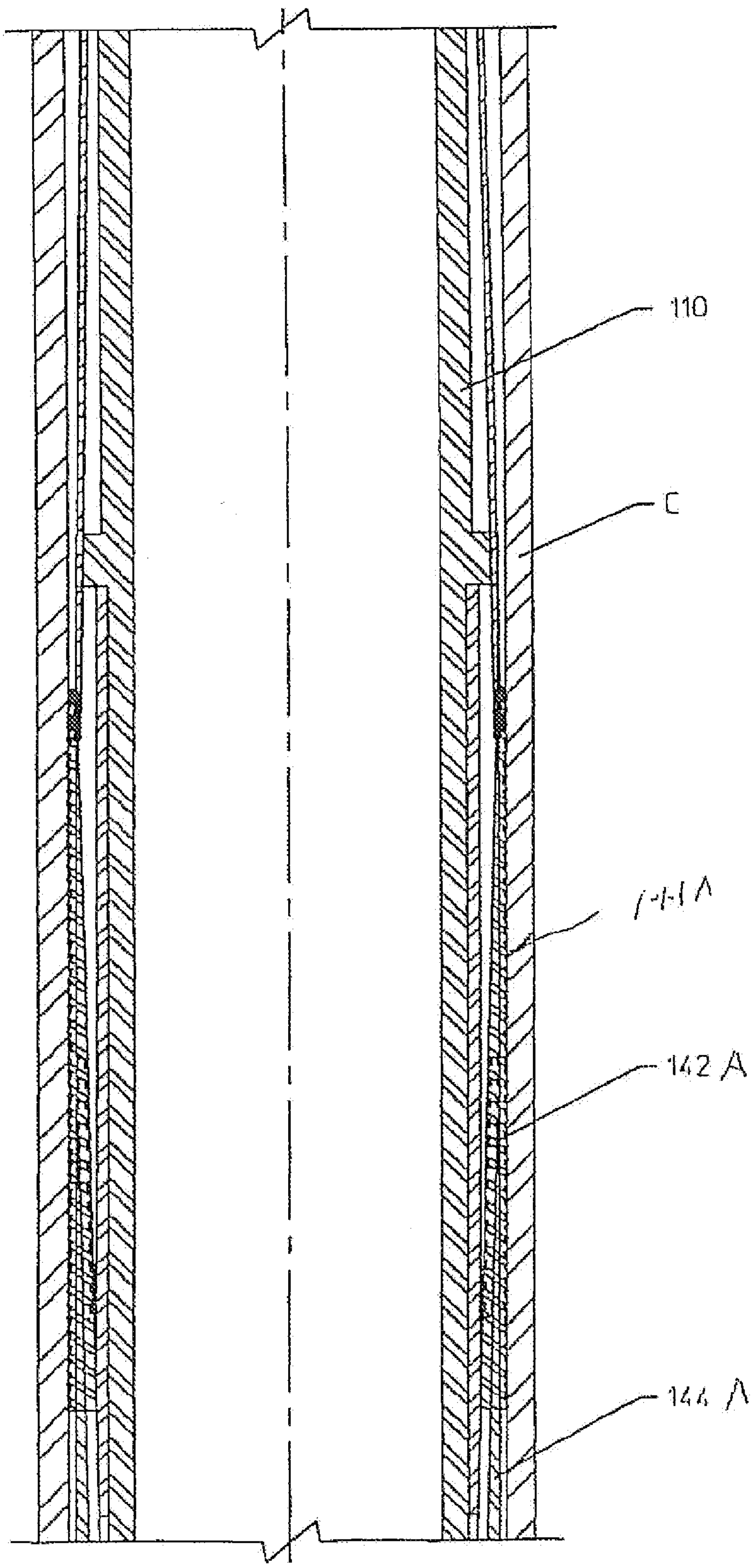


FIGURE 8E

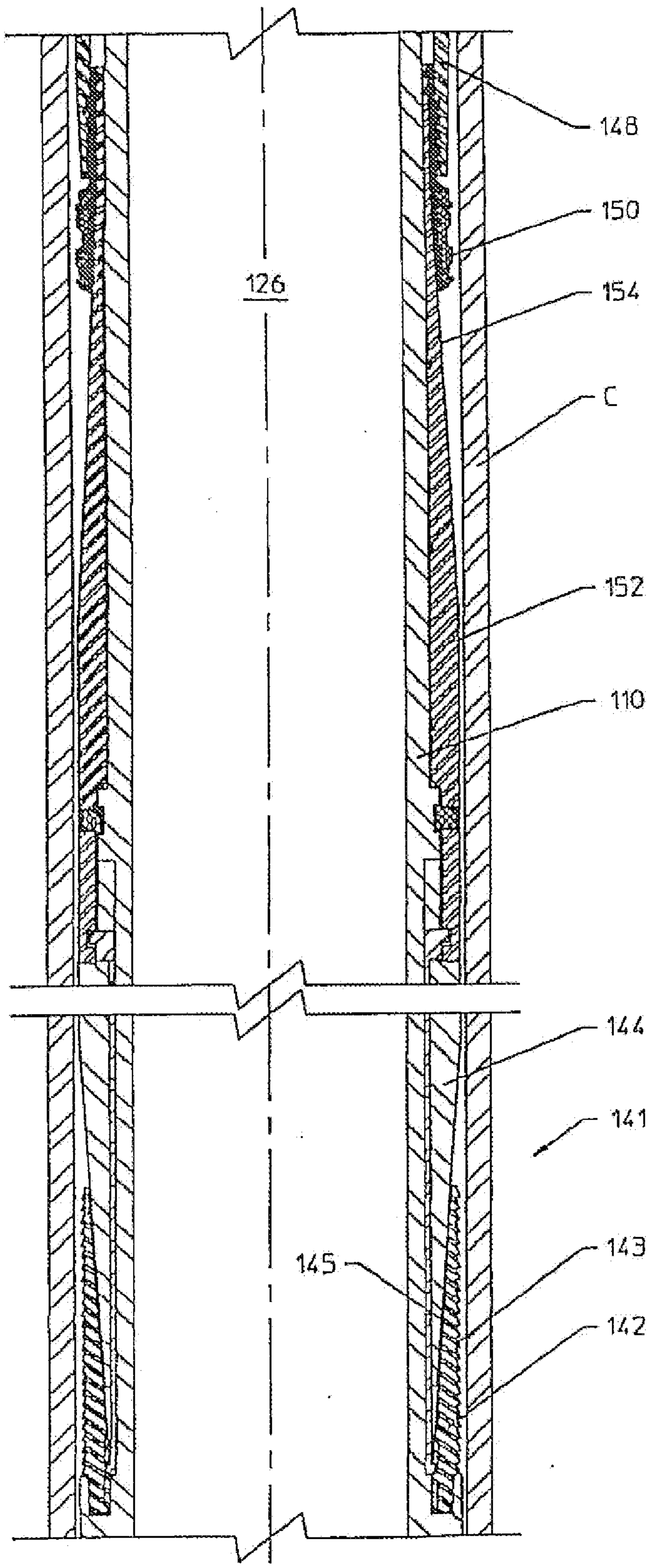


FIGURE 9A

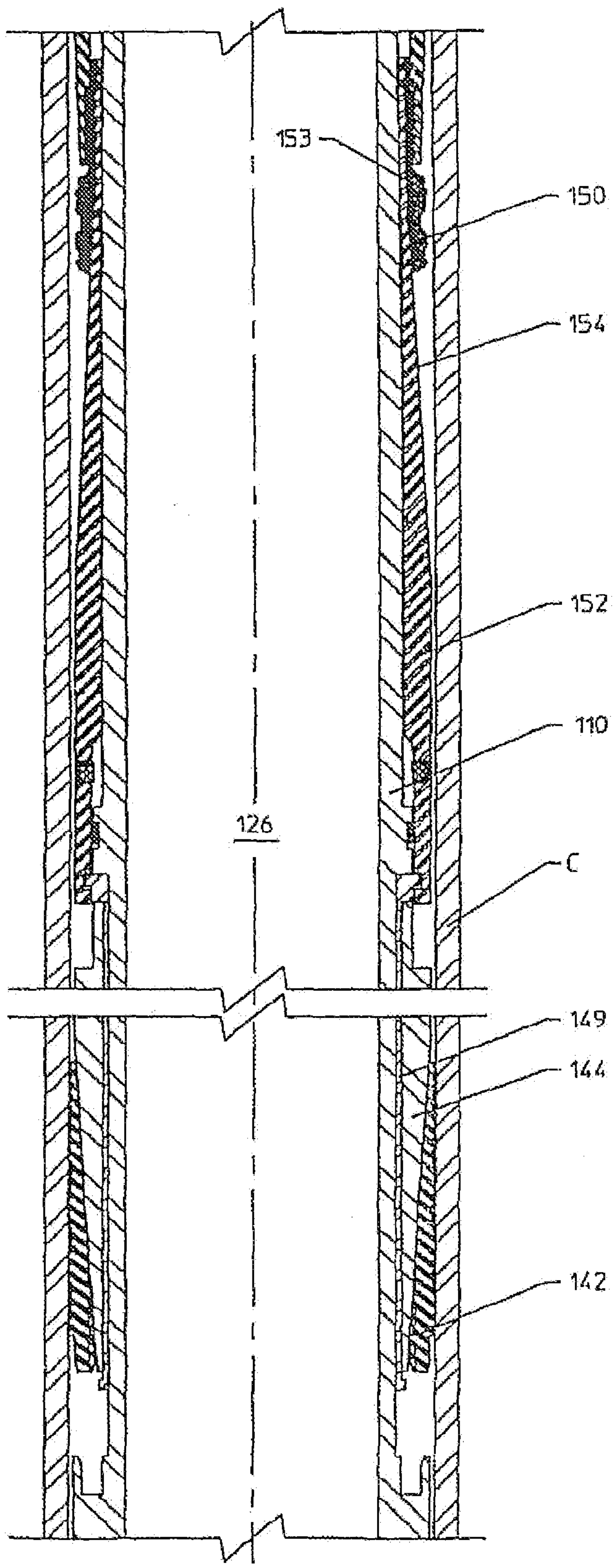


FIGURE 9B

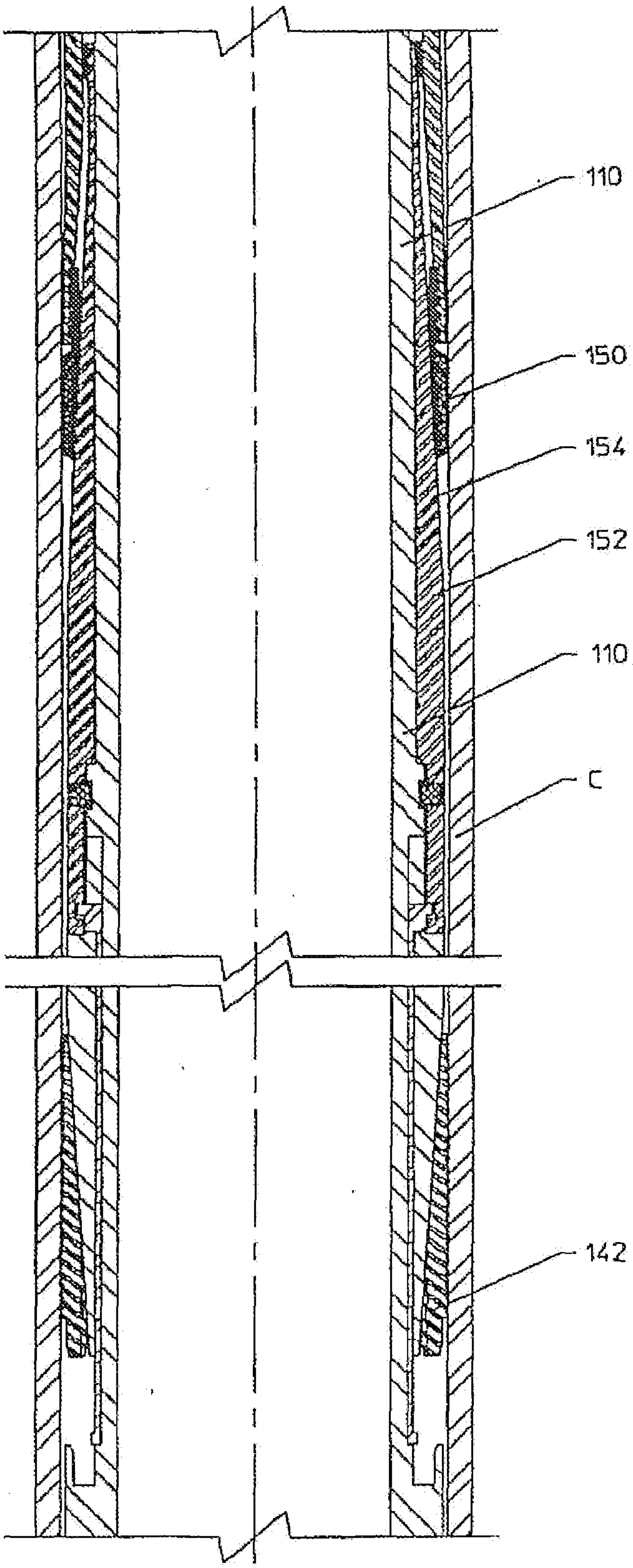


FIGURE 9C

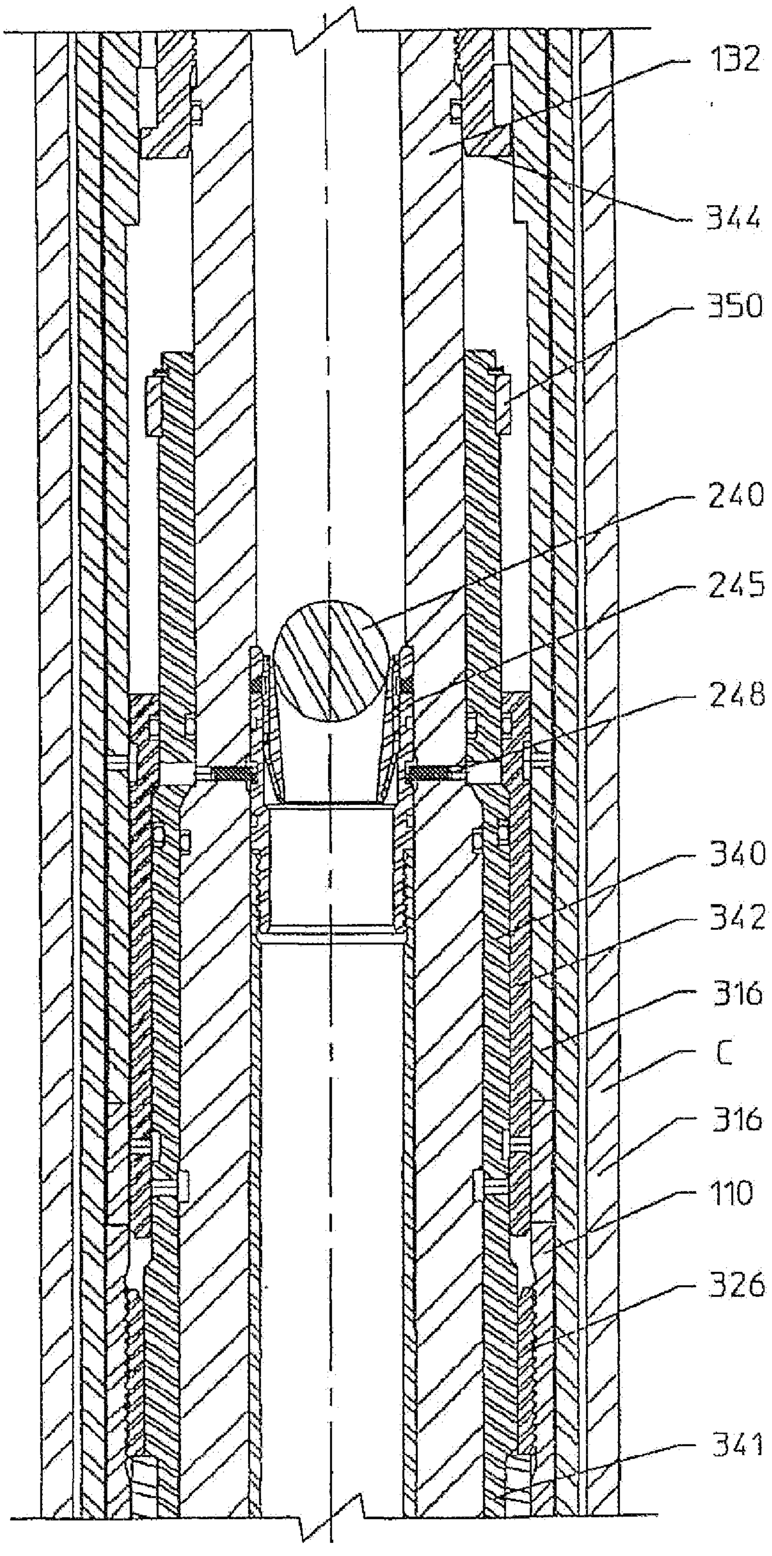


FIGURE 10A

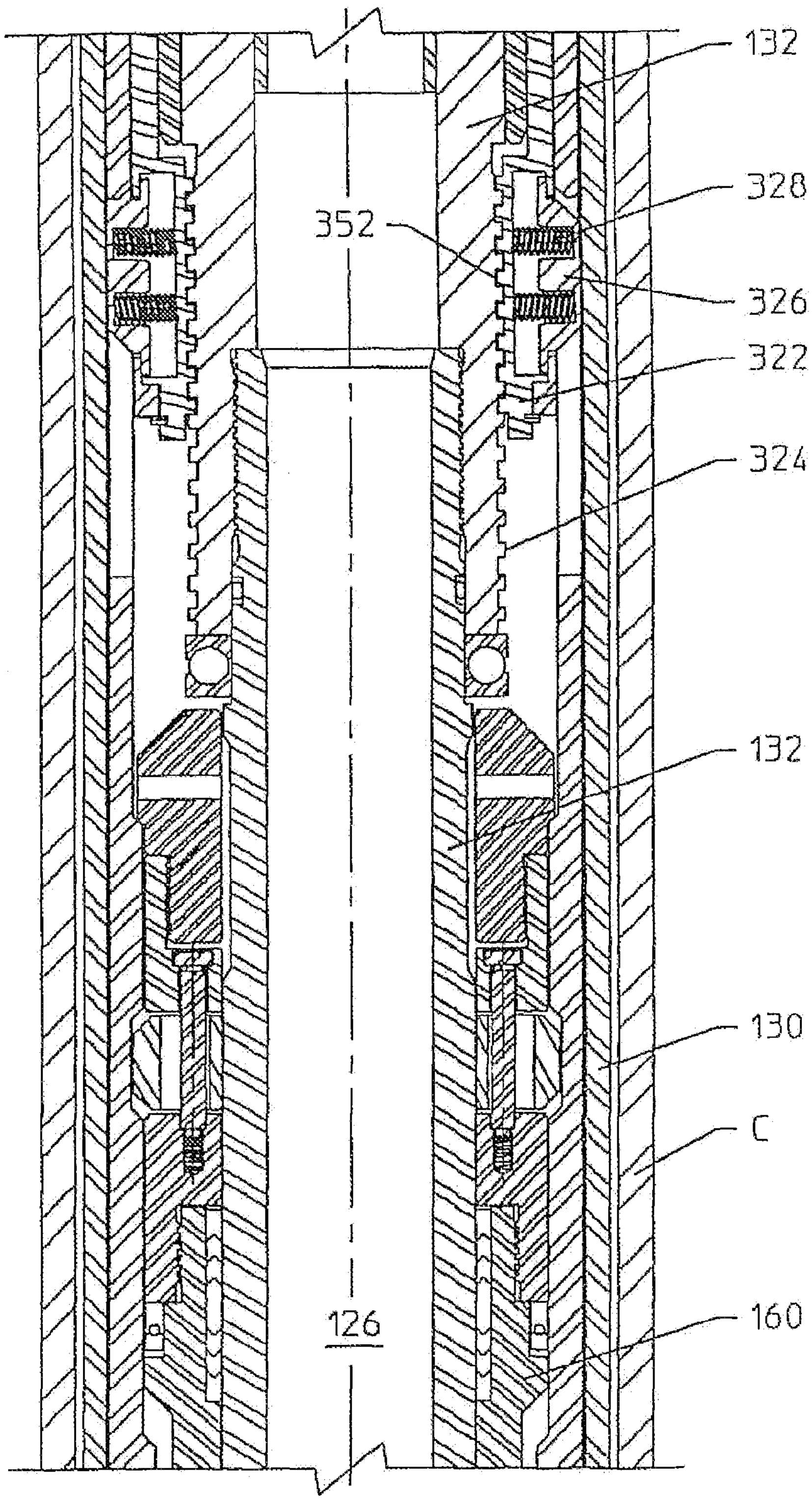


FIGURE 10B

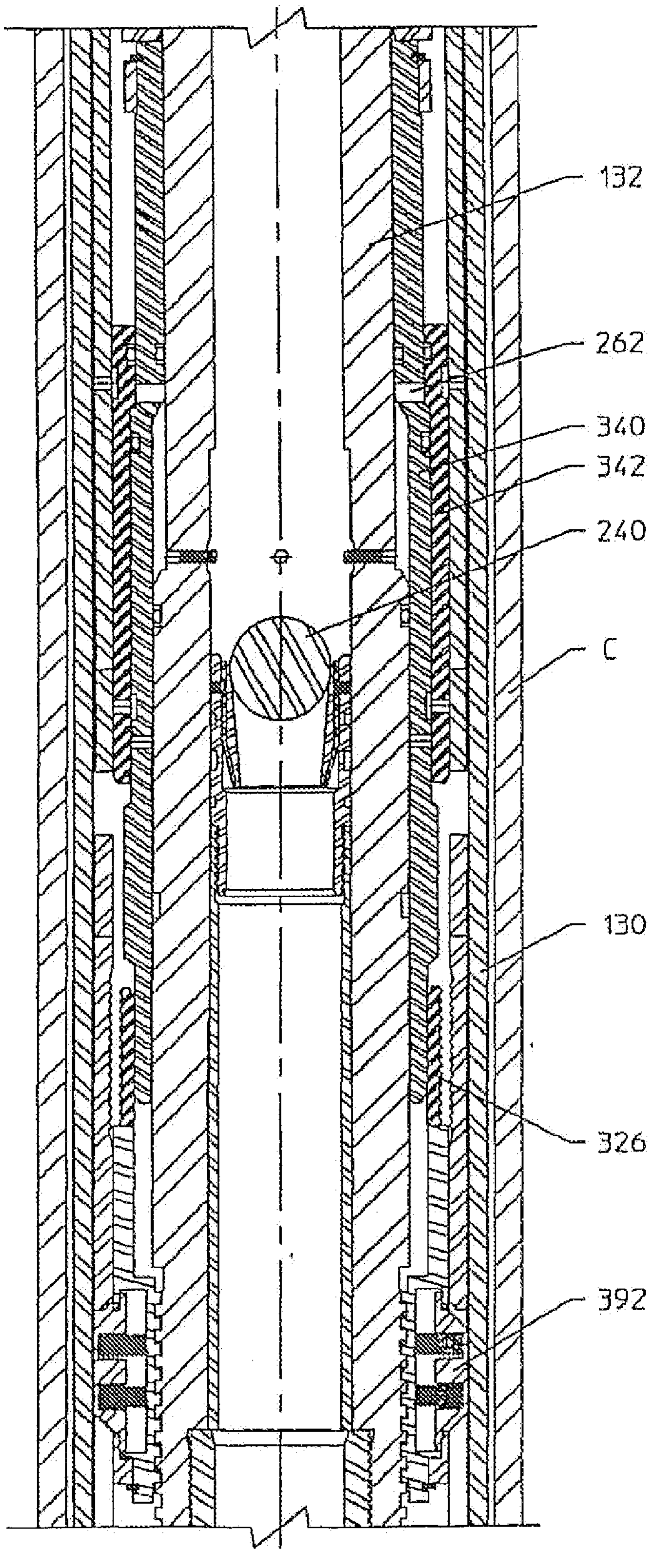


FIGURE 10C

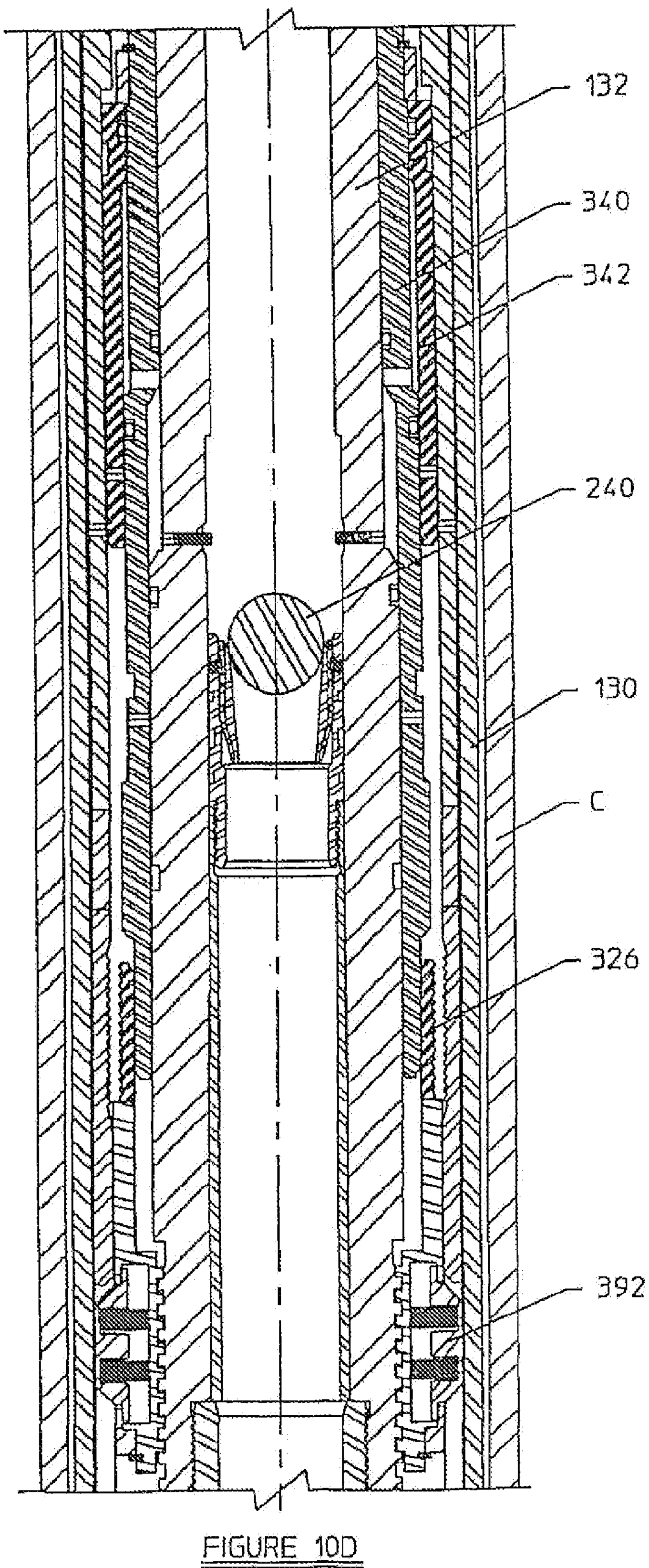


FIGURE 10D

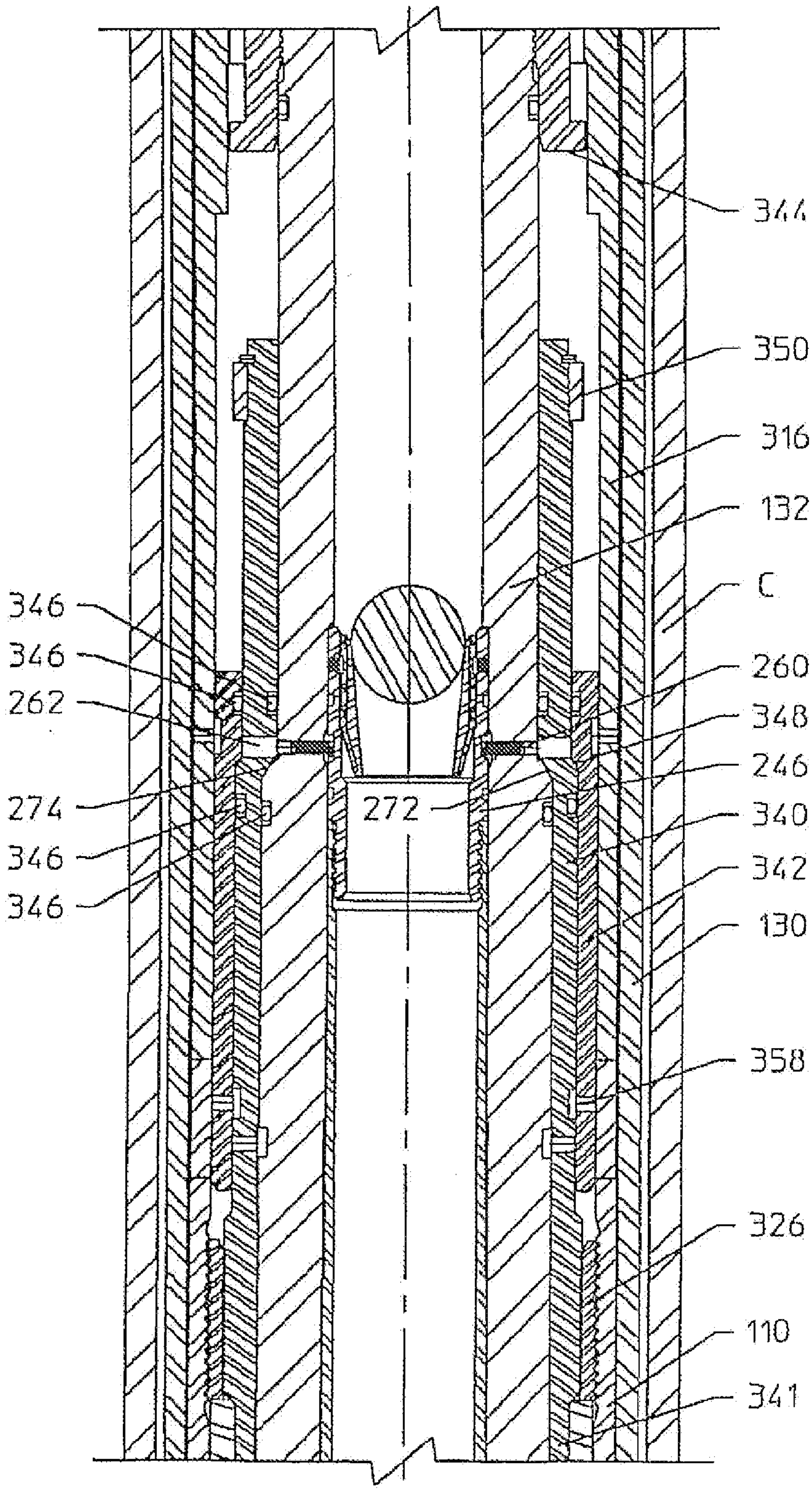

344
350
316
132
C
346
346
262
260
348
246
274
272
340
346
346
342
130
358
326
110
341

FIGURE 11A

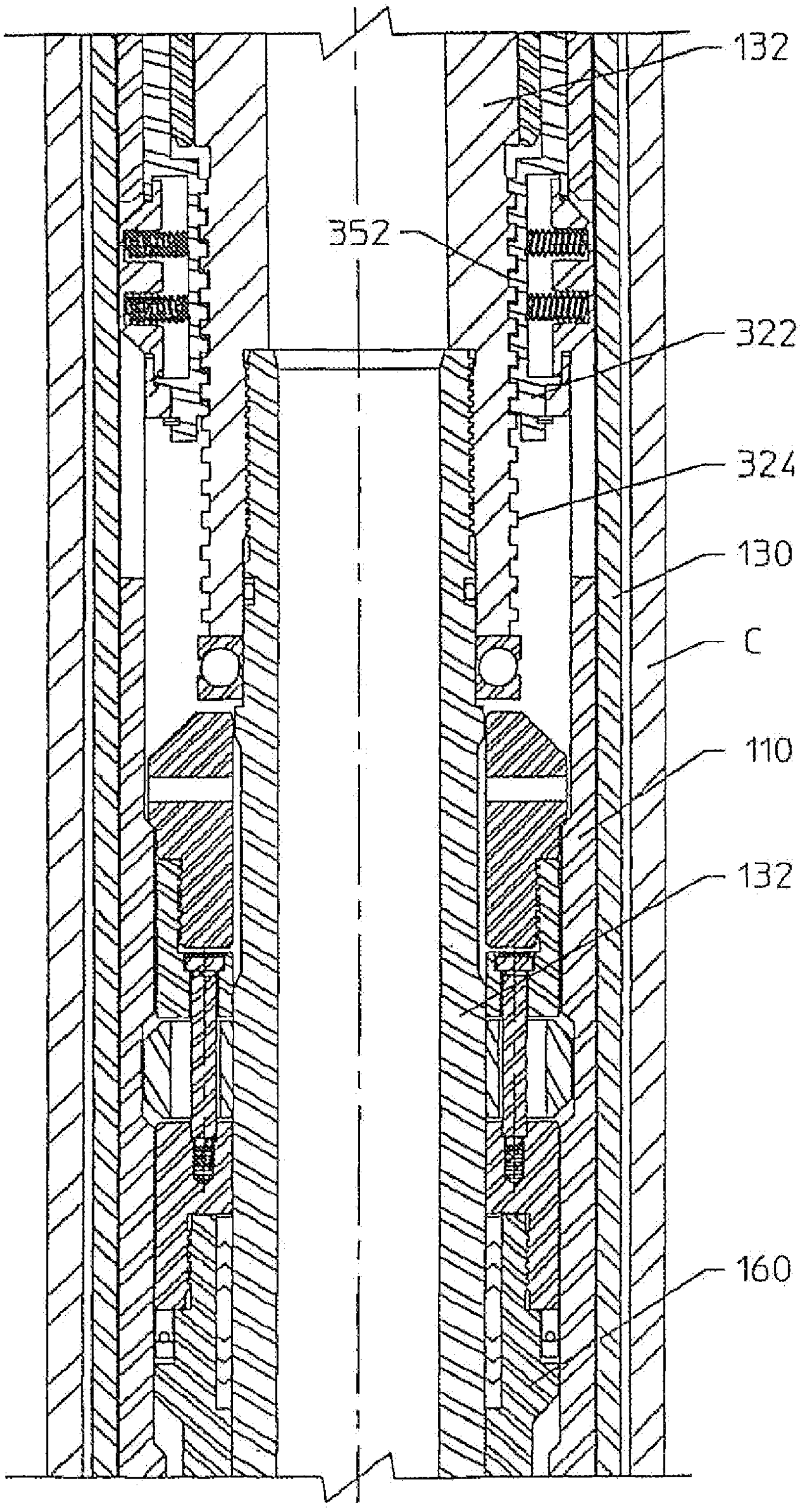


FIGURE 11B

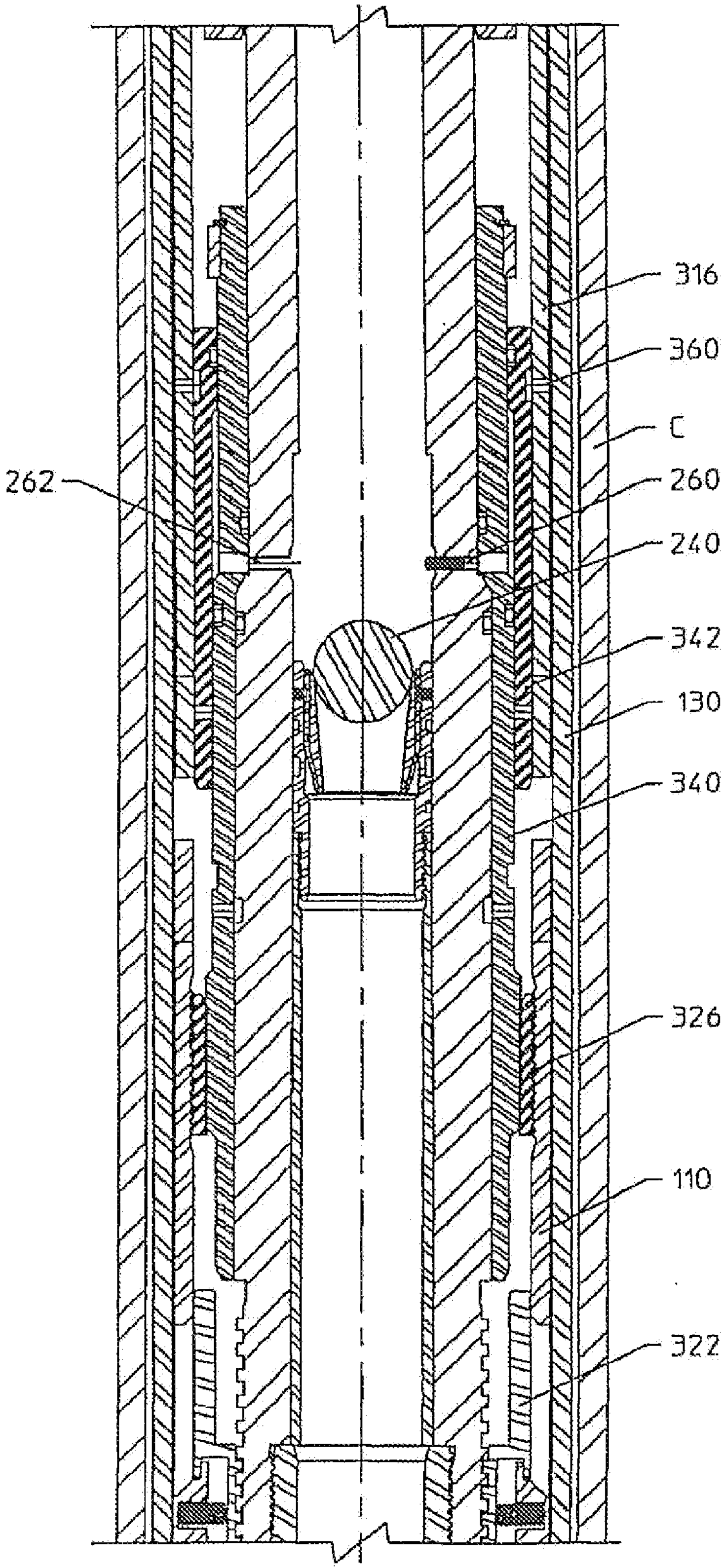


FIGURE 11C

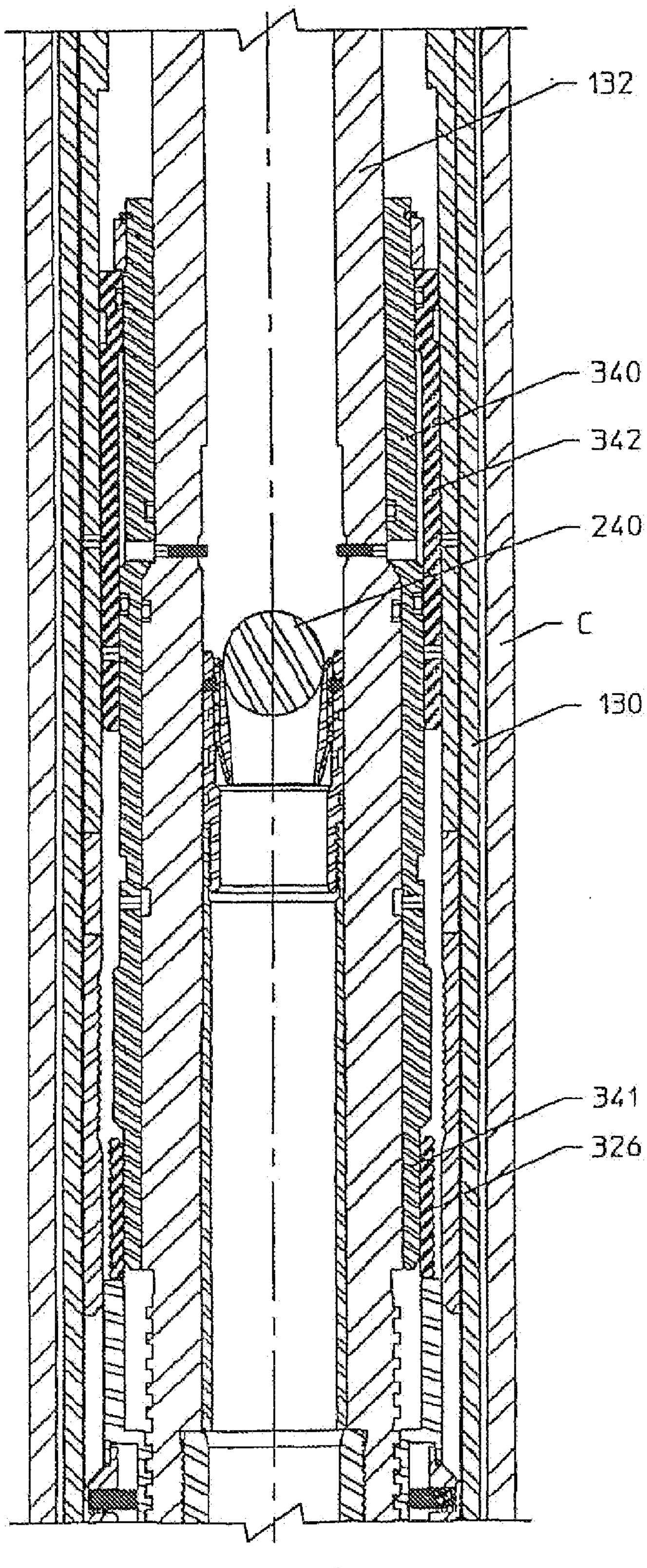


FIGURE 11D

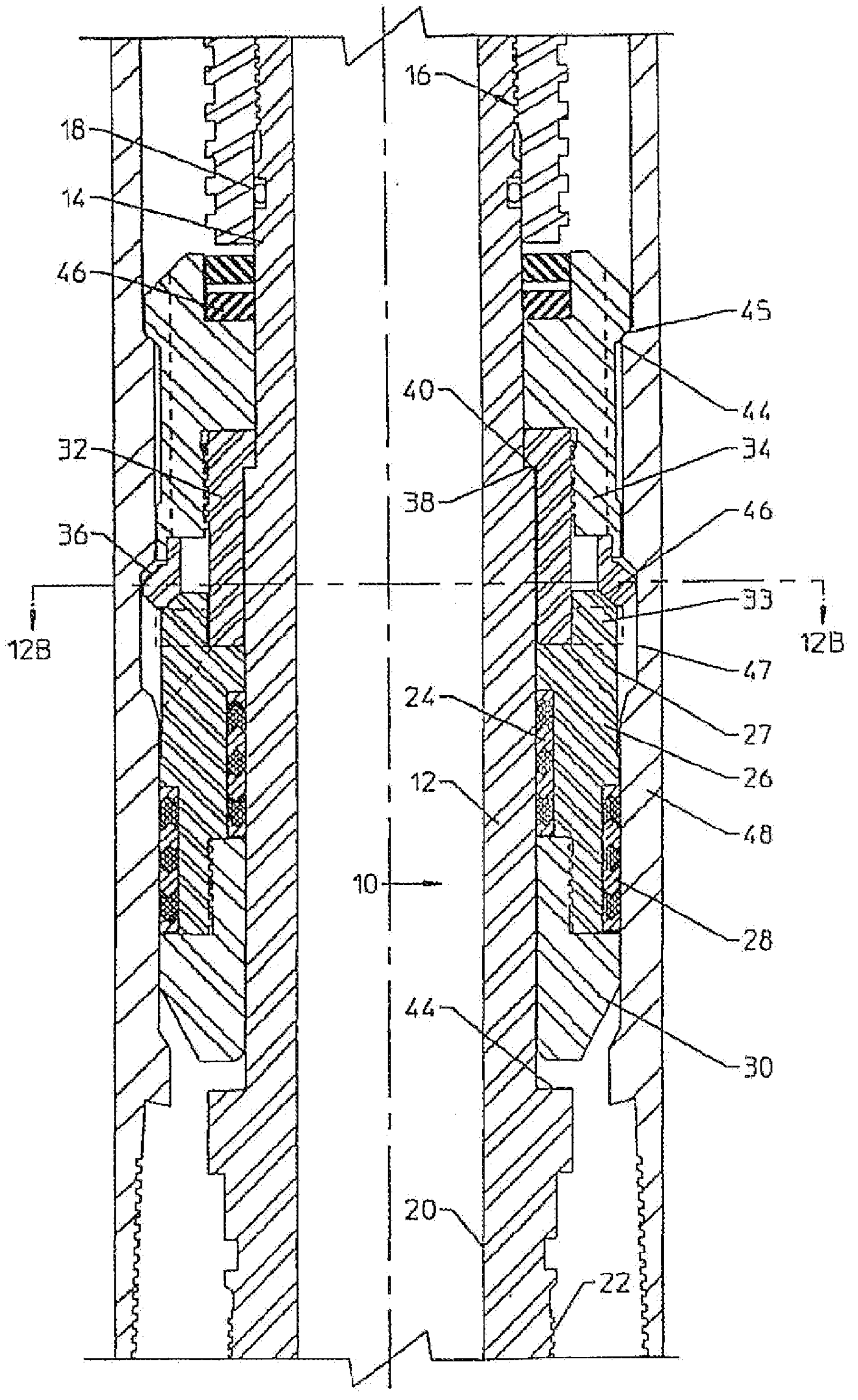

16
18
14
46
45
40
44
32
34
38
36
46
33
12B
12B
47
27
24
26
12
48
10
28
44
30
20
22

FIGURE 12A

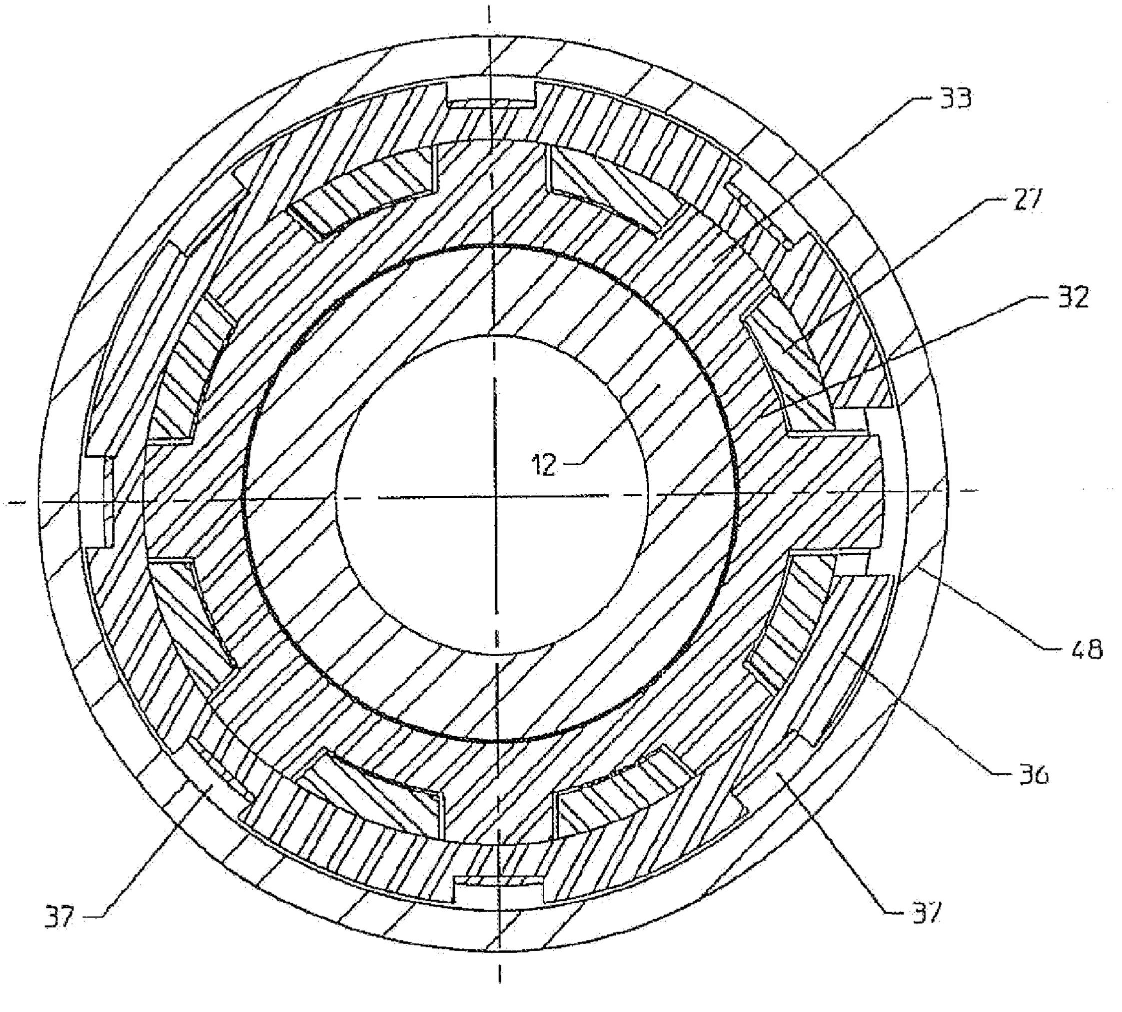


FIGURE 12B

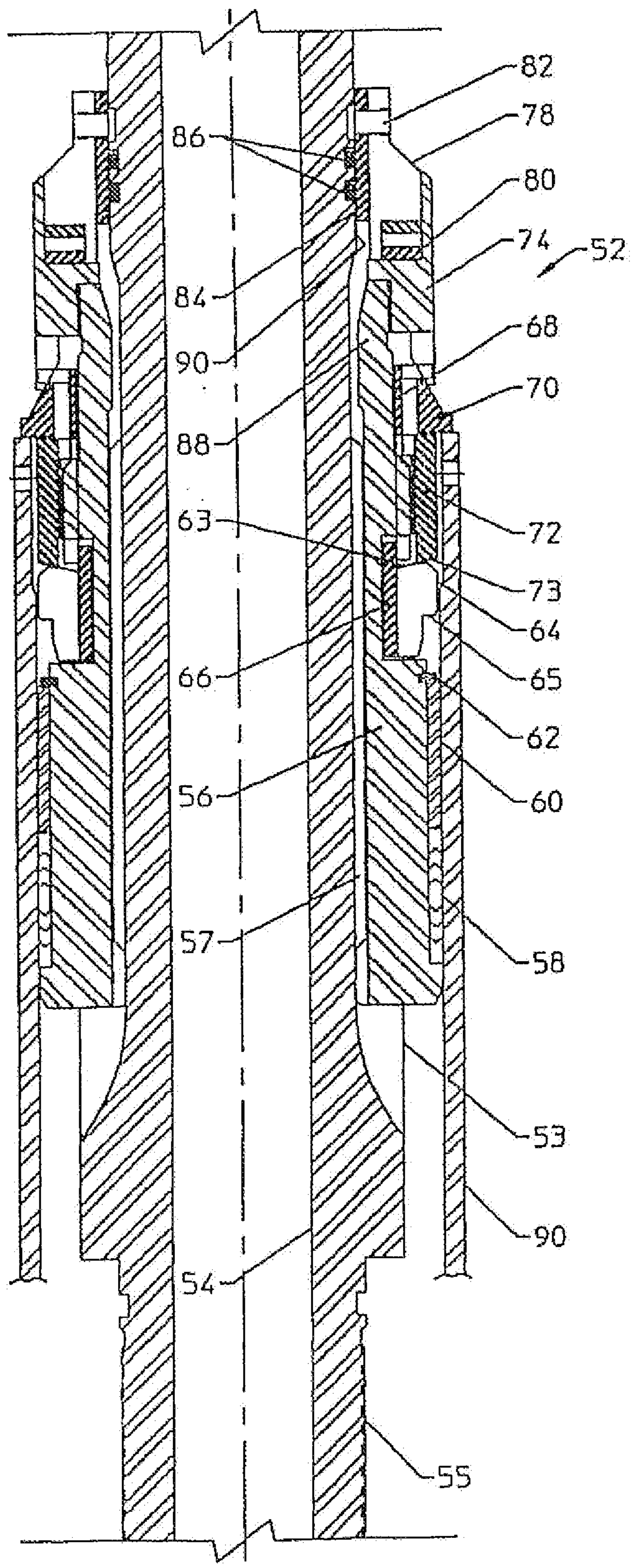

82
78
86
80
74
52
84
68
90
70
88
72
63
73
64
66
65
62
56
60
57
58
53
90
54
55

FIGURE 13

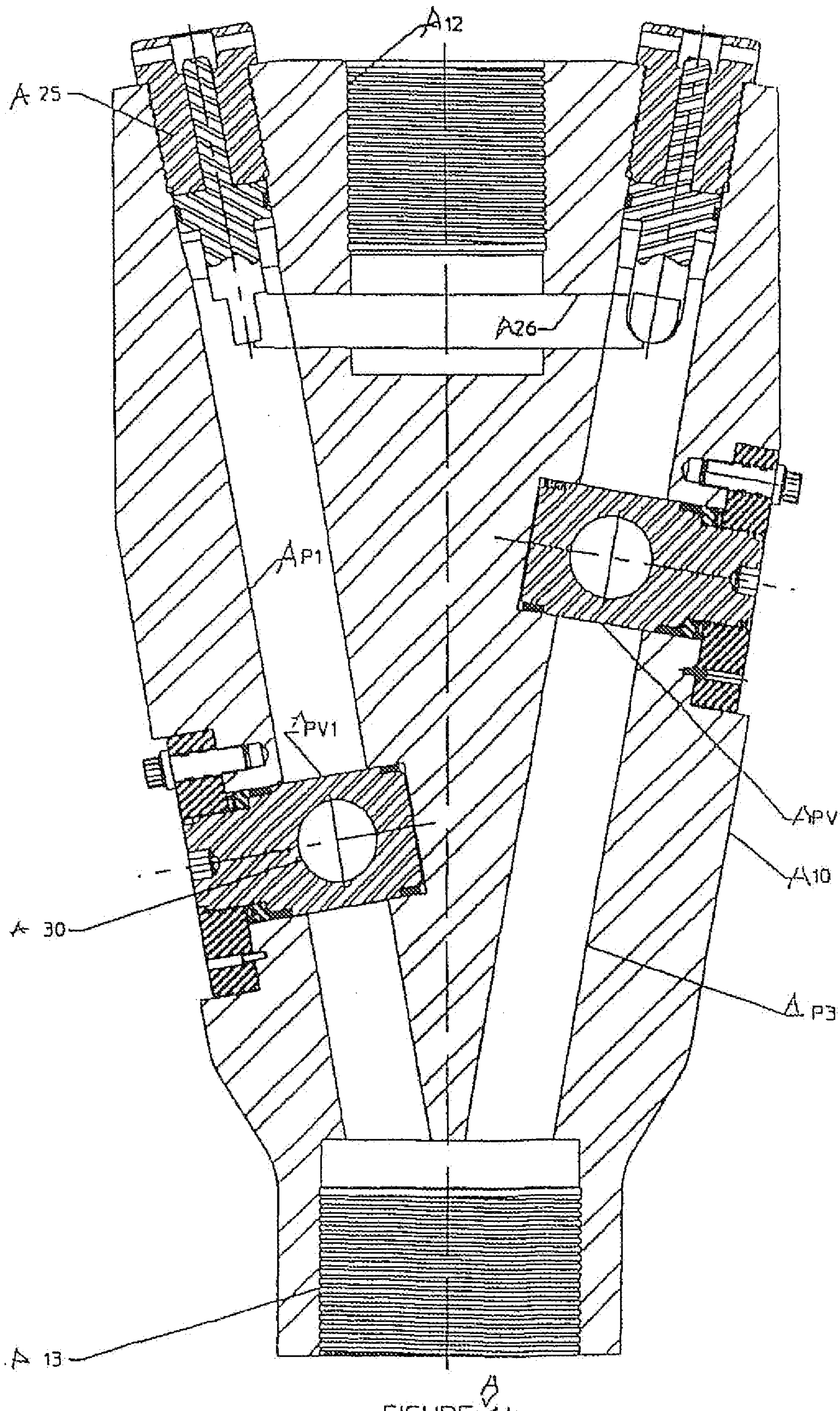


FIGURE A 1A

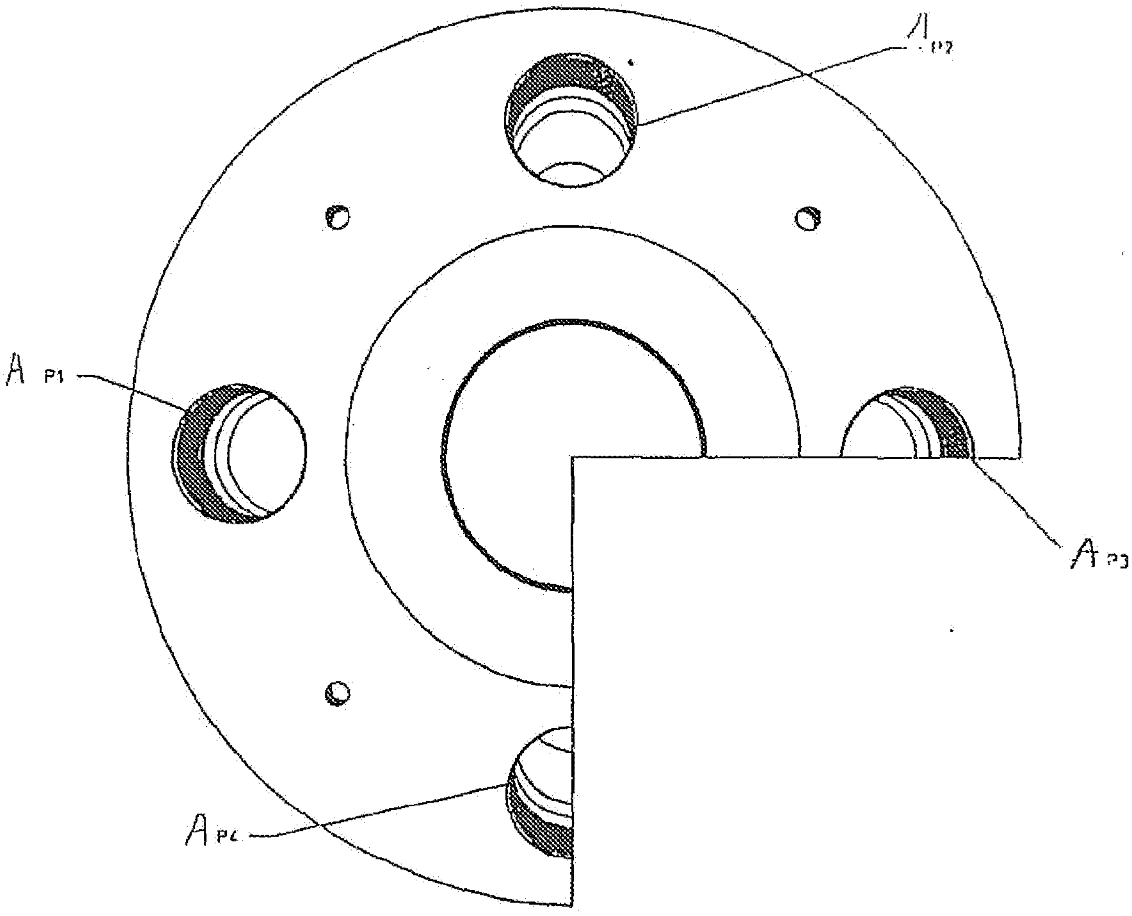
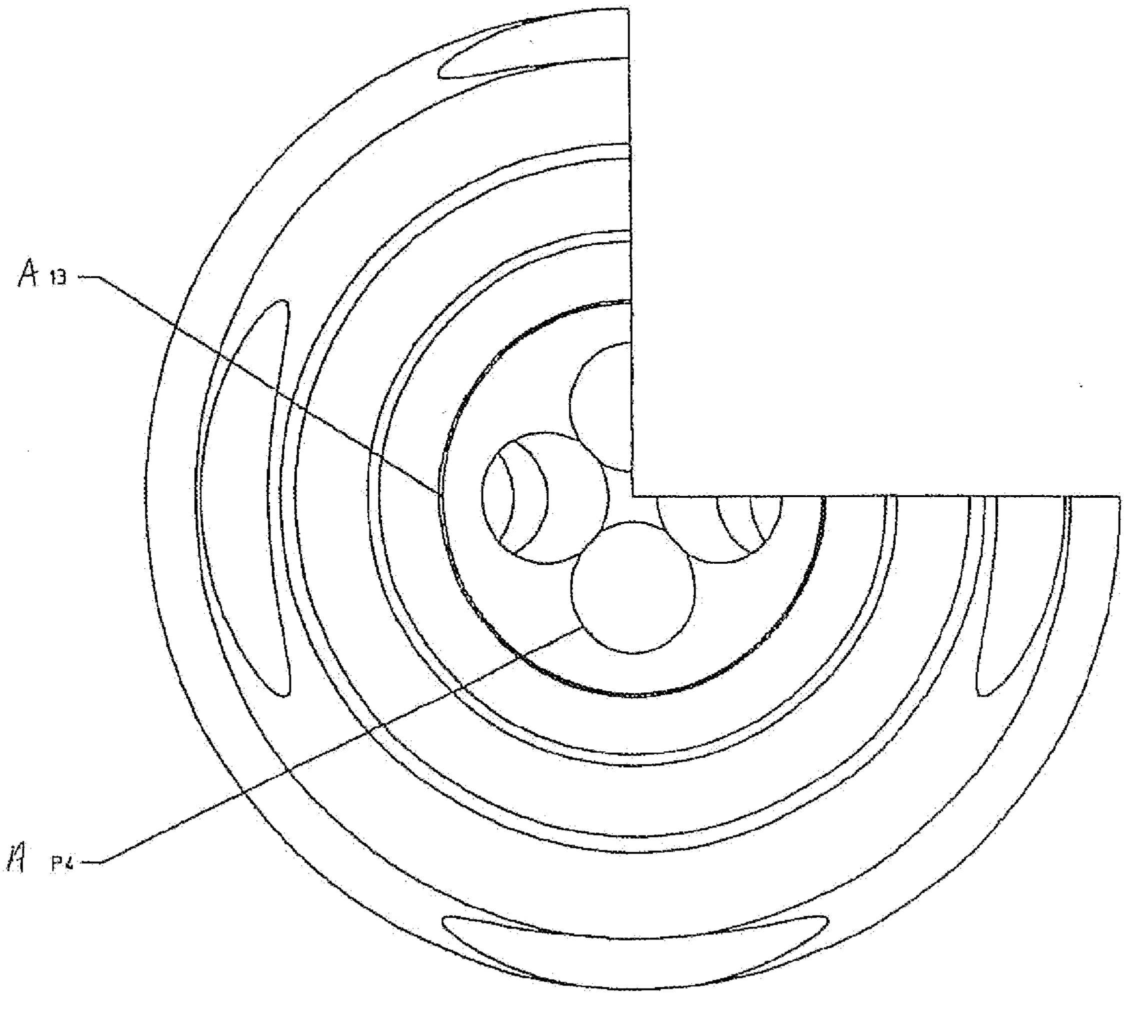


FIGURE 18A



A
FIGURE 1C

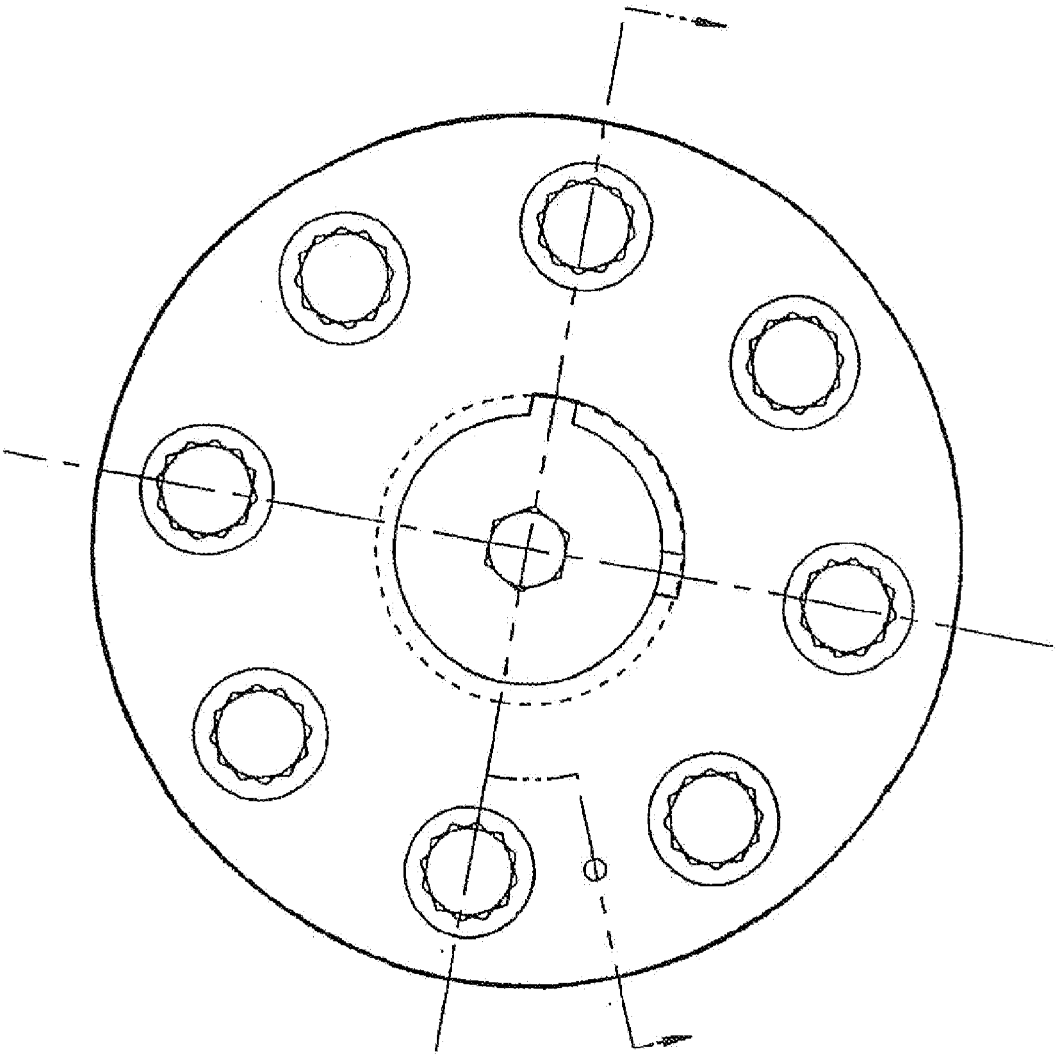


FIGURE A1D

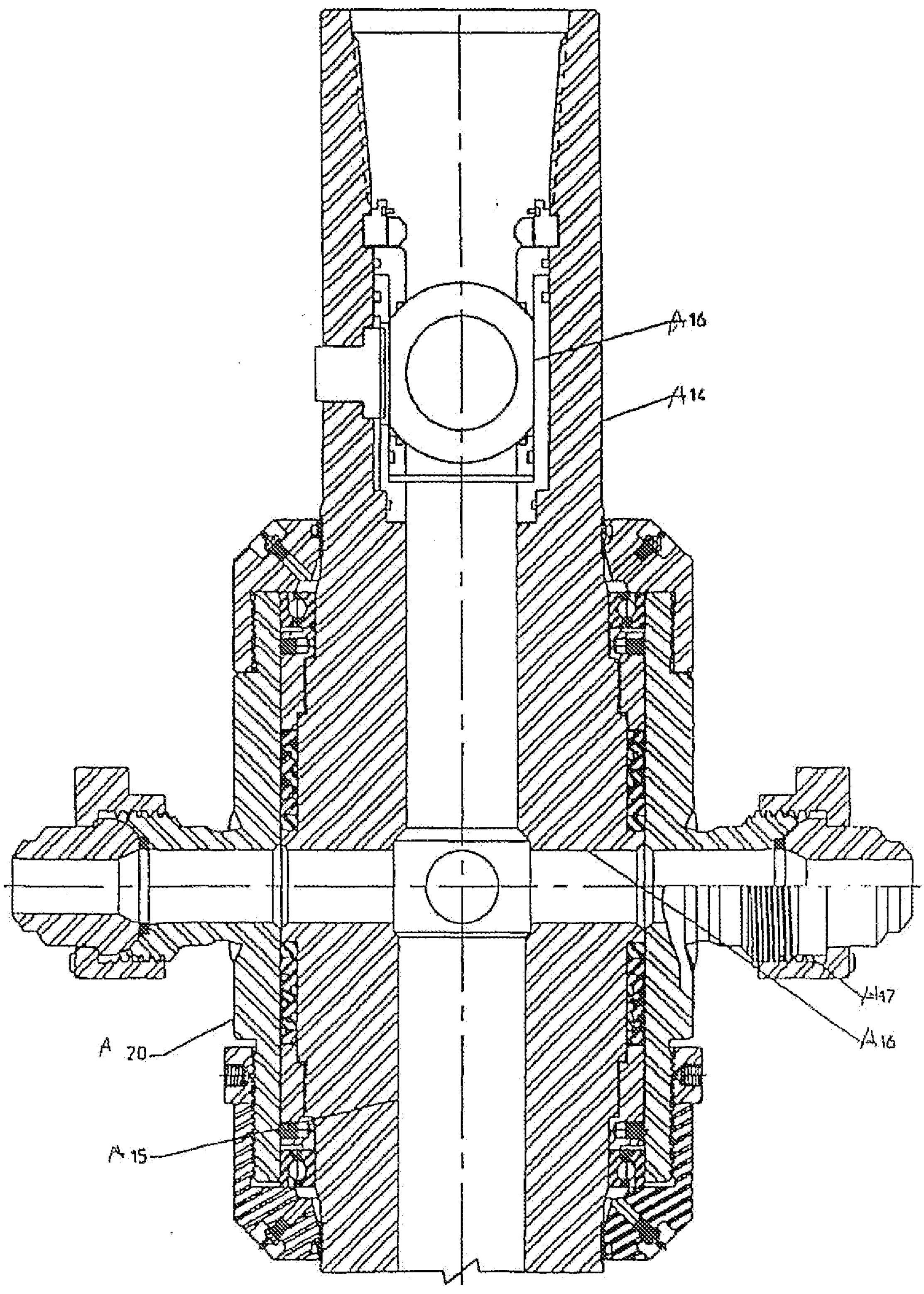


FIGURE A2A

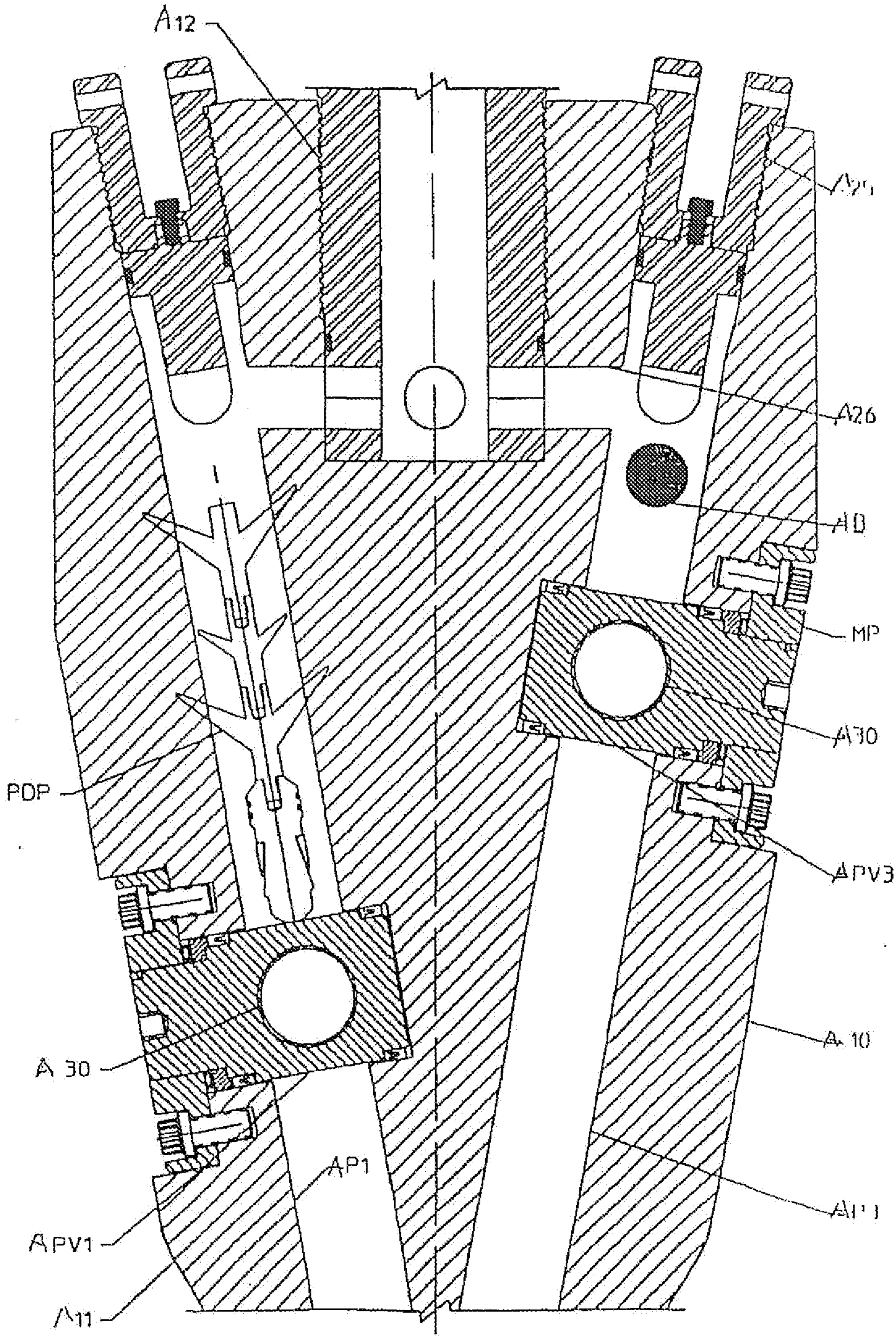


FIGURE A2B

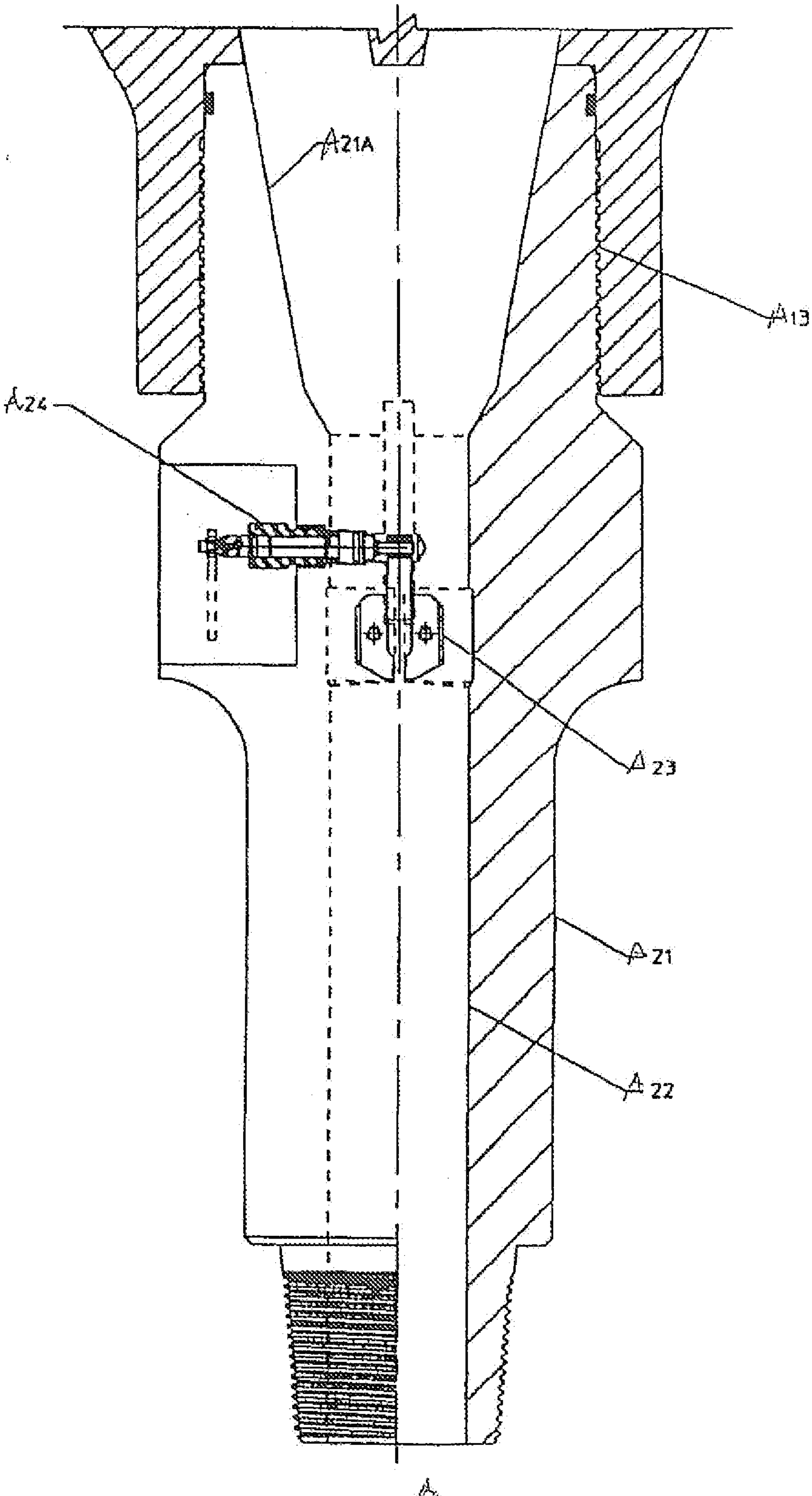


FIGURE A2C

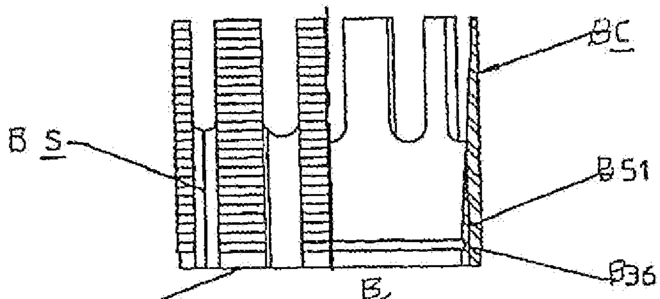


FIGURE B 1A

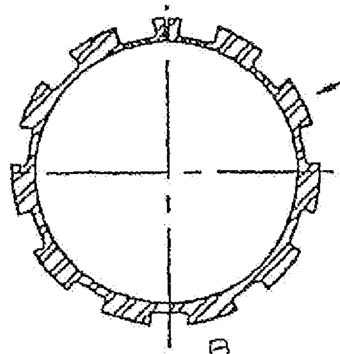


FIGURE B 1B

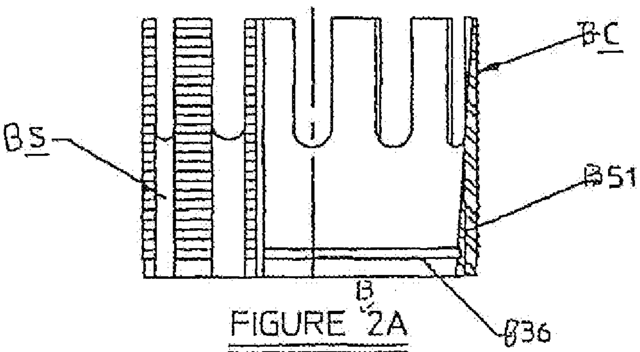


FIGURE B 2A

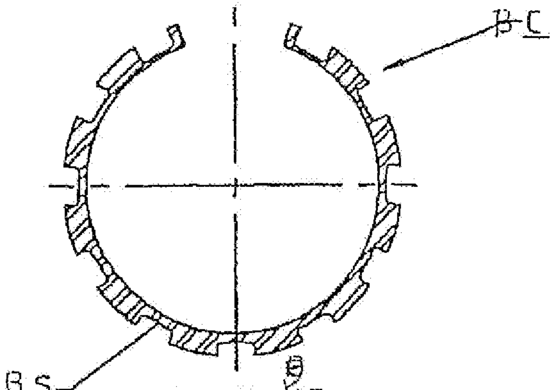


FIGURE B 2B

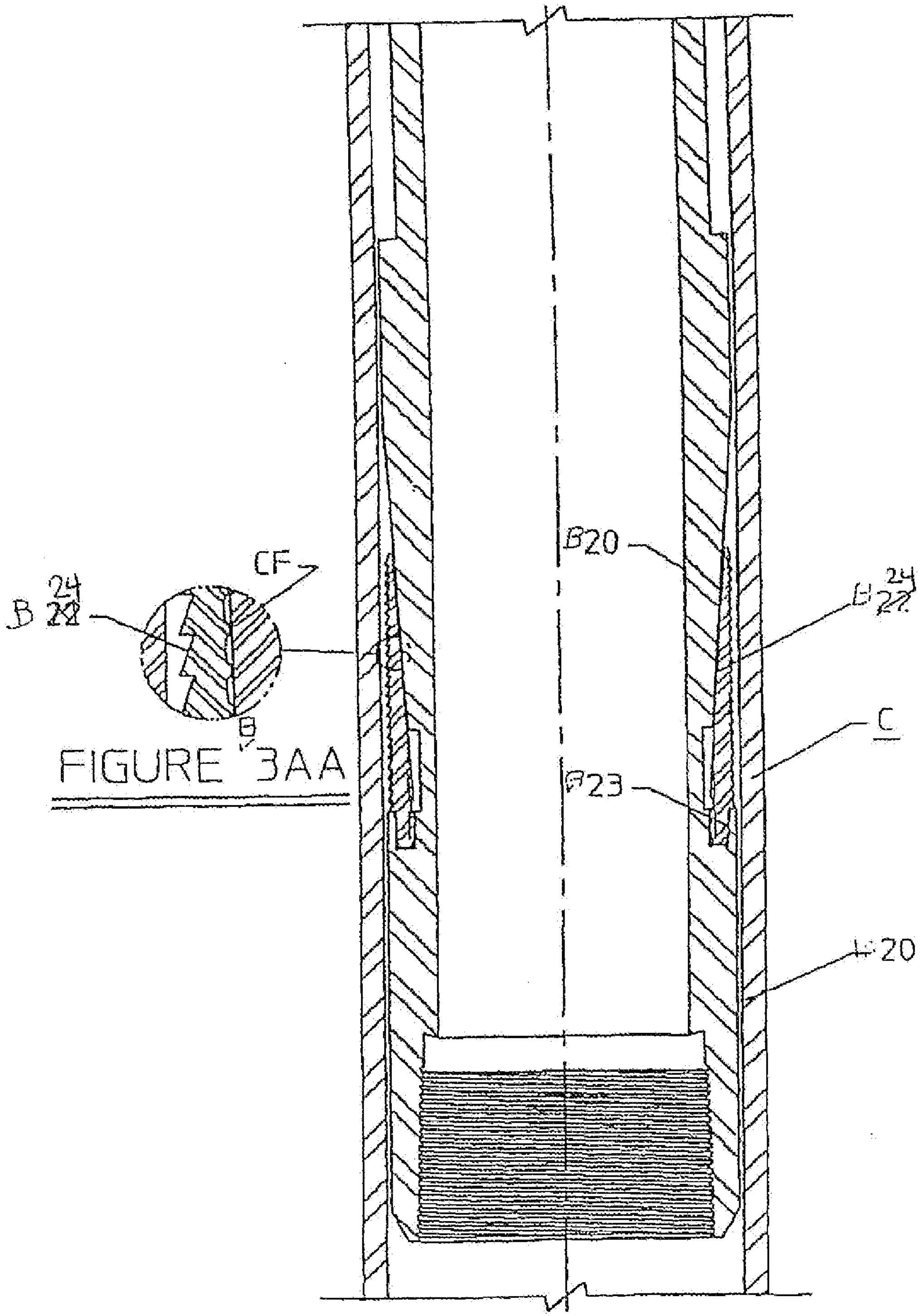


FIGURE B 3AA

FIGURE B 3A

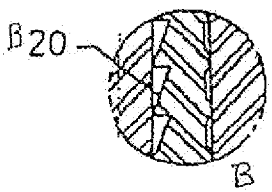


FIGURE 3BB

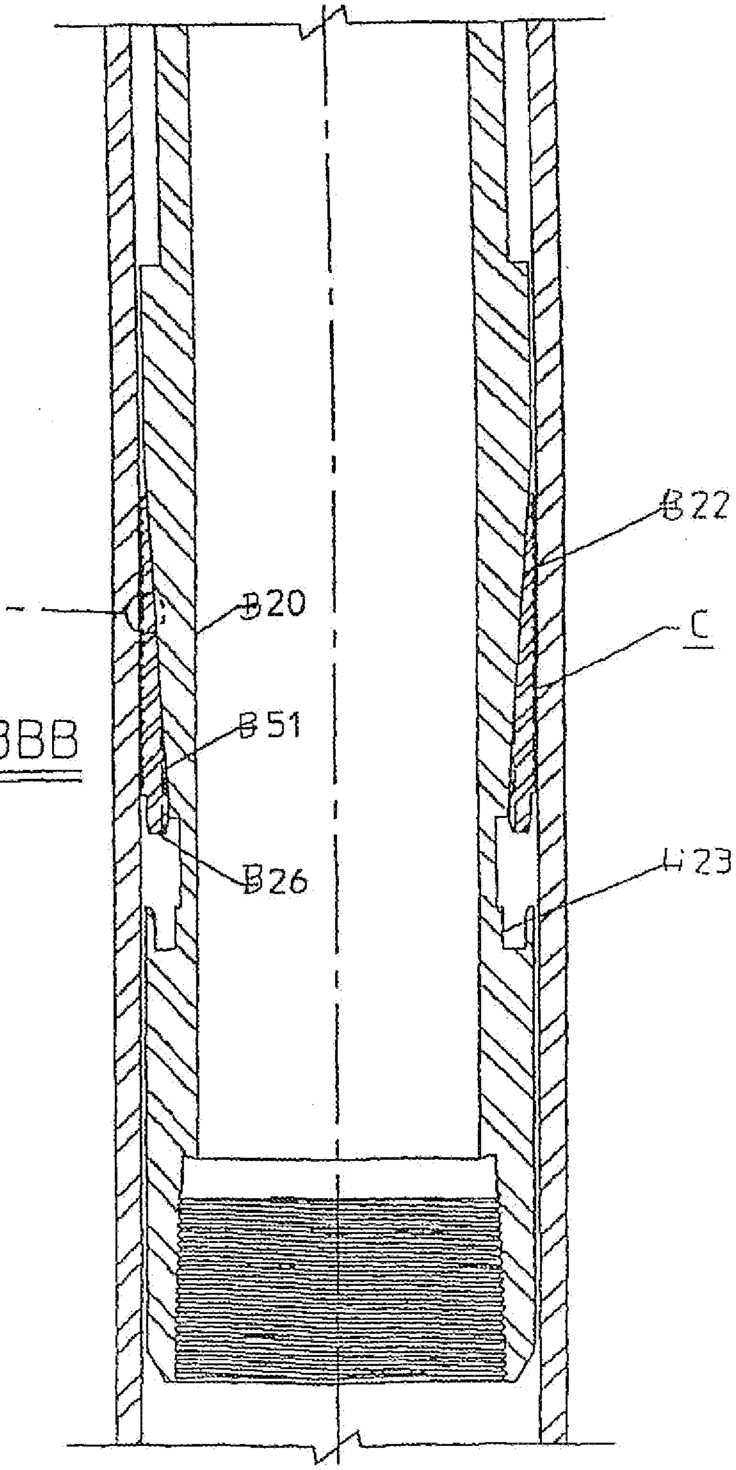


FIGURE 3B

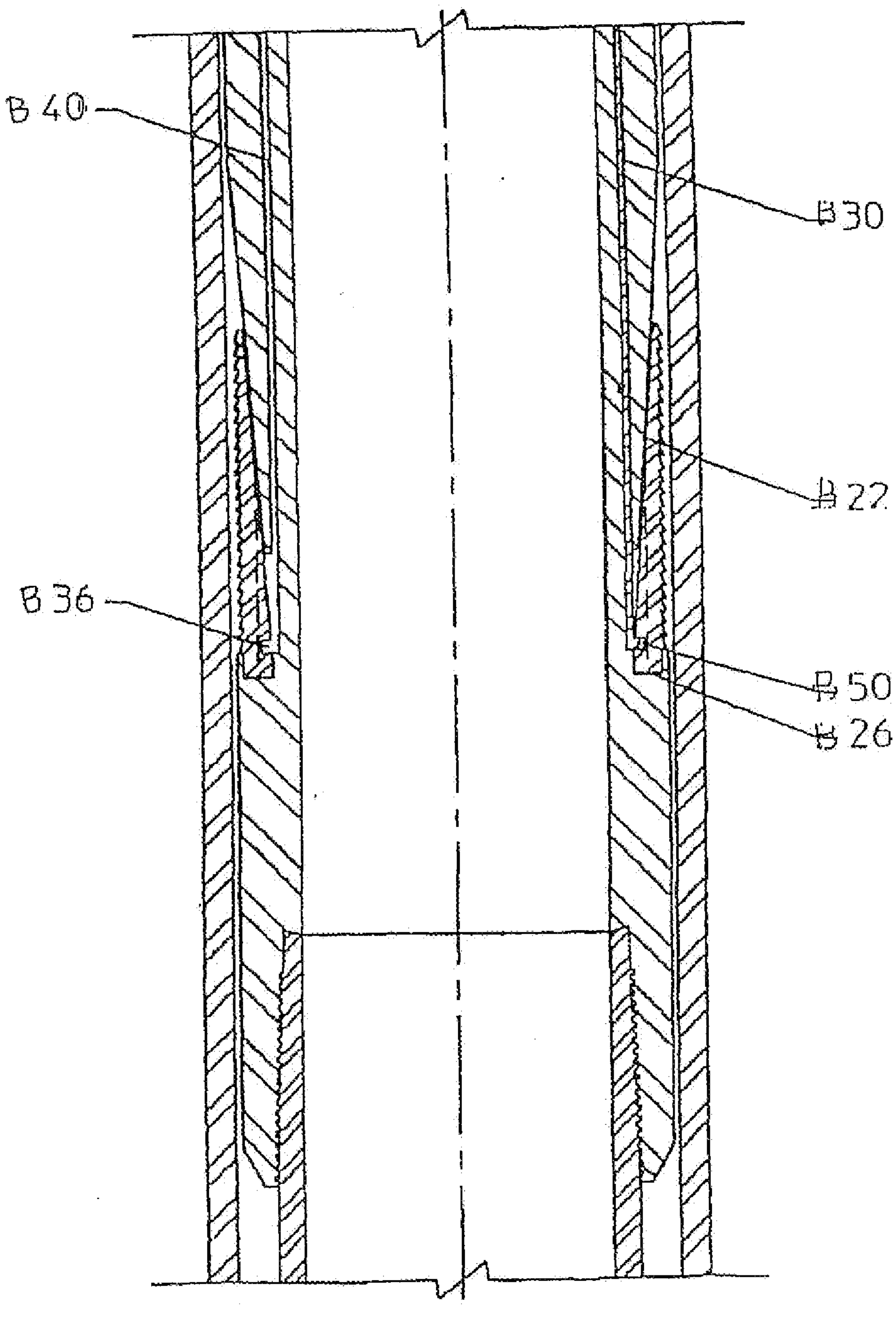


FIGURE B4

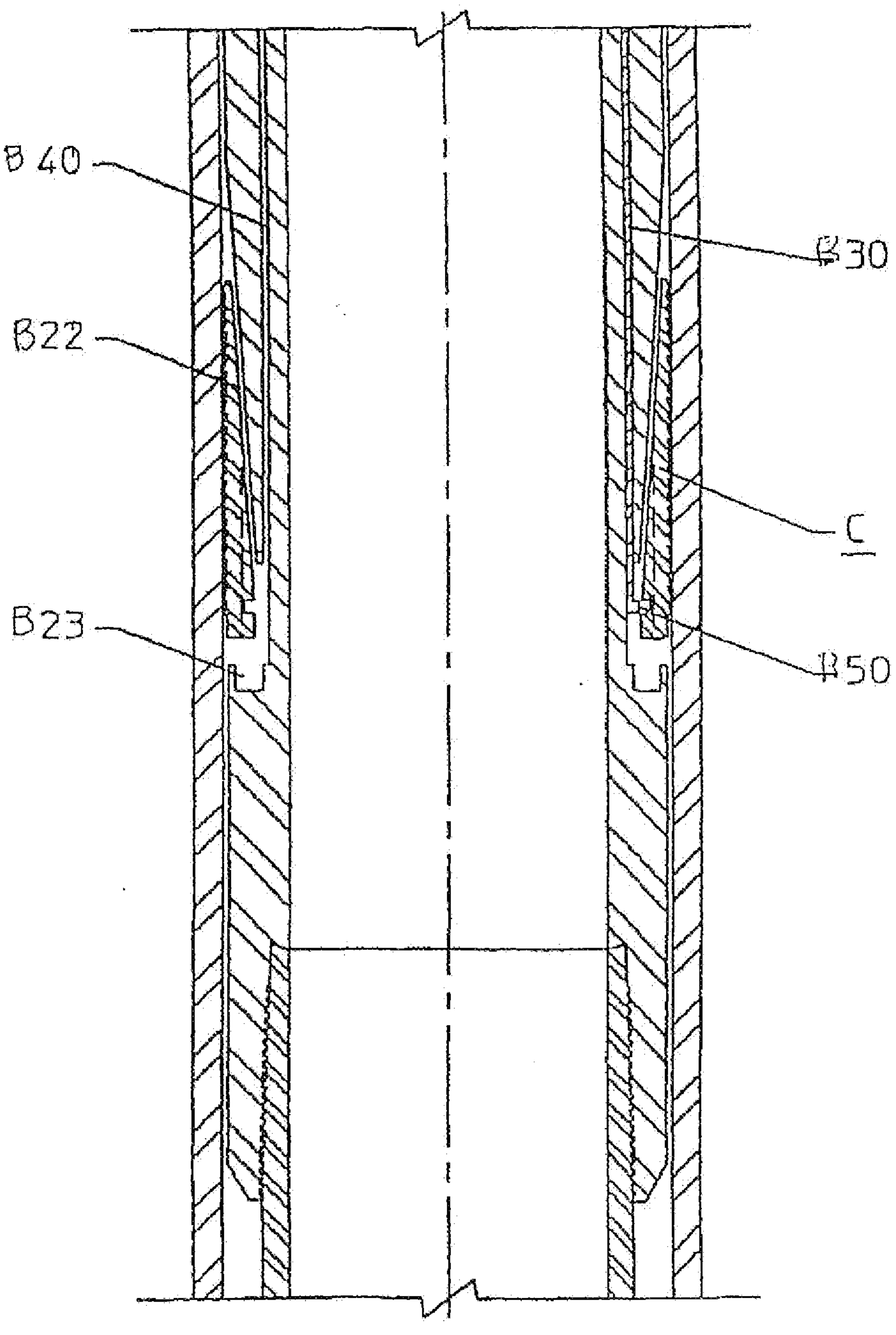


FIGURE B 5

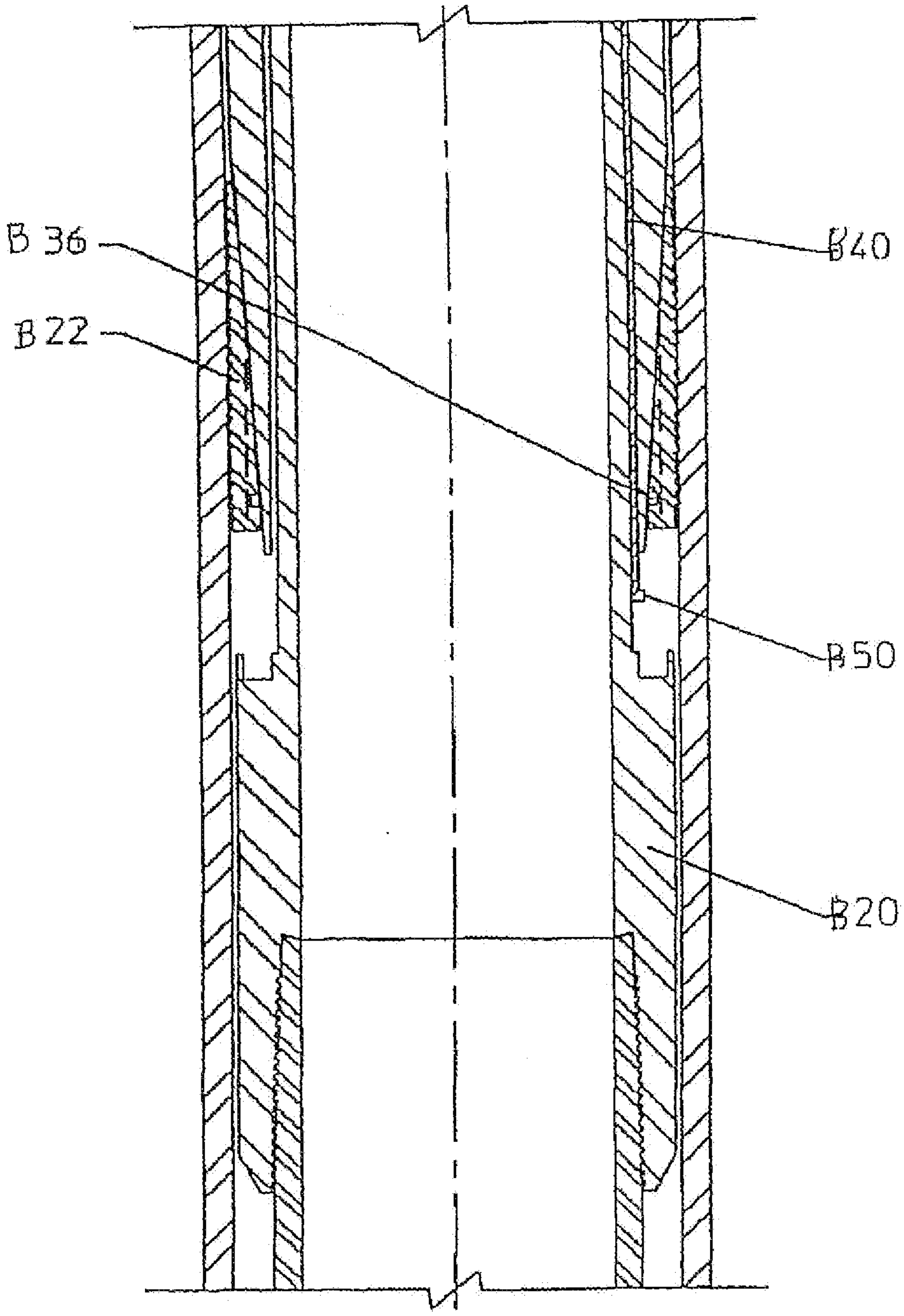


FIGURE B6

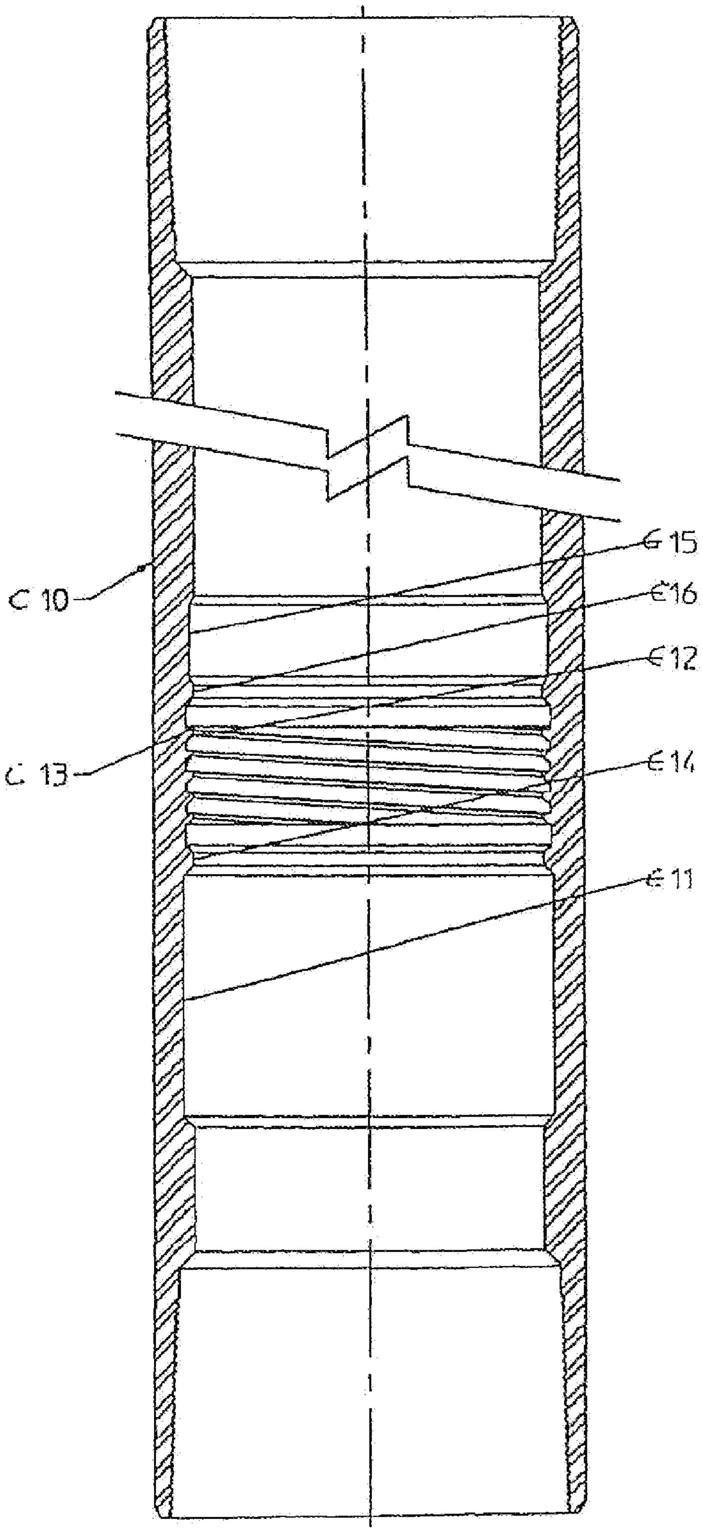


FIGURE C1

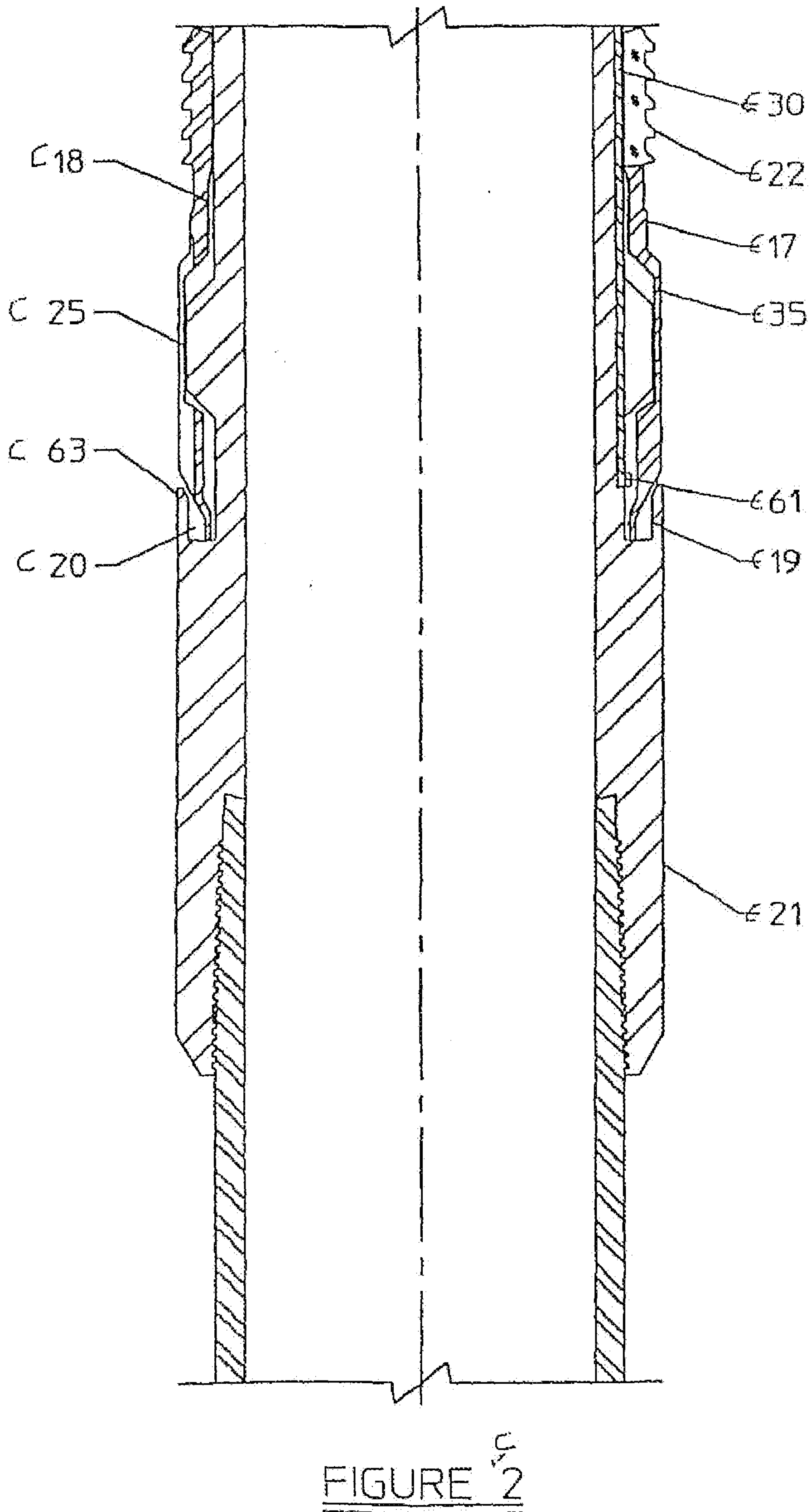


FIGURE 2

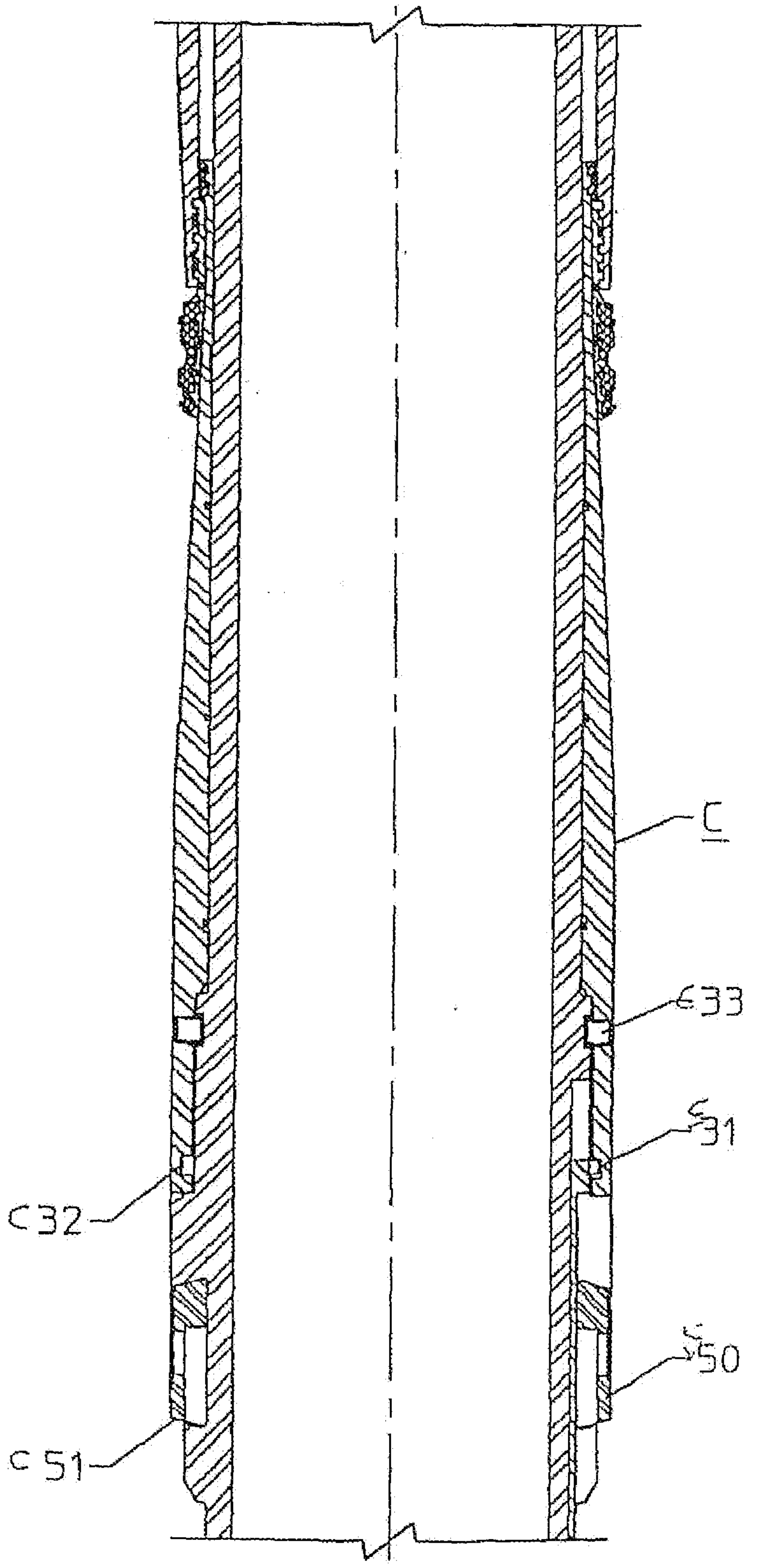


FIGURE 2A

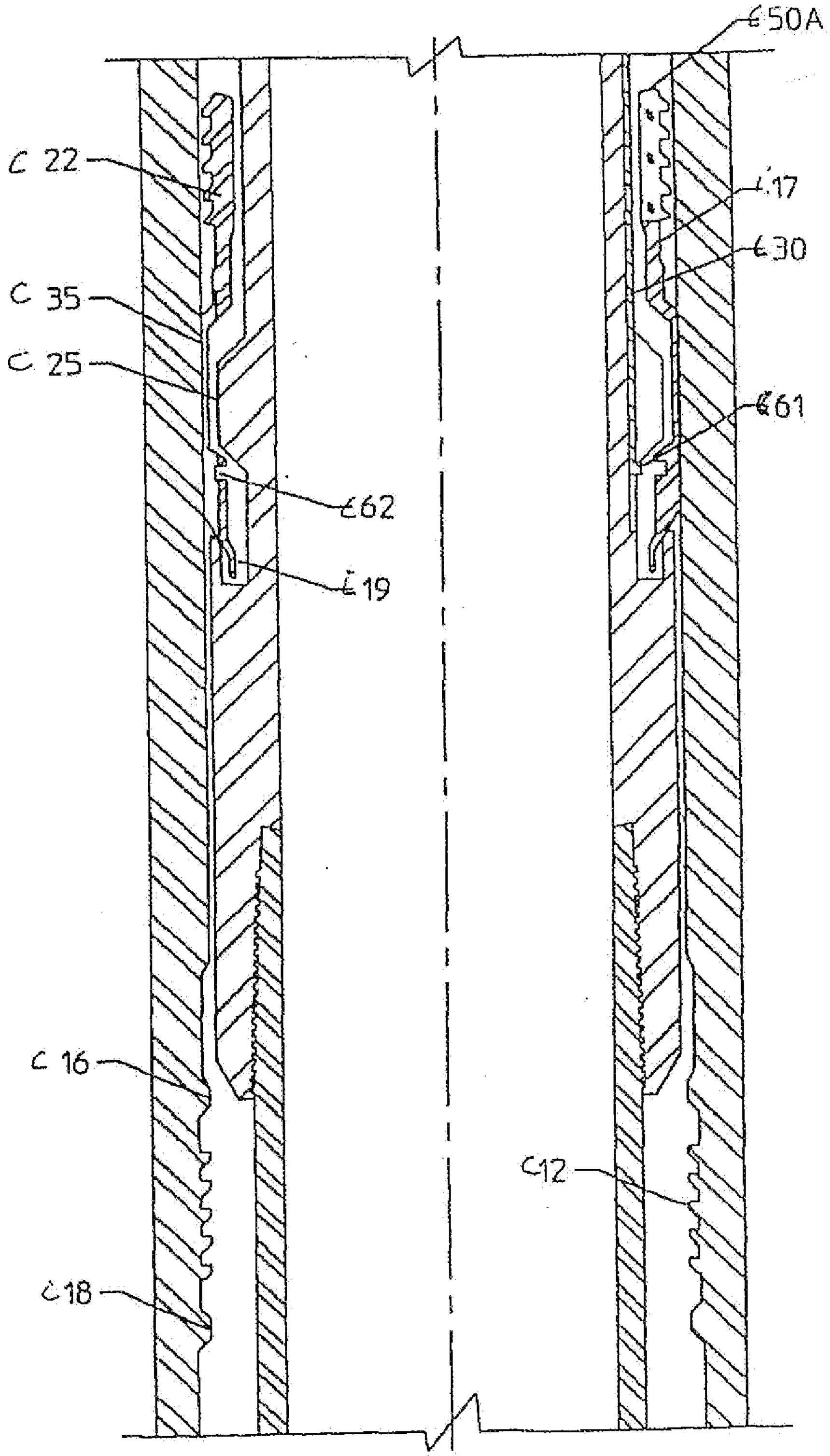


FIGURE 3

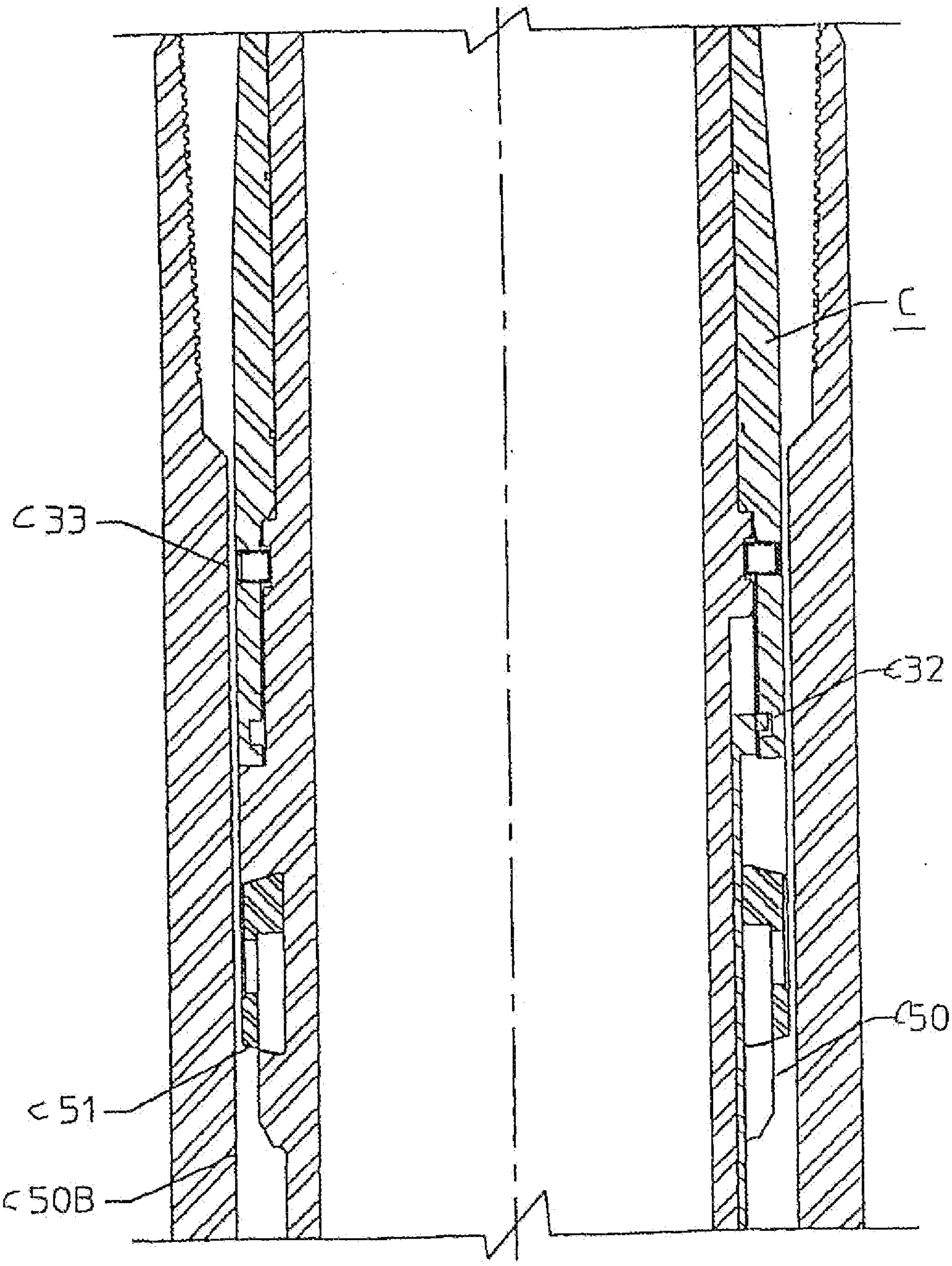


FIGURE 5 3A

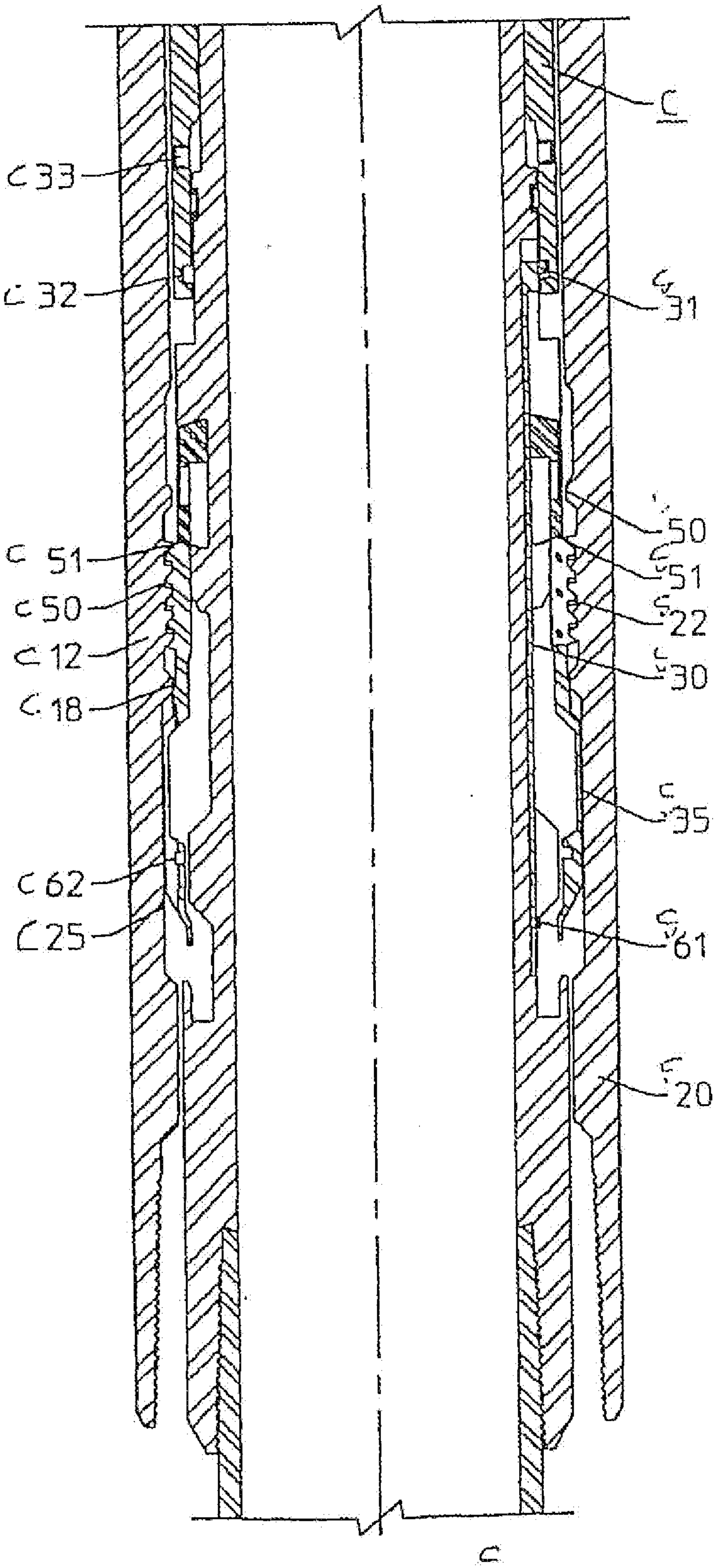


FIGURE 4

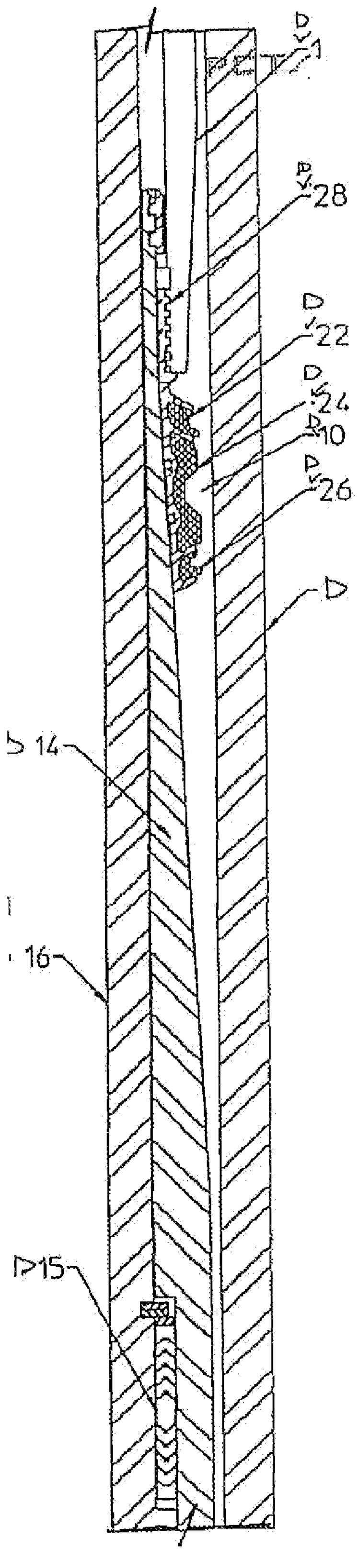


FIGURE 1

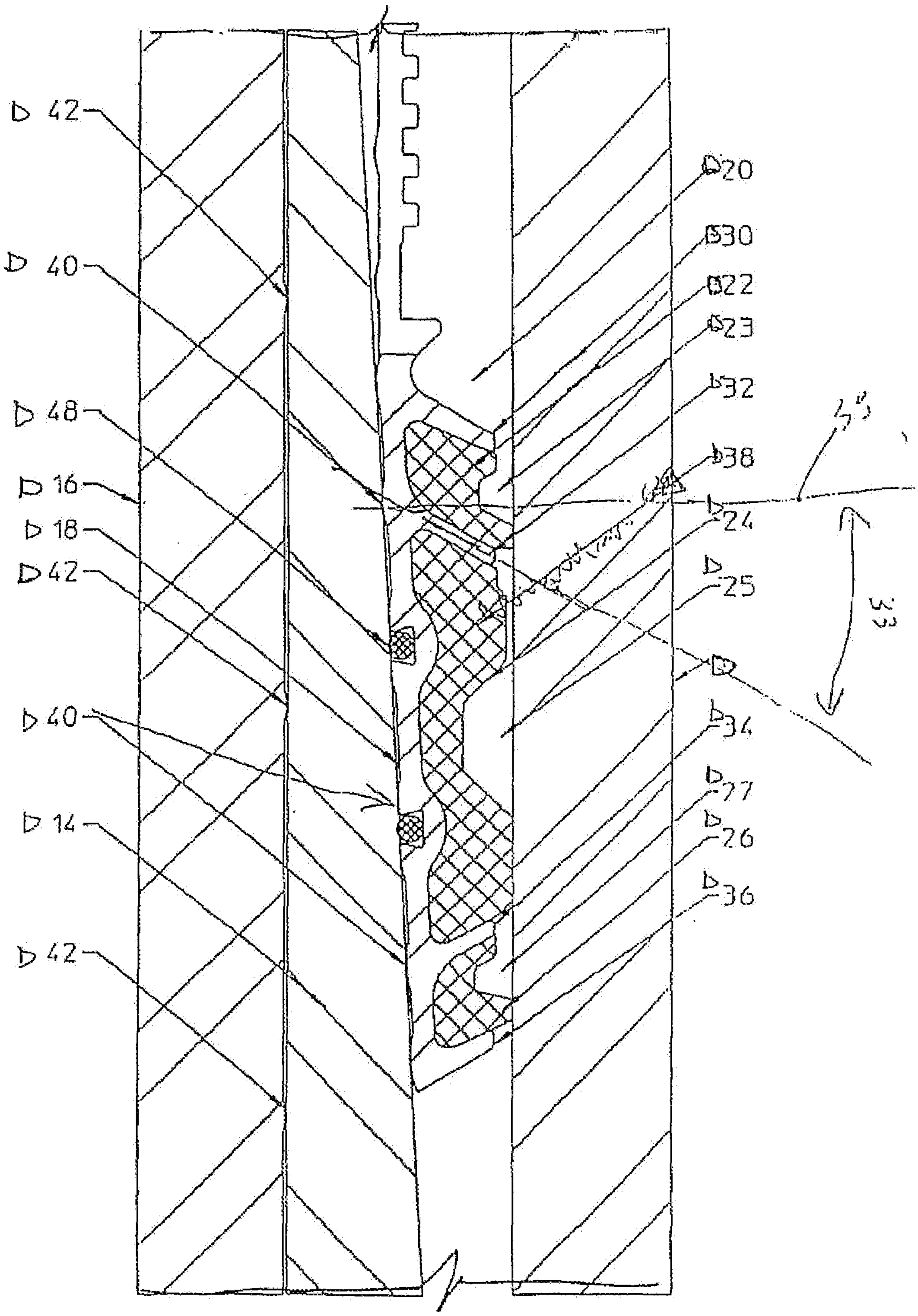


FIGURE 2

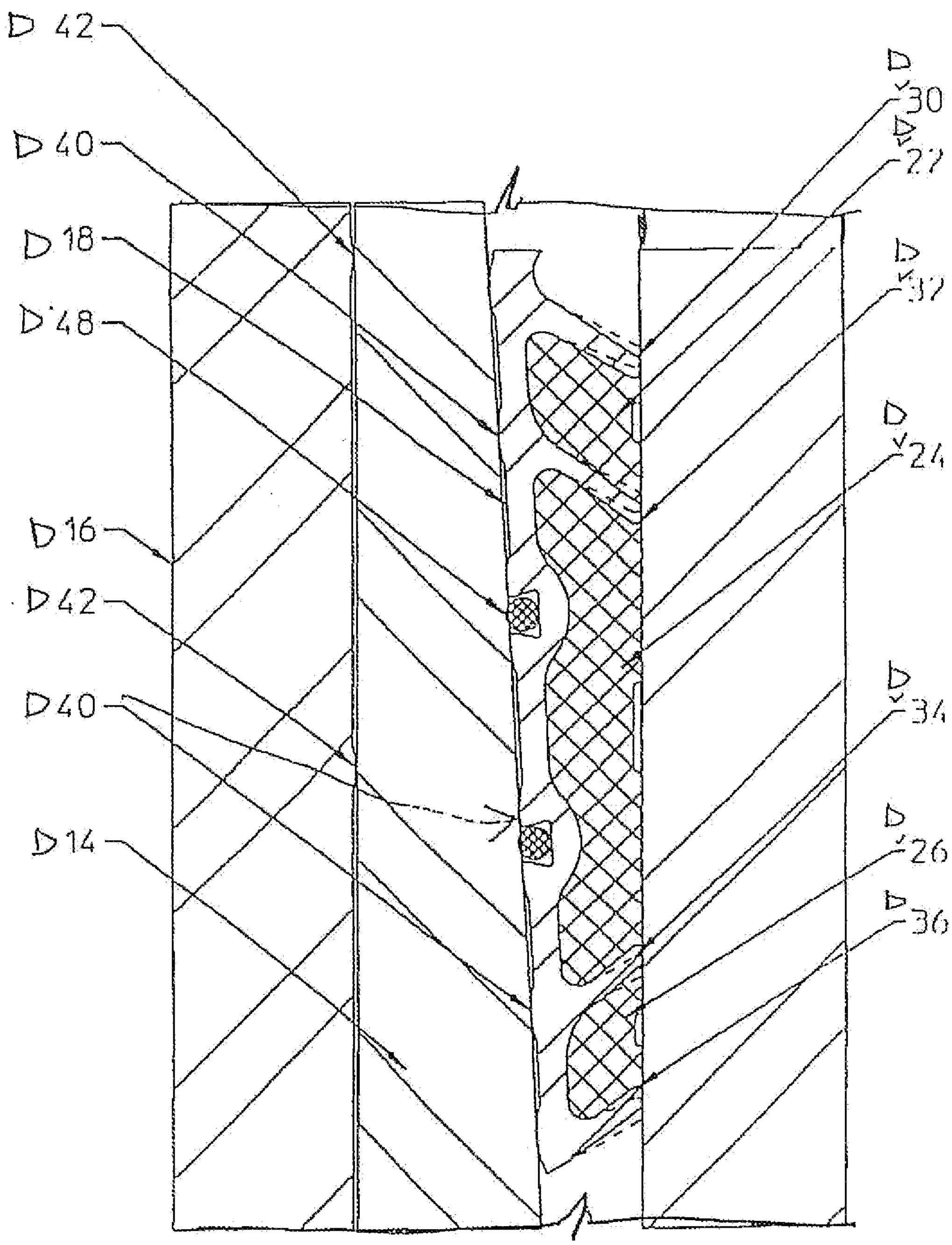


FIGURE 3

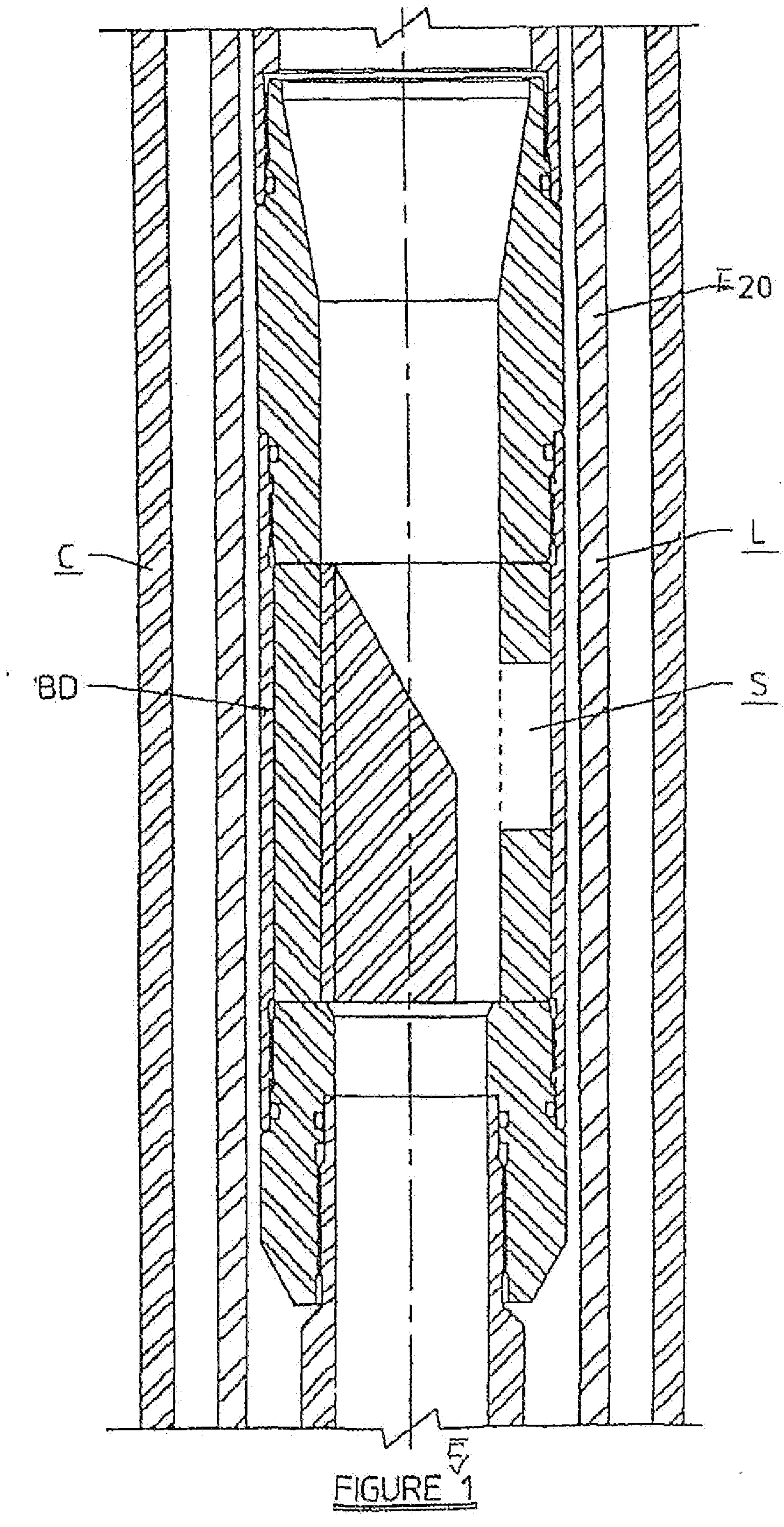


FIGURE 1

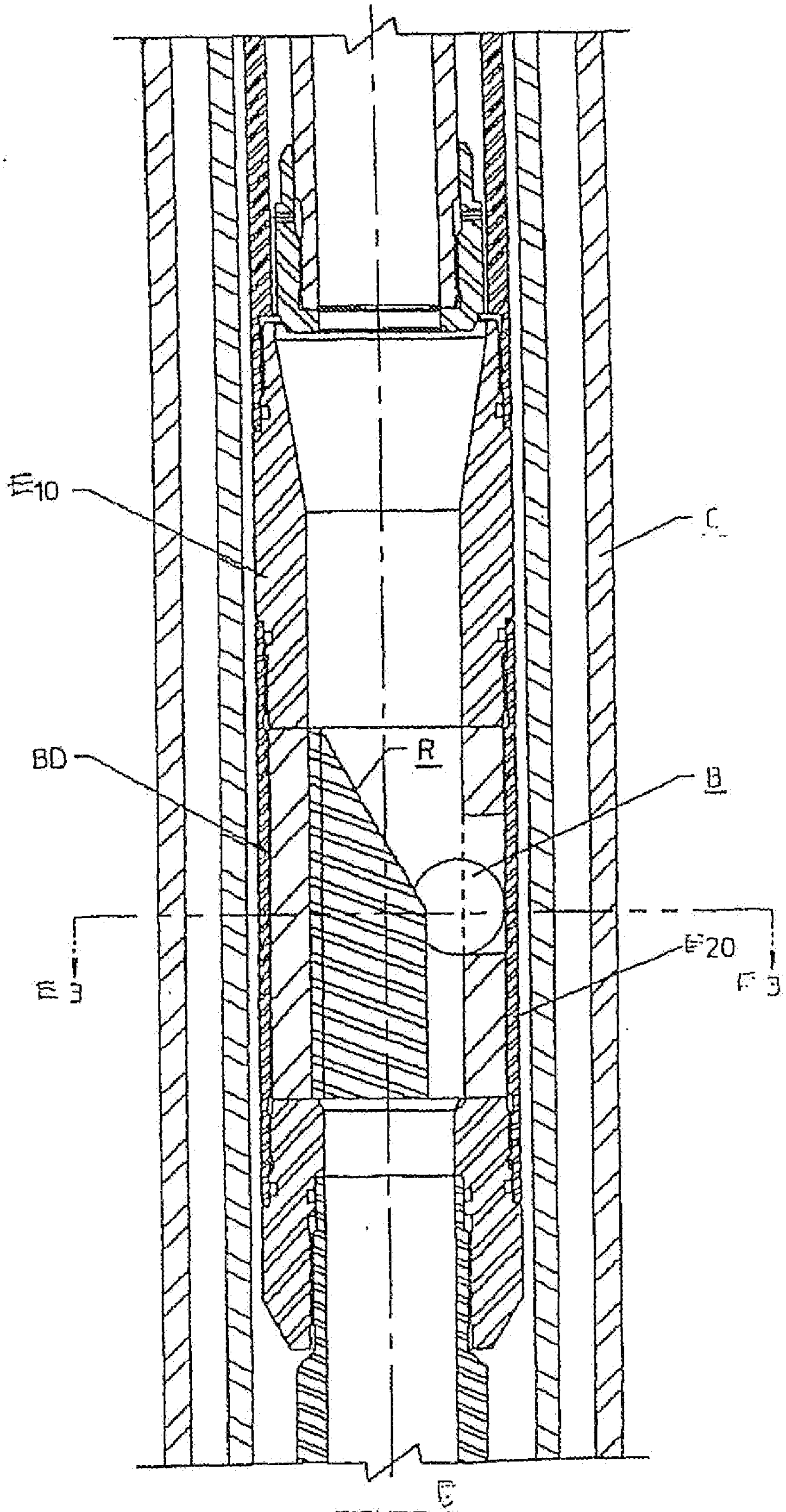


FIGURE 2

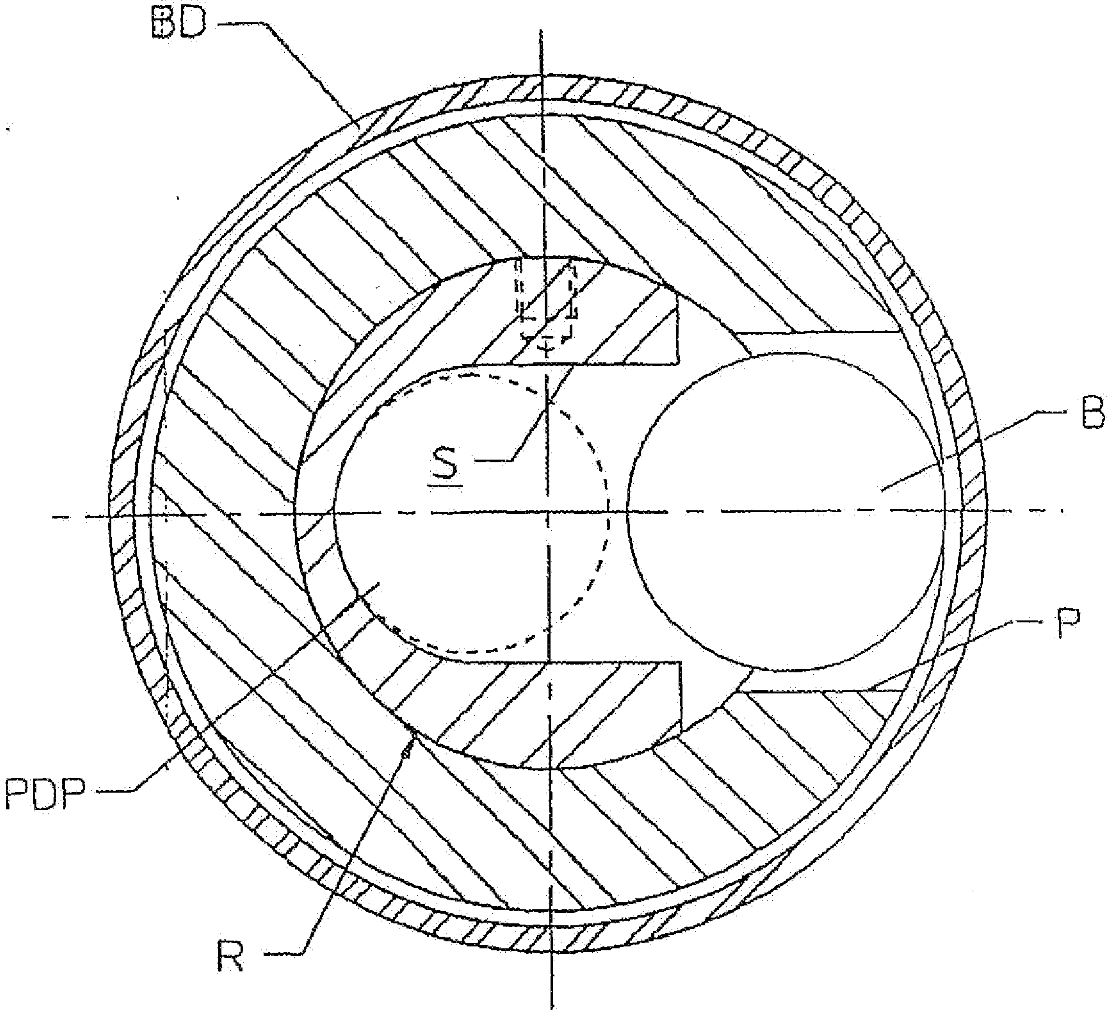


FIGURE 3

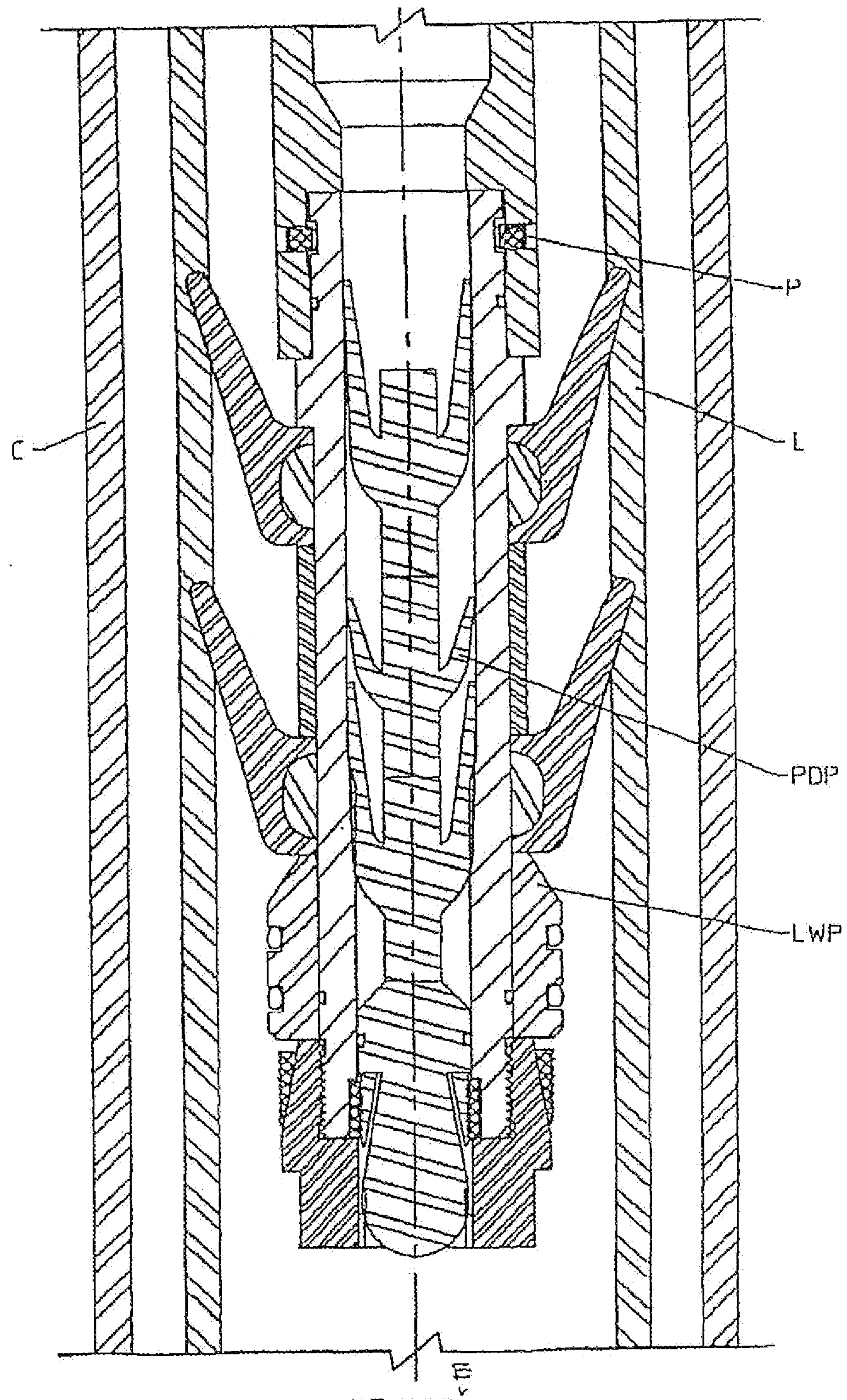


FIGURE 4

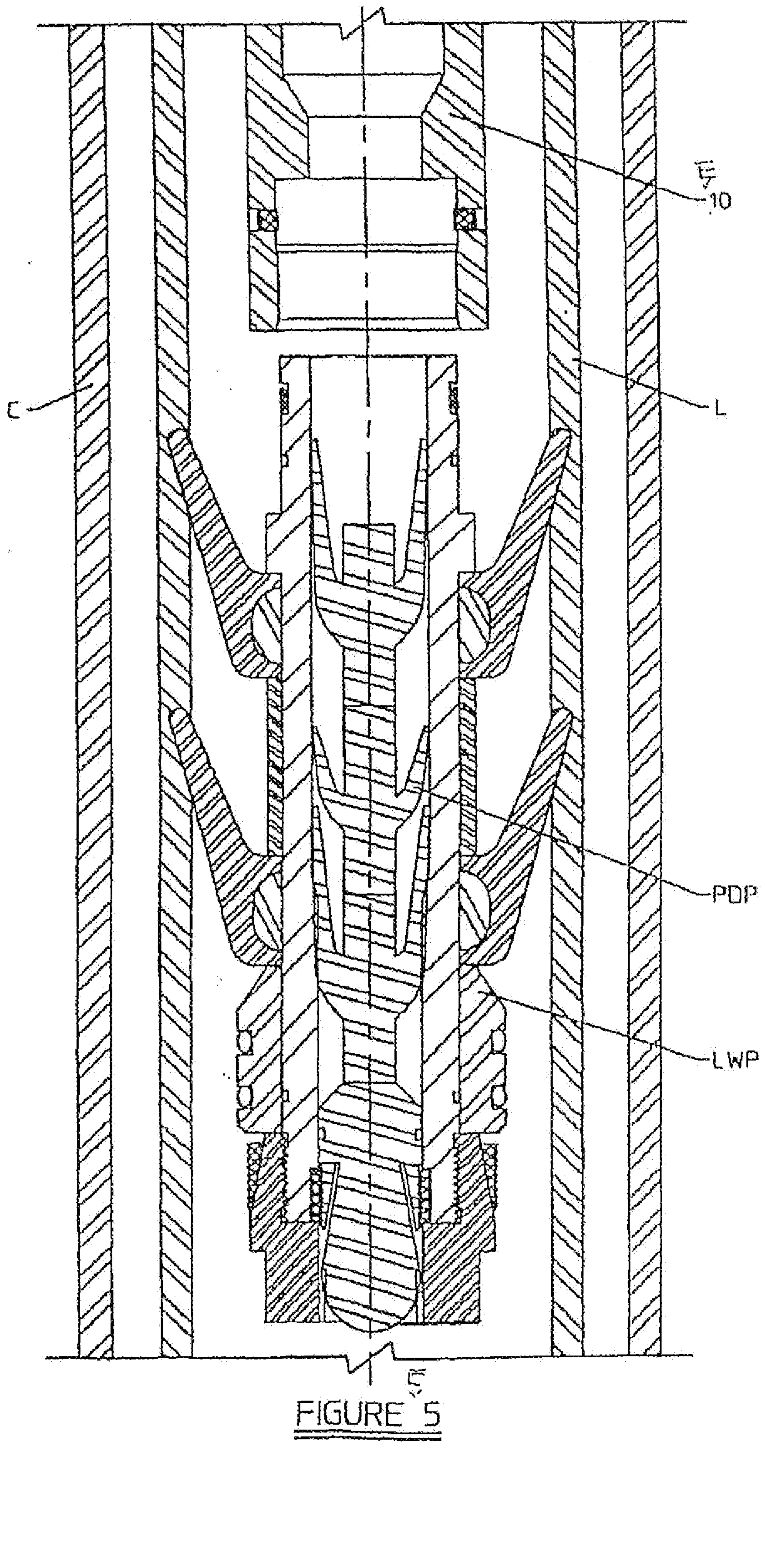


FIGURE 5

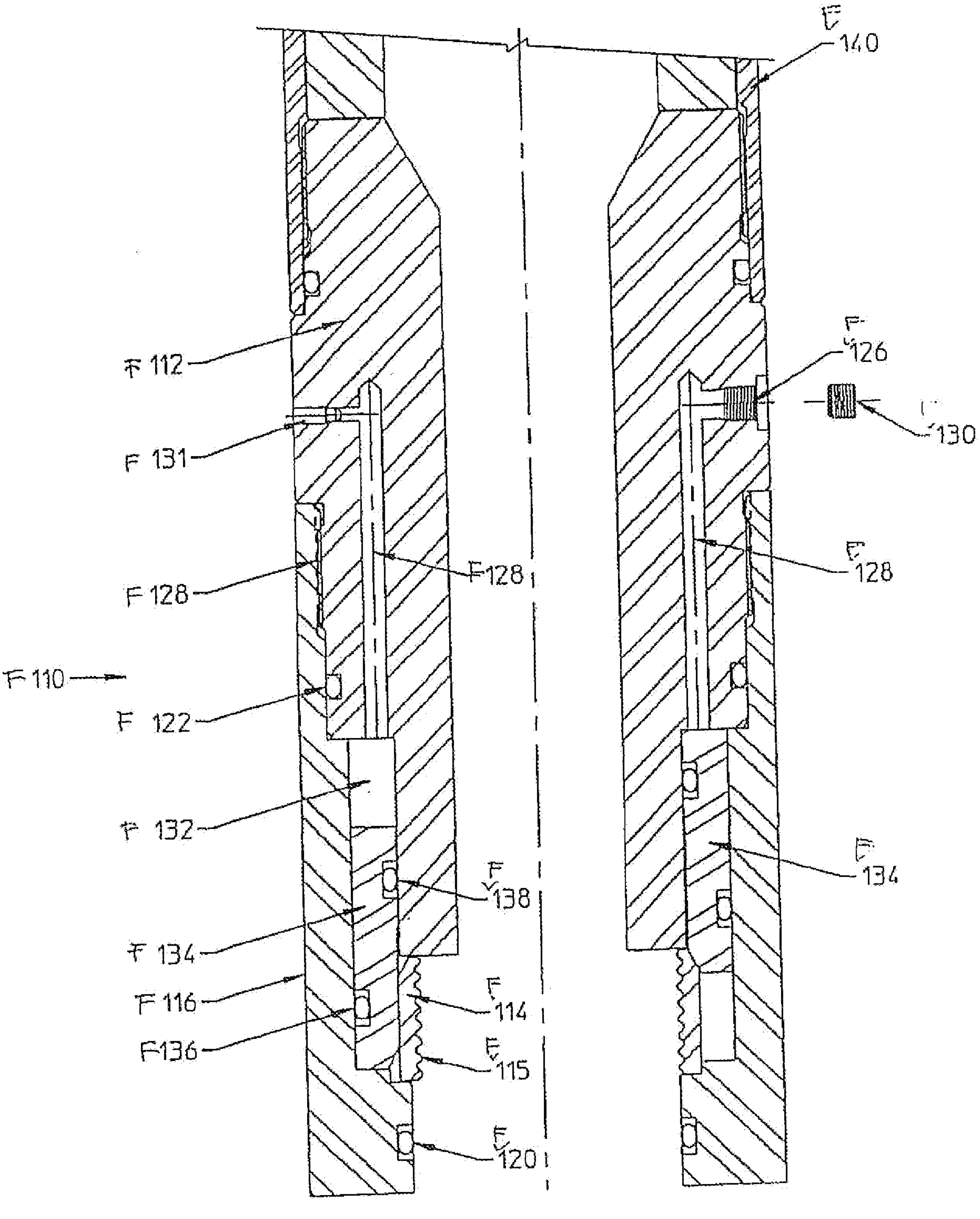

F 140
F 112
F 126
F 130
F 131
F 128
F128
F 128
F 110
F 122
F 132
F 134
F 138
F 134
F 116
F 114
F136
F 115
F 120

FIGURE 1

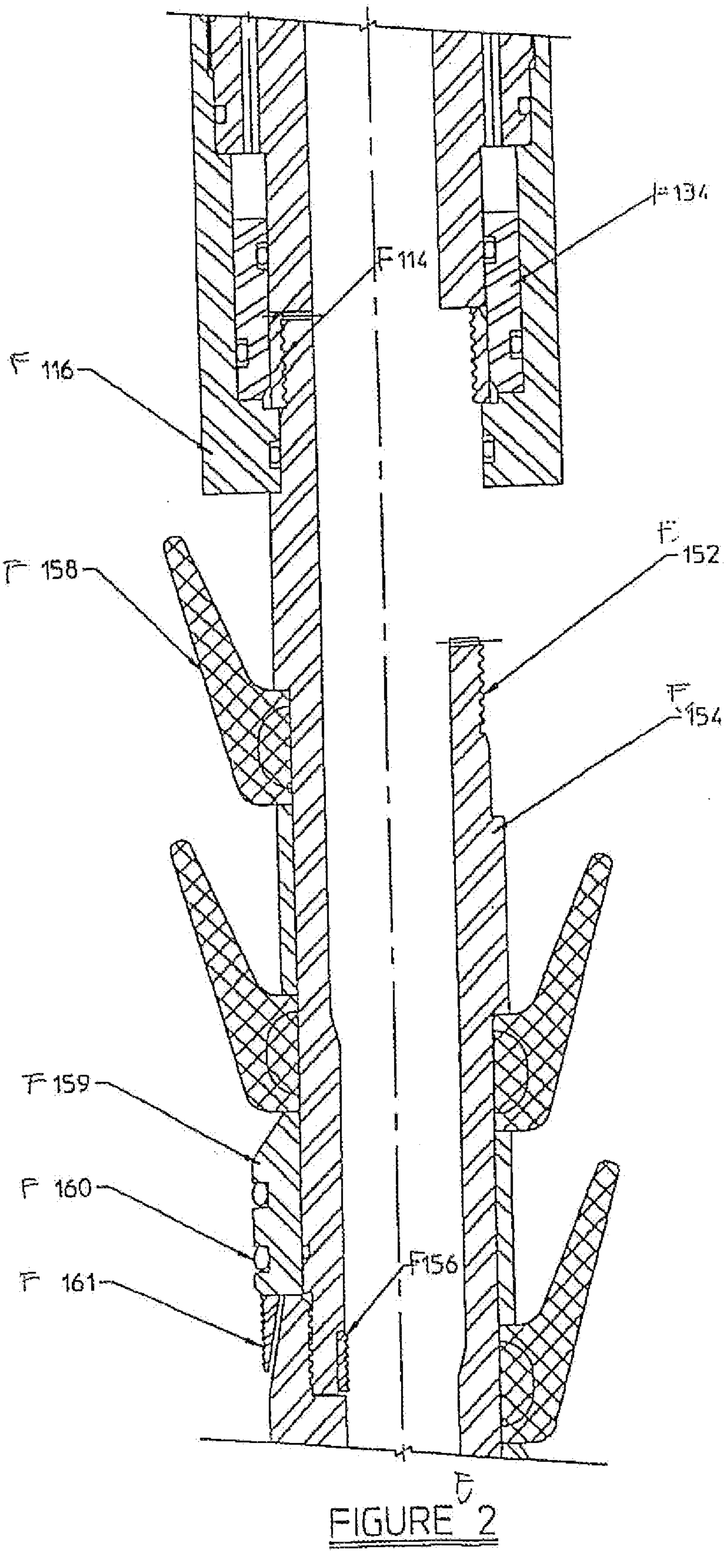


FIGURE 2

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 60292049 B **[0001]**
- US 60316572 B **[0001]**
- US 60316459 B **[0001]**
- US 09943854 B **[0001]**
- US 09943701 B **[0001]**
- US 09981487 B **[0001]**
- US 10083320 B **[0001]**
- US 101004945 B **[0001]**
- US 10004588 B **[0001]**
- US 4281711 A **[0014]**
- US 6182752 B **[0055]**
- US 6206095 B **[0055]**
- US 60292099 B **[0071]**
- US 4757860 A **[0093] [0096]**
- US 5076356 A **[0096]**
- US 5511620 A **[0096]**
- US 5333692 A **[0096]**
- US 29204901 P **[0106]**
- US 4624312 A **[0145]**
- US 4934452 A **[0145]**
- US 5036922 A **[0145]**