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(54) **INDUCTIVE POWER COUPLER**

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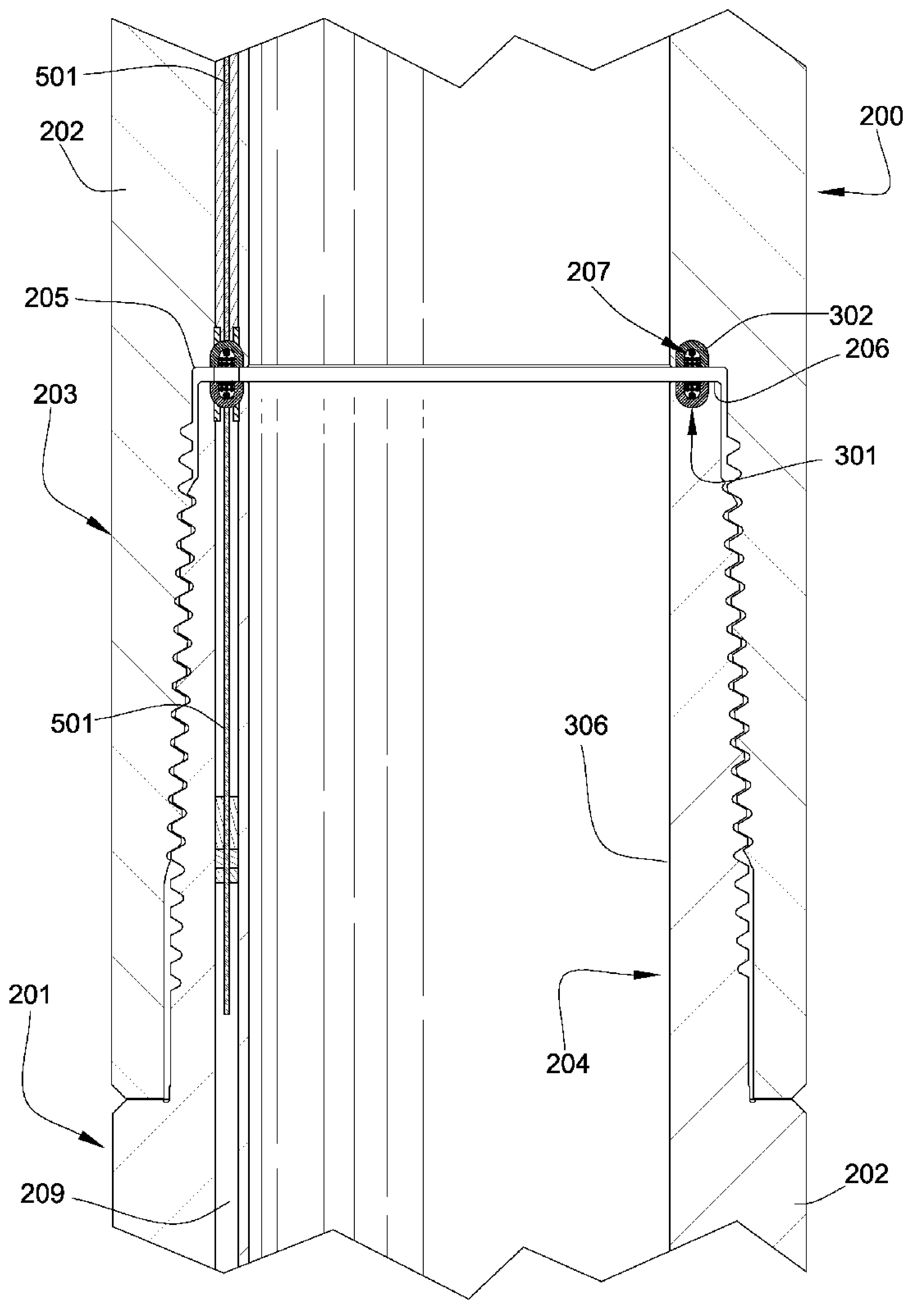
(57) **ABSTRACT**

In one aspect of the present invention, a downhole tool string component has a tubular body with at least one end adapted for threaded connection to an adjacent tool string component. The end has at least one shoulder that abuts an adjacent shoulder of an adjacent end of the adjacent tool string component. At least two electrically conducting coils are disposed within an annular recess formed in the at least one shoulder and an annular trough is disposed in the annular recess. The annular trough houses at least one of the at least two electrically conducting coils and each coil is electrically insulated from each other.



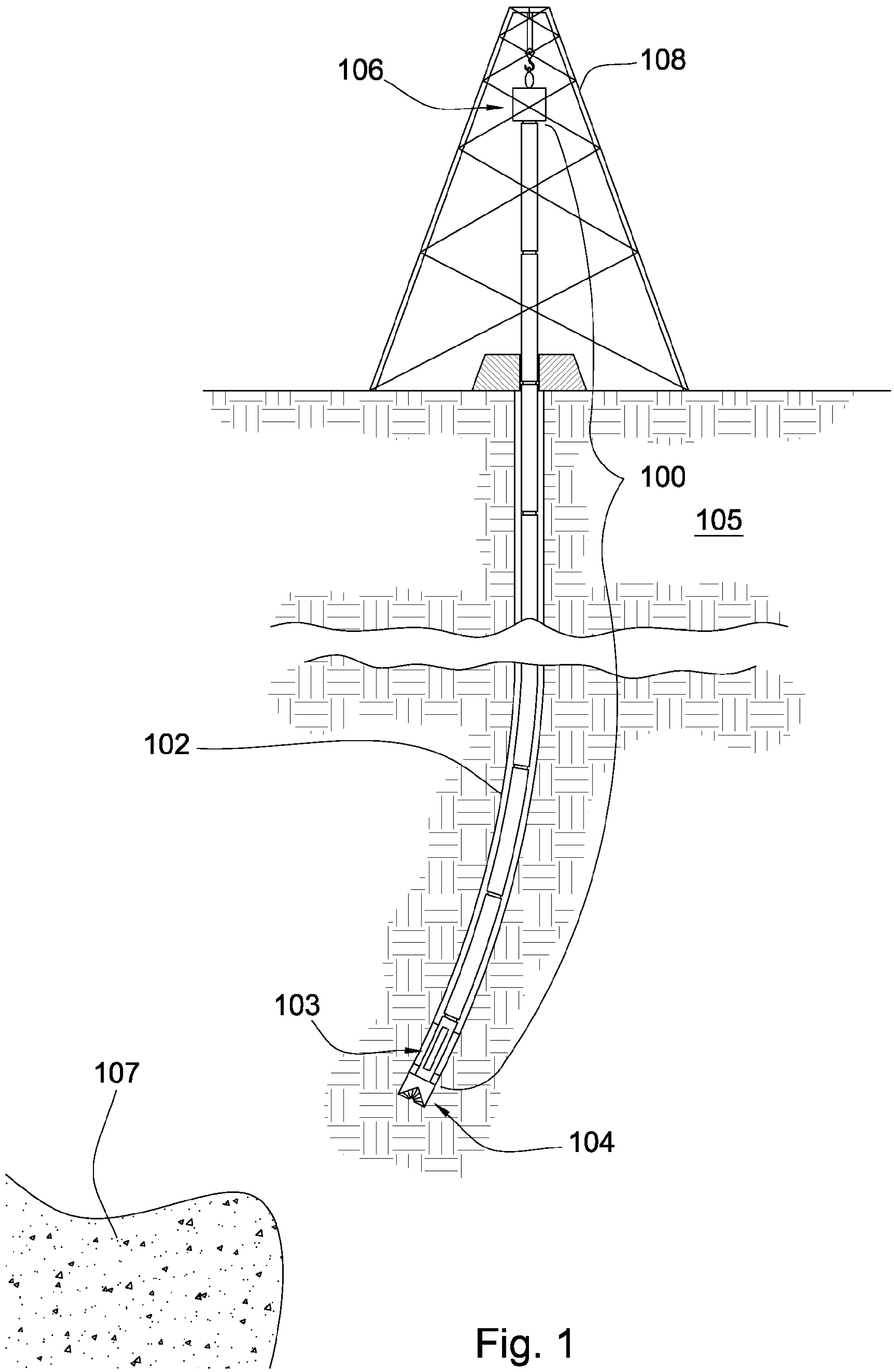


Fig. 1

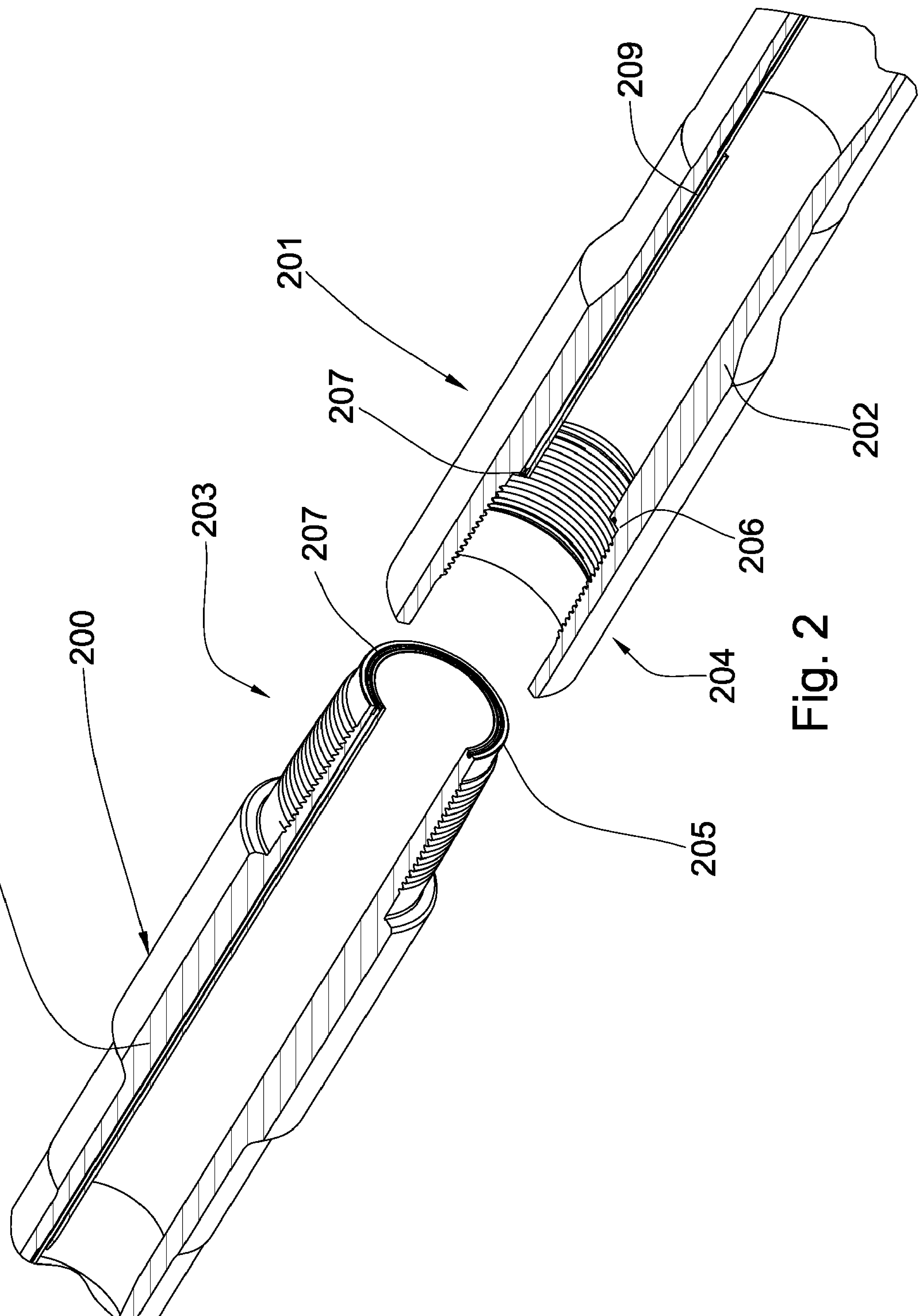


Fig. 2

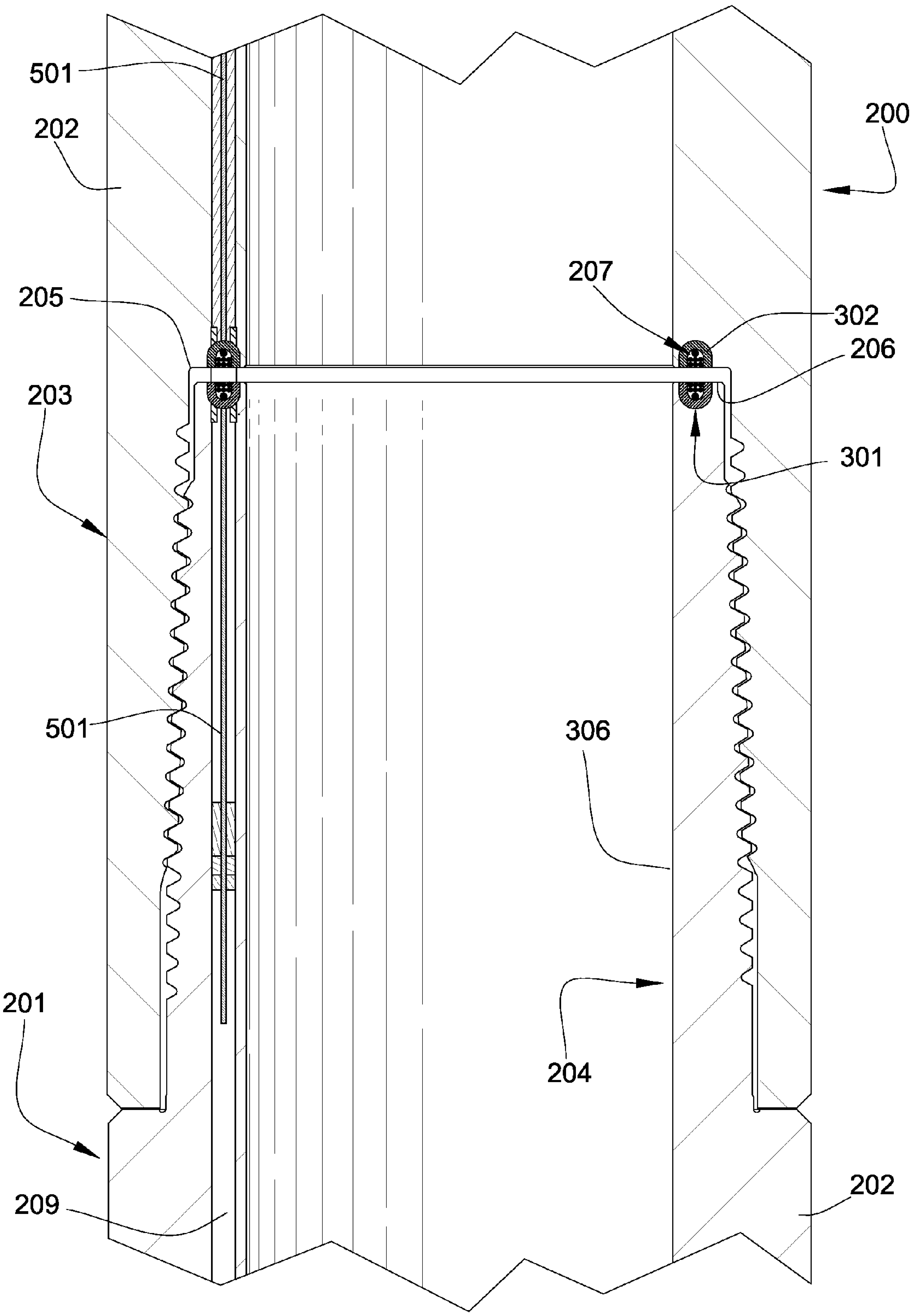


Fig. 3

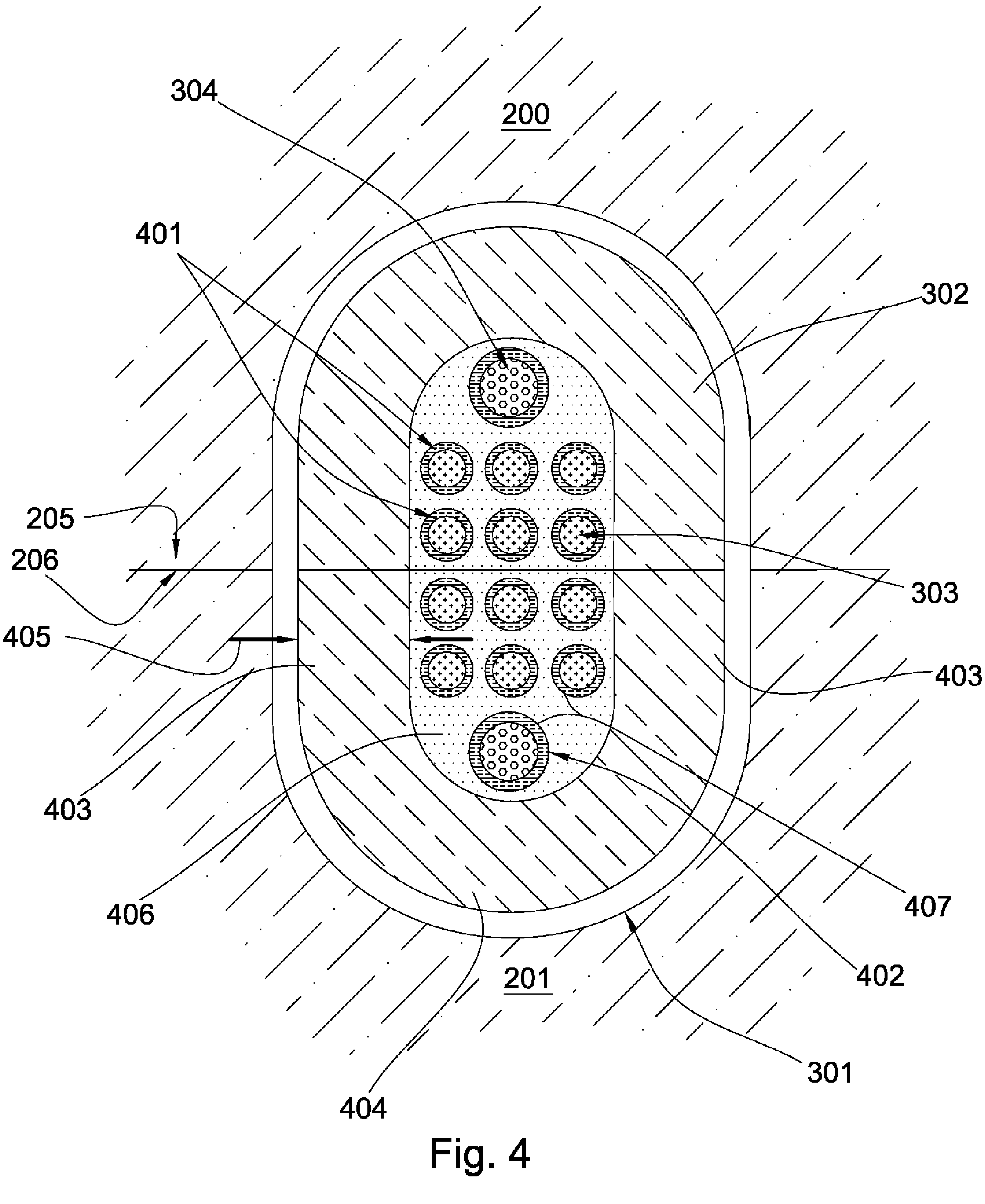


Fig. 4

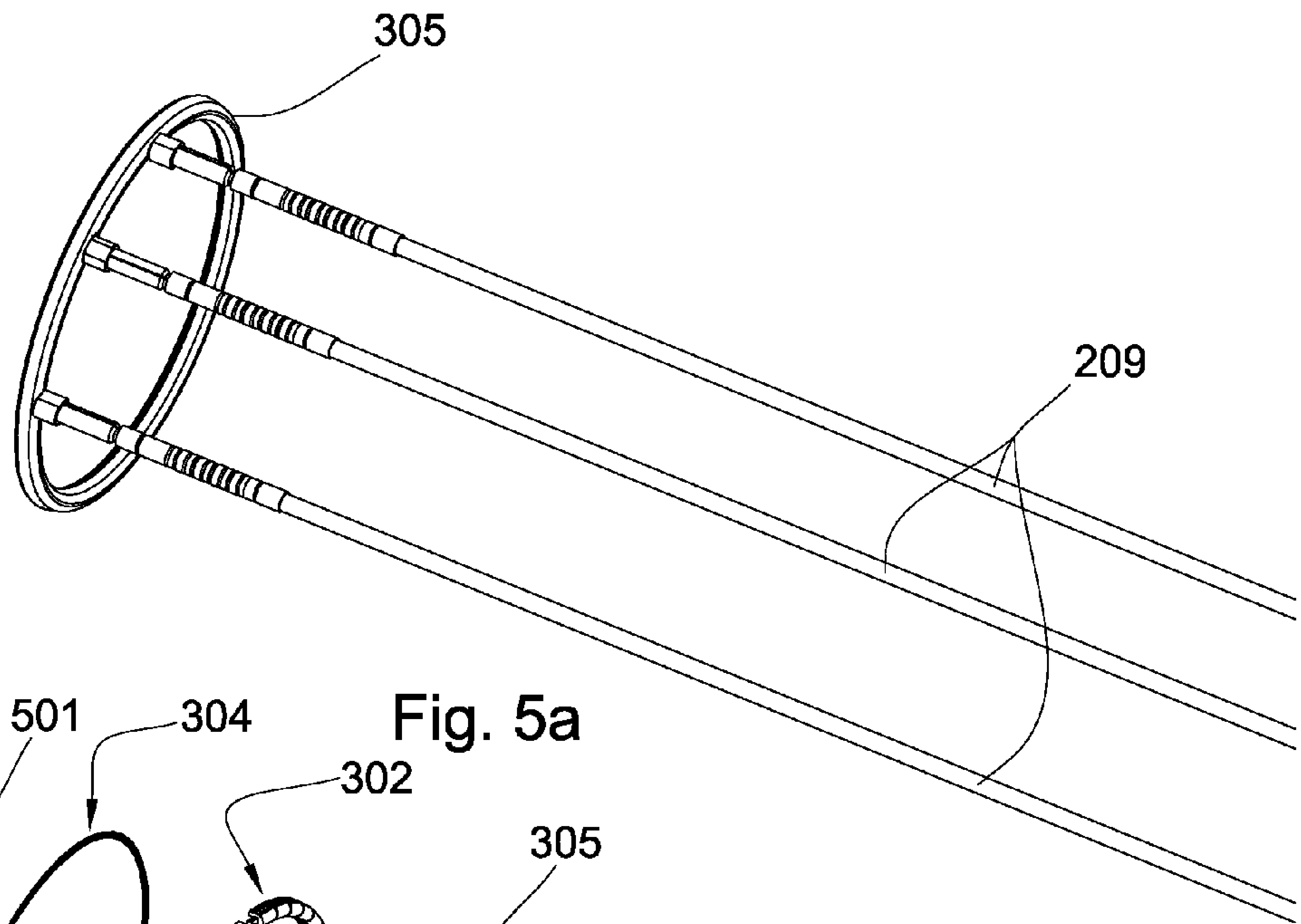


Fig. 5a

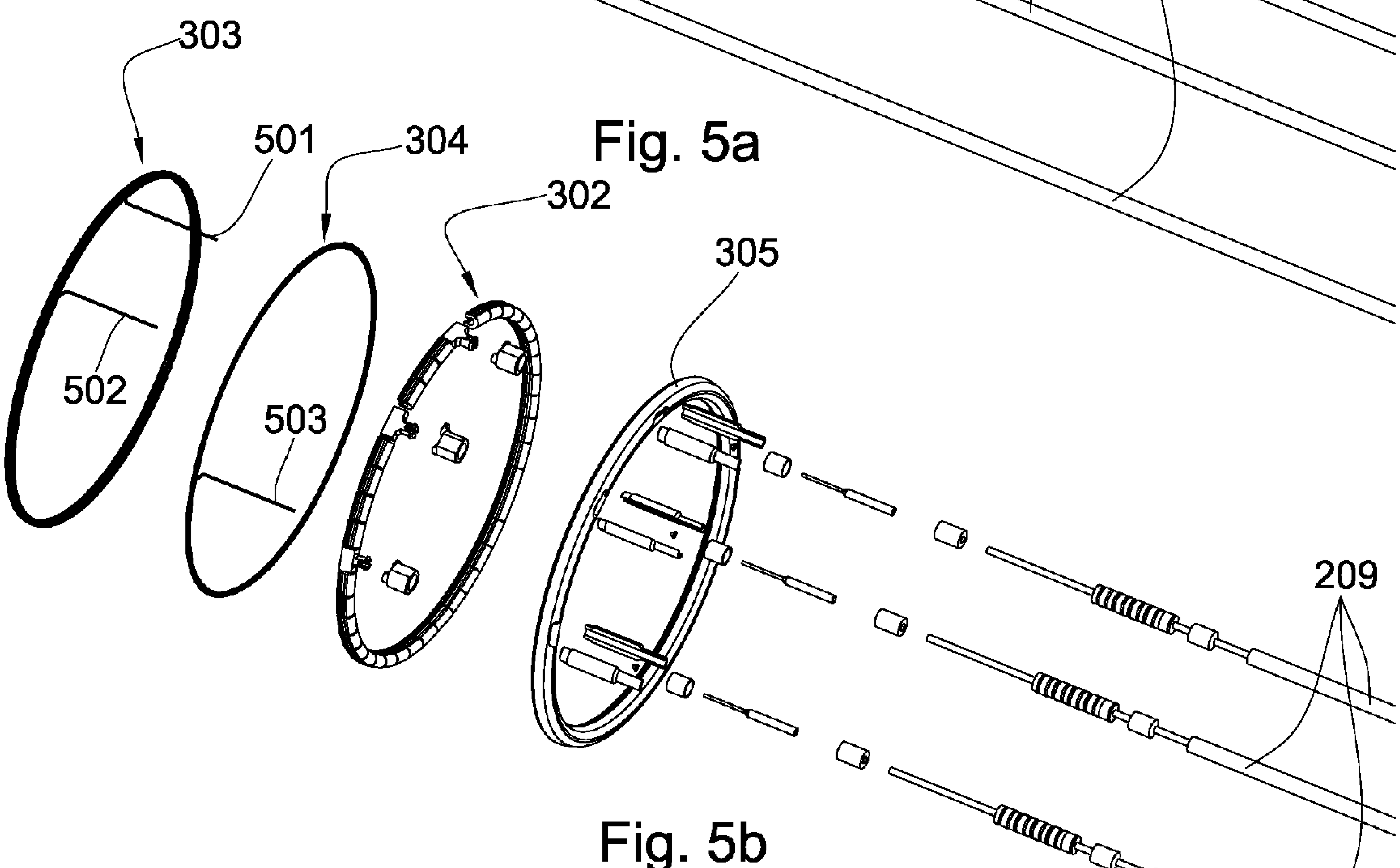


Fig. 5b

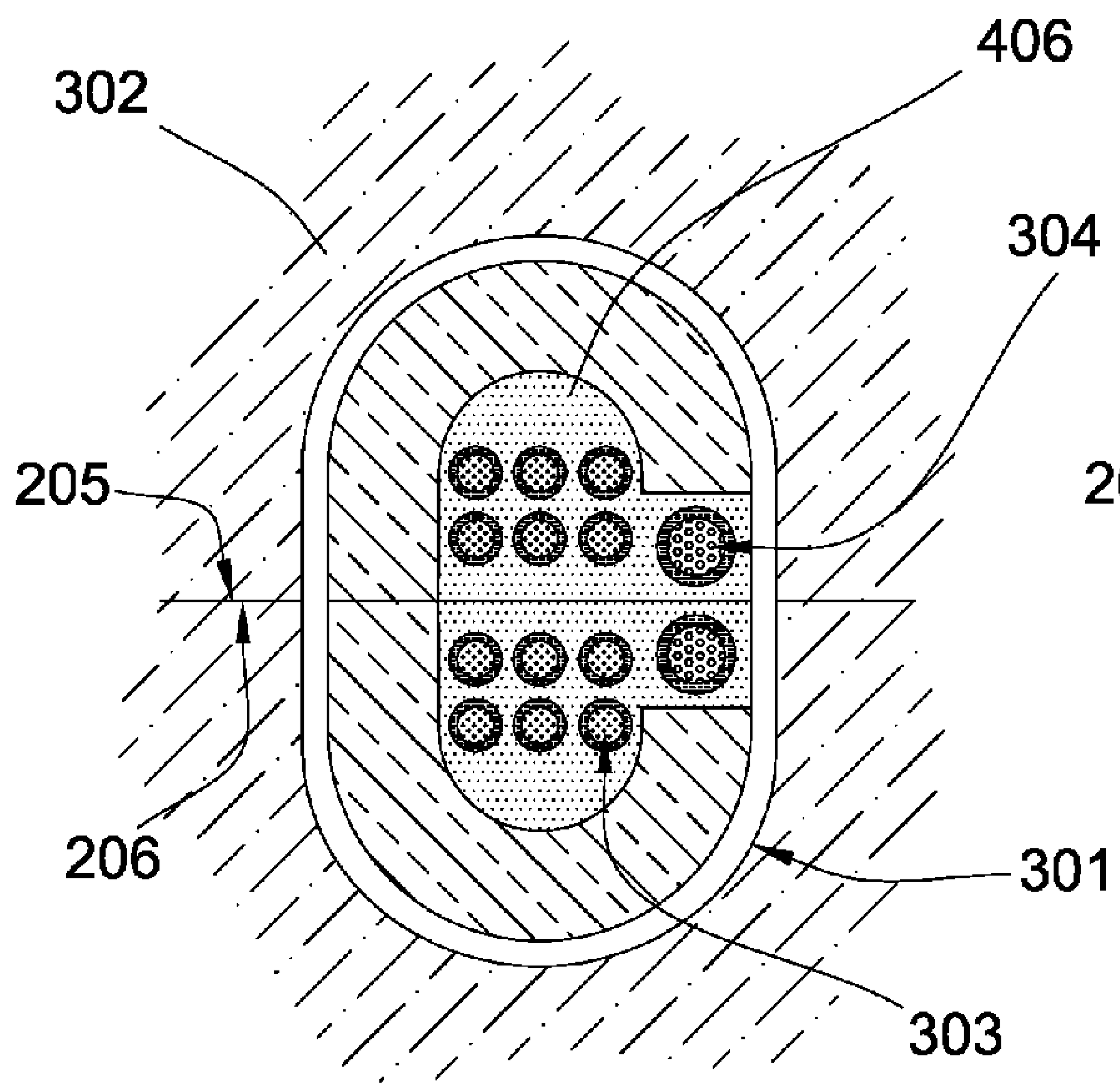


Fig. 6a

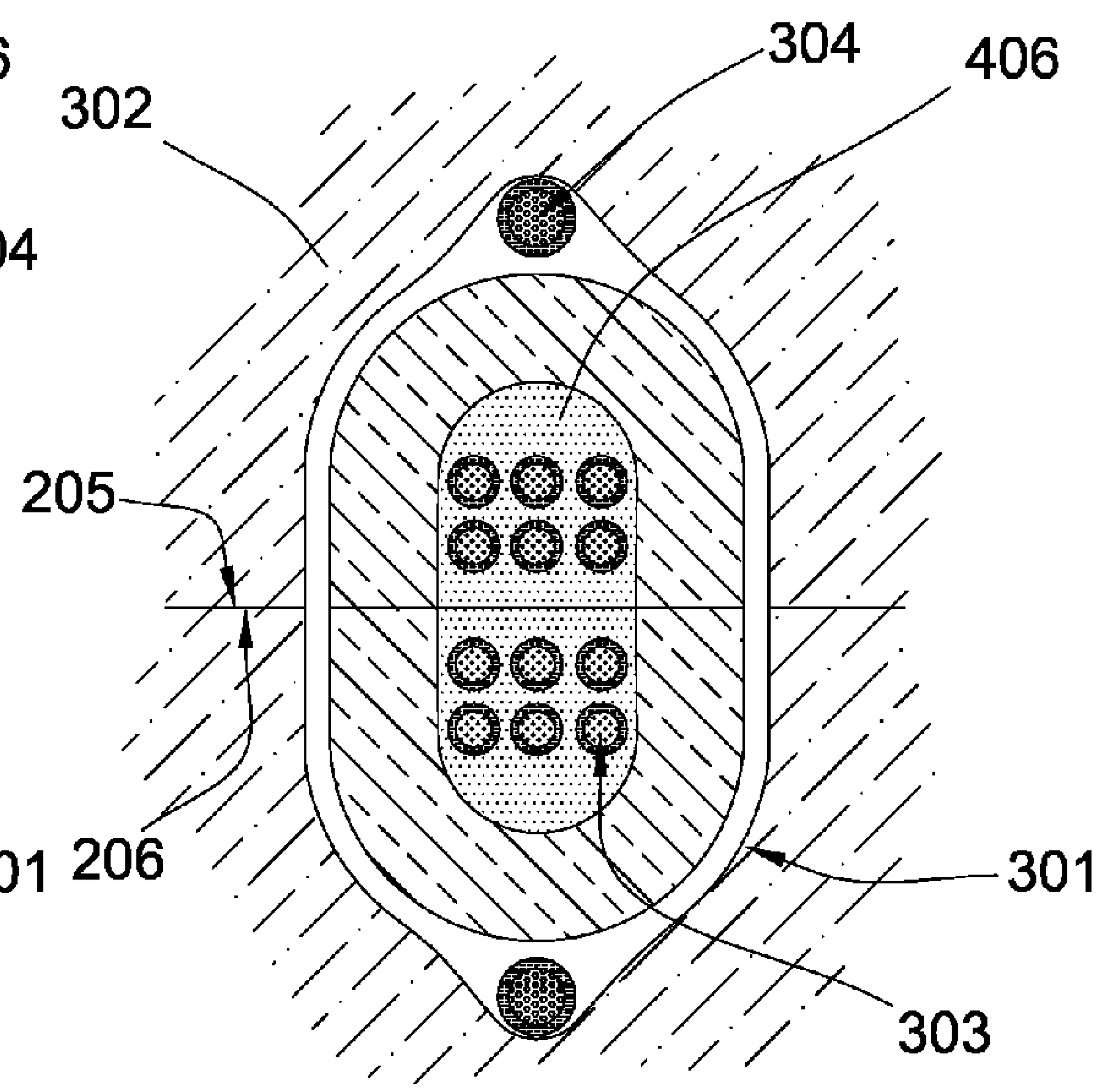


Fig. 6b

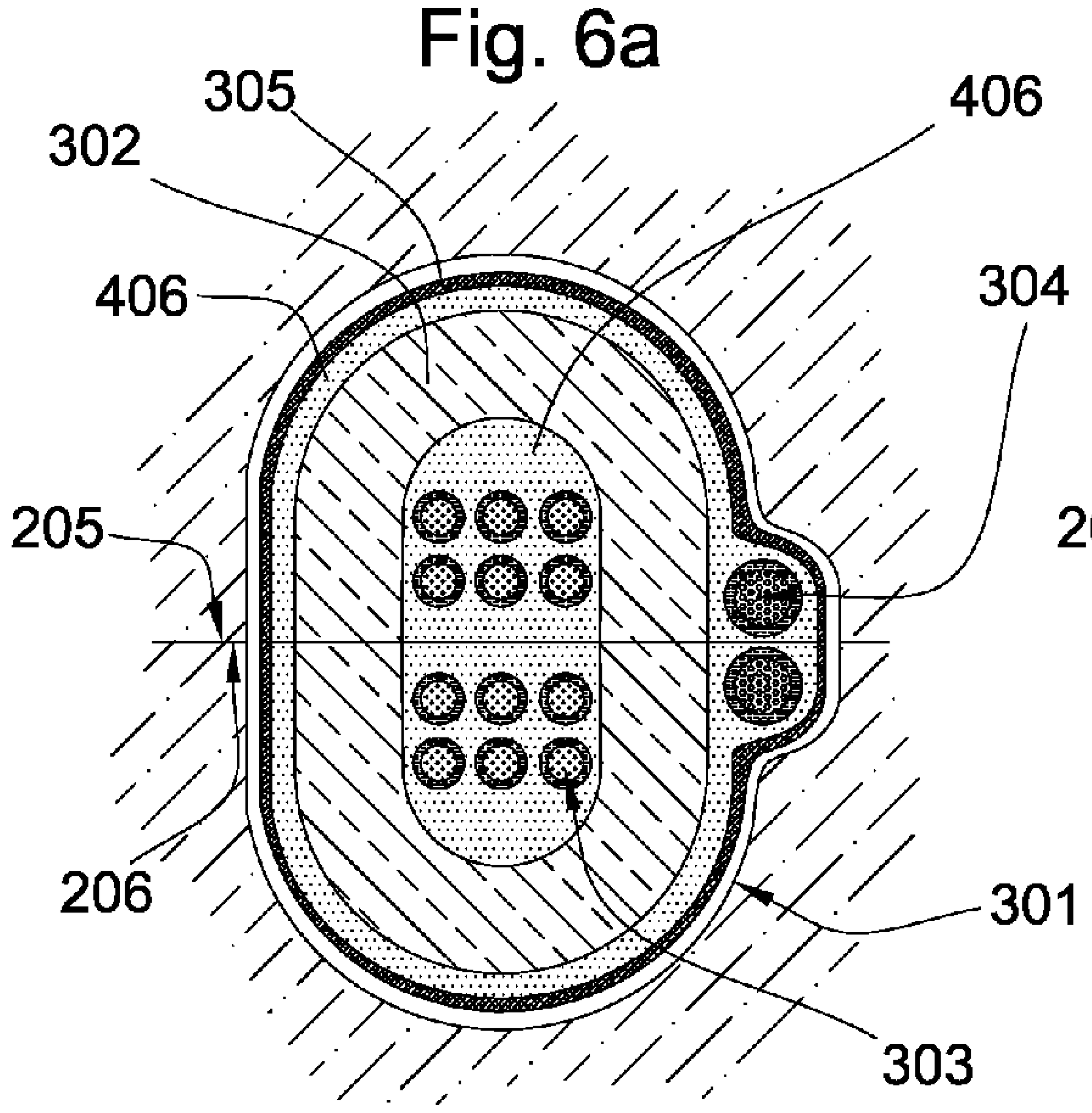


Fig. 6c

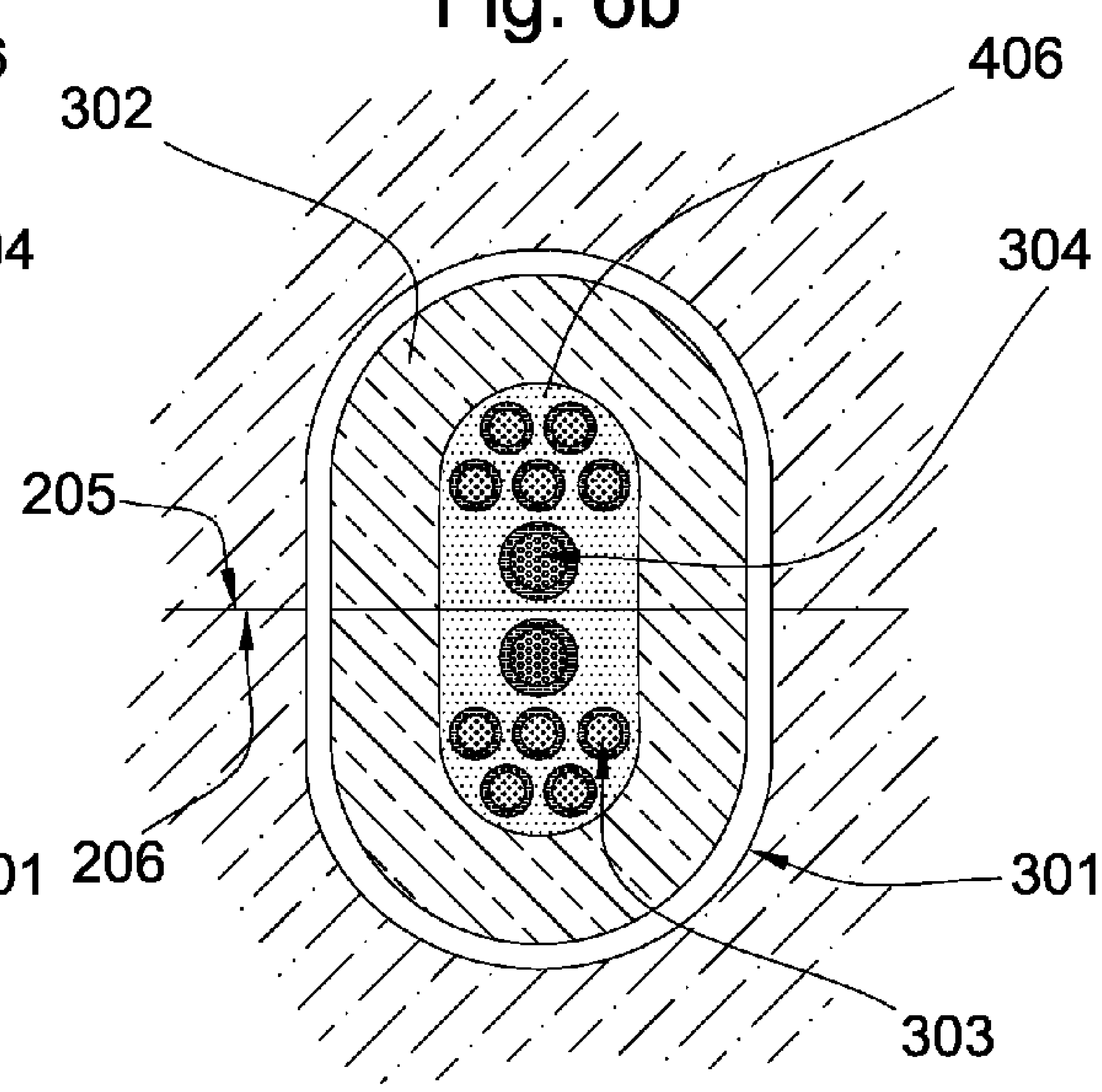


Fig. 6d

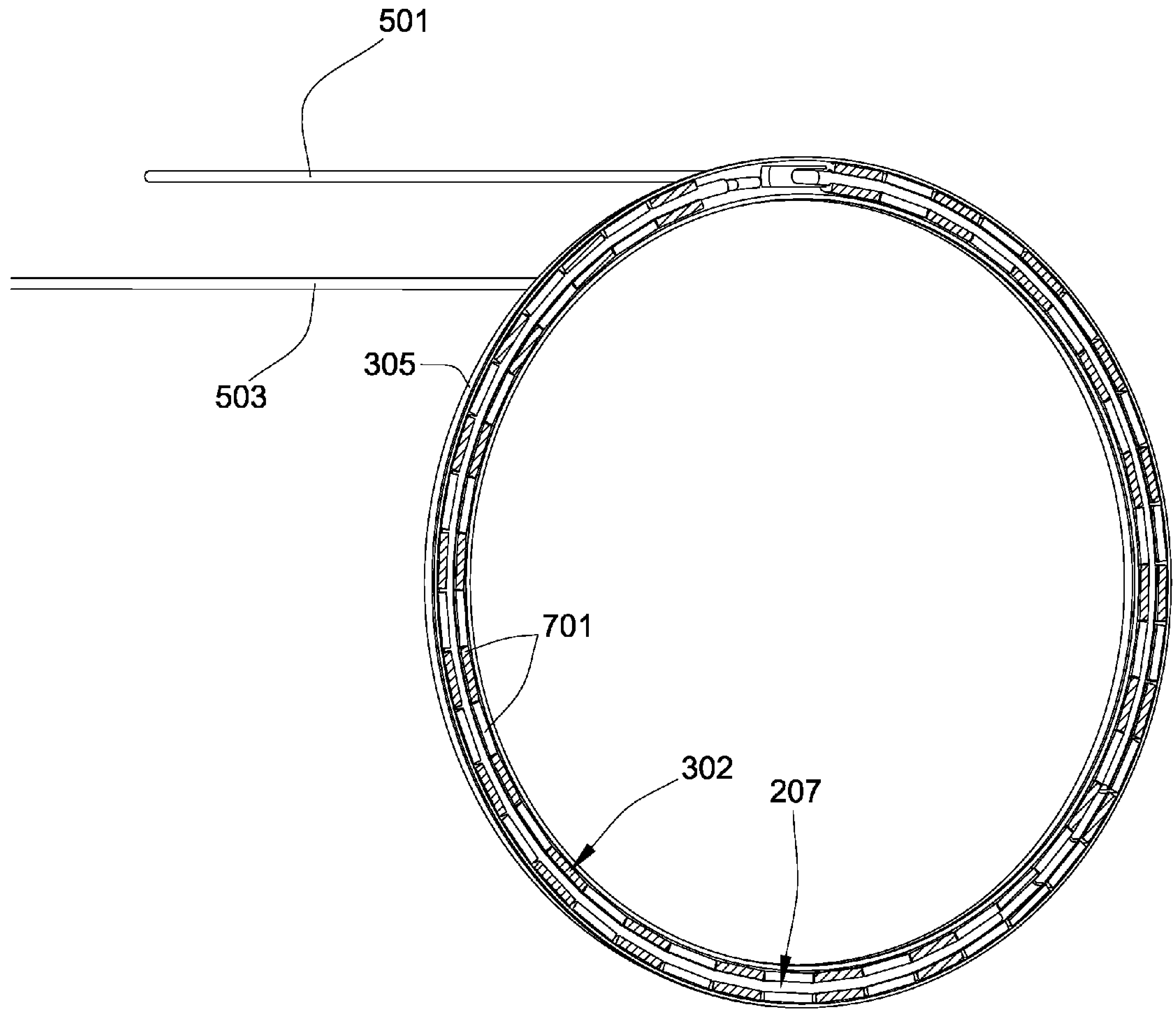


Fig. 7a

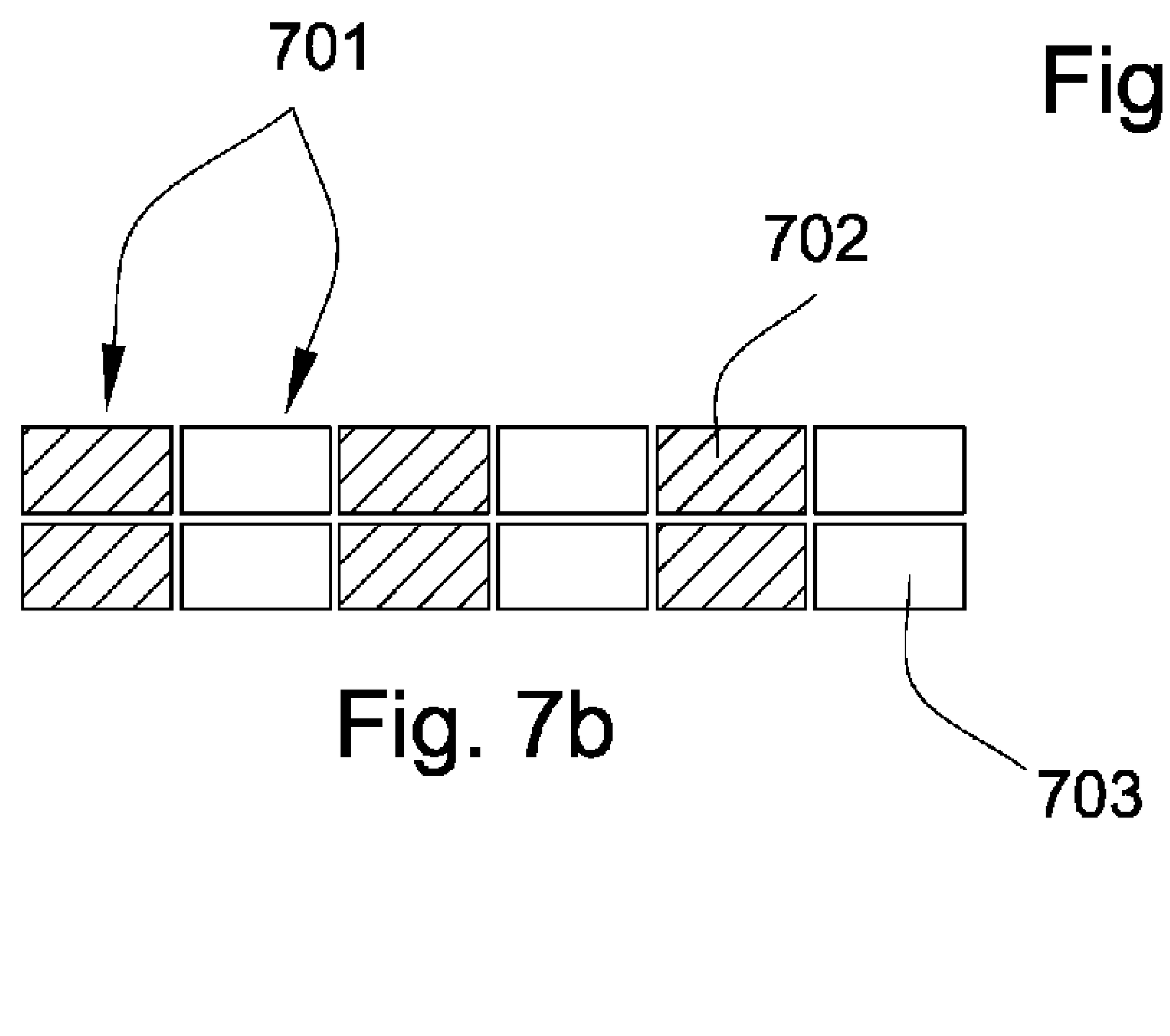


Fig. 7b

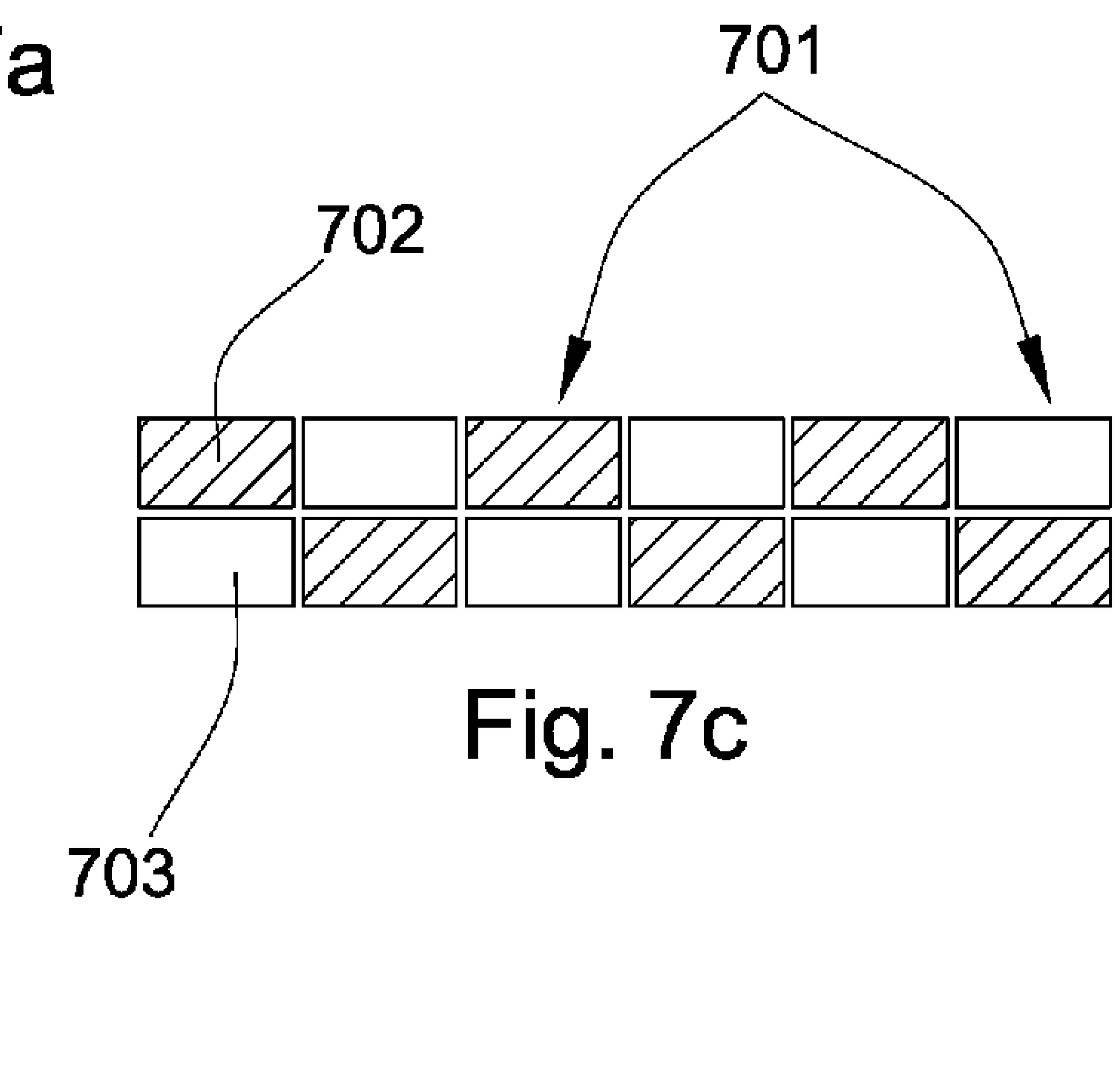


Fig. 7c

INDUCTIVE POWER COUPLER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation in-part of U.S. application Ser. No. 11/421,387 filed on May 31, 2006, which is a continuation in-part of U.S. application Ser. No. 11/421,357, now U.S. Pat. No. 7,382,273." U.S. application Ser. No. 11/421,357 is a continuation in-part of U.S. application Ser. No. 11/133,905, now U.S. Pat. No. 7,277,026, filed on May 21, 2005 and entitled, "Downhole Component with Multiple Transmission Elements." All of these references are herein incorporated by reference for all that they contain.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to downhole drilling, and more particularly, to systems and methods for transmitting power and data to components of a downhole tool string. As downhole instrumentation and tools have become increasingly more complex in their composition and versatile in their functionality, the need to transmit power and/or data through tubular tool string components is becoming ever more significant. Real-time logging tools located at a drill bit and/or throughout a tool string require power to operate. Providing power downhole is challenging, but if accomplished it may greatly increase the efficiency of drilling. Data collected by logging tools are even more valuable when they are received at the surface in real time.

[0003] Many attempts have been made to provide high-speed data transfer or usable power transmission through tool string components. One technology developed involves using inductive couplers to transmit an electric signal across a tool joint. U.S. Pat. No. 2,414,719 to Cloud discloses an inductive coupler positioned within a downhole pipe to transmit a signal to an adjacent pipe.

[0004] U.S. Pat. No. 4,785,247 to Meador discloses an apparatus and method for measuring formation parameters by transmitting and receiving electromagnetic signals by antennas disposed in recesses in a tubular housing member and including apparatus for reducing the coupling of electrical noise into the system resulting from conducting elements located adjacent the recesses and housing.

[0005] U.S. Pat. No. 4,806,928 to Veneruso describes a downhole tool adapted to be coupled in a pipe string and positioned in a well that is provided with one or more electrical devices cooperatively arranged to receive power from surface power sources or to transmit and/or receive control or data signals from surface equipment. Inner and outer coil assemblies arranged on ferrite cores are arranged on the downhole tool and a suspension cable for electromagnetically coupling the electrical devices to the surface equipment is provided.

[0006] U.S. Pat. No. 6,670,880 to Hall also discloses the use of inductive couplers in tool joints to transmit data or power through a tool string. The '880 patent teaches of having the inductive couplers lying in magnetically insulating, electrically conducting troughs. The troughs conduct magnetic flux while preventing resultant eddy currents.

[0007] U.S. Pat. No. 7,277,026, also to Hall, discloses a tubular component in a downhole tool string with first and second inductive couplers in a first end and third and fourth inductive couplers in a second end. A first conductive medium connects the first and third couplers and a second conductive medium connects the second and fourth couplers. The first and third couplers are independent of the second and fourth couplers.

[0008] All of the above cited references are herein incorporated by reference for all that it discloses.

BRIEF SUMMARY OF THE INVENTION

[0009] In one aspect of the present invention, a downhole tool string component has a tubular body with at least one end adapted for threaded connection to an adjacent tool string component. The end has at least one shoulder that abuts an adjacent shoulder of an adjacent end of the adjacent tool string component. At least two electrically conducting coils are disposed within an annular recess formed in the at least one shoulder and an annular trough is disposed in the annular recess. The annular trough houses at least one of the at least two electrically conducting coils and each coil is electrically insulated from each other.

[0010] The adjacent shoulder may have at least two adjacent electrically conducting coils and an adjacent annular trough disposed in an adjacent annular recess formed in the adjacent shoulder configured similar to the at least two electrically conducting coils and the annular trough in the downhole tool string component and may couple when the downhole components are connected together at their ends, wherein the at least two coils and the at least two adjacent coils induce magnetic fields in each other when the coils are electrically energized.

[0011] The at least two electrically conducting coils and the annular trough may be part of a modular unit that plugs into an electrical circuit disposed in the downhole tool string component. The annular trough may concentrate a magnetic field generated by at least one of the at least two electrically conducting coils.

[0012] A first coil of the at least two electrically conducting coils may have at least two annular loops. The first coil may be housed within the annular trough. A magnetic current with a frequency of 35 kHz to 150 kHz may be emitted from the first coil when the first coil is electrically energized. The first coil may have a positive lead and a negative lead that connects the first coil into an electrical circuit disposed in the downhole tool string component.

[0013] A second coil of the at least two electrically conducting coils may have a single annular loop. The second coil may be grounded to the at least one shoulder. The second coil may be housed within the annular trough. The second coil may be disposed outside of the annular trough. The second coil may have a lead that connects the first coil into an electrical circuit disposed in the downhole tool string component. A magnetic current with a frequency of 2 MHz to 7 MHz may be emitted from the second coil when the second coil is electrically energized.

[0014] The annular trough may comprise segments with a composition alternated between at least two different ferrite alloys. The at least two different ferrite alloys may be manganese zinc ferrite and nickel zinc ferrite. The annular trough may comprise a material comprising a composition selected from the group consisting of ferrite, Ni, Fe, Cu, Mo, Mn, Co, Cr, V, C, Si, Zn alloys and combinations thereof. The annular trough may comprise two side walls and a bottom of uniform thickness.

[0015] The downhole tool string component may be a drill pipe, drill collar, a bottom hole assembly, a reamer, a jar, a production pipe, a mandrel, a sleeve, or combinations thereof.

An electronic amplifier may be disposed in the downhole tool string component that may amplify an electrical signal of at least one of the at least two electrically conducting coils.

[0016] A steel housing may be disposed within the annular recess and houses the annular trough. One of the at least two electrically conducting coils may be disposed intermediate the steel housing and the annular trough.

[0017] In another aspect of the present invention, an inductive coupler comprises at least two electrically conducting coils disposed within an annular recess. An annular trough is disposed in the annular recess and houses at least one of the at least two electrically conducting coils. Both of the coils are electrically isolated from one another.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** is a cross-sectional diagram of an embodiment of a drill string suspended in a bore hole.

[0019] FIG. **2** is a cross-sectional diagram of an embodiment of a downhole tool string component and an adjacent downhole tool string component.

[0020] FIG. **3** is a cross-sectional diagram of another embodiment of a downhole tool string component and an adjacent downhole tool string component.

[0021] FIG. **4** is a cross-sectional diagram of an embodiment of an at least one shoulder and an adjacent shoulder.

[0022] FIG. **5***a* is a perspective diagram of an embodiment of at least two electrically conducting coils and an annular trough assembled in a modular unit.

[0023] FIG. **5***b* is an exploded diagram of another embodiment of at least two electrically conducting coils and an annular trough assembled in a modular unit.

[0024] FIG. **6***a* is a cross-sectional diagram of another embodiment of an at least one shoulder and an adjacent shoulder.

[0025] FIG. **6***b* is a cross-sectional diagram of another embodiment of an at least one shoulder and an adjacent shoulder.

[0026] FIG. **6***c* is a cross-sectional diagram of another embodiment of an at least one shoulder and an adjacent shoulder.

[0027] FIG. **6***d* is a cross-sectional diagram of another embodiment of an at least one shoulder and an adjacent shoulder.

[0028] FIG. **7***a* is a perspective diagram of another embodiment of at least two electrically conducting coils and an annular trough assembled in a modular unit.

[0029] FIG. **7***b* is a perspective diagram of an embodiment of an array of annular trough segments comprising at least two different ferrite alloys.

[0030] FIG. **7***c* is a perspective diagram of another embodiment of an array of annular trough segments comprising at least two different ferrite alloys.

DETAILED DESCRIPTION OF THE INVENTION AND THE PREFERRED EMBODIMENT

[0031] FIG. **1** is an embodiment of a drill string **100** suspended by a derrick **108**. A downhole assembly **103** is located at the bottom of a bore hole **102** and comprises a drill bit **104**. As the drill bit **104** rotates downhole the drill string **100** advances farther into the earth The drill string may penetrate soft or hard subterranean formations **105**. The downhole assembly **103** and/or downhole components may comprise data acquisition devices which may gather data. The data may be sent to the surface via a transmission system to a data swivel **106**. The data swivel **106** may send the data to the surface equipment. Further, the surface equipment may send data and/or power to downhole tools and/or the downhole assembly **103**.

[0032] Referring now to FIGS. **2** through **3**, the downhole assembly **103** comprises a downhole tool string component **200** with a tubular body **202** comprising at least one end **203** adapted for threaded connection to an adjacent tool string component **201**. The at least one end **203** of the downhole tool string component **200** may be a pin end while an adjacent end **204** of the adjacent tool string component **201** may be a box end or vice versa. The downhole tool string component **200** may be a drill pipe, drill collar, a bottom-hole assembly component, a heavy weight drill pipe, a cross over sub, a reamer, a jar, a production pipe, a mandrel, a sleeve, or combinations thereof. In the embodiment disclosed in FIGS. **2** through **3**, the downhole tool string component **200** is a drill pipe and the adjacent tool string component **201** is a drill pipe.

[0033] The at least one end **203** of the downhole tool string component **200** comprises at least one shoulder **205** that abuts an adjacent shoulder **206** of the adjacent end **204** of the adjacent tool string component **201**. At least two electrically conducting coils **207** are disposed within an annular recess **301** formed in the at least one shoulder **205**. An annular trough **302** is also disposed in the annular recess **301** and houses at least one of the at least two electrically conducting coils **207**. The adjacent shoulder **206** also comprises at least two adjacent electrically conducting coils **207** and an adjacent annular trough **302** that are disposed in an adjacent annular recess **301** formed in the adjacent shoulder **206** and are configured similar to the at least two electrically conducting coils **207** and the annular trough **302** in the downhole tool string component **200**.

[0034] Referring to FIG. **4**, each coil **207** of the at least two electrically conducting coils **207** is electrically insulated from each other. In the embodiment of FIG. **4**, the at least two electrically conducting coils **207** comprises a first coil **303** and a second coil **304**. The first coil **303** and the second coil **304** may be coated with an insulating material **407**. The insulating material **407** may comprise a varnish, enamel, a polymer, or combinations thereof. A filler material **406** may be disposed in the annular trough **302** to fill in the empty space not occupied by the at least two electrically conducting coils **207**. The filler material **406** may comprise a polymer selected from the group consisting of epoxy, natural rubber, fiberglass, carbon fiber composite, polyurethane, silicon, a fluorinated polymer, grease, polytetrafluoroethylene and perfluoroalkoxy, fluorinated ethylene propylene copolymer (FEP), or a combination thereof. The filler material **406** may be electrically insulating.

[0035] The annular trough **302** may comprise a material with a composition selected from the group consisting of ferrite, Ni, Fe, Cu, Mo, Mn, Co, Cr, V, C, Si, Zn alloys and combinations thereof. The at least two coils **207** may comprise an electrically conductive material such as copper. The at least two coils **207** in the downhole tool string component **200** and the at least two coils **207** in the adjacent tool string component **201** may couple when the downhole tool string components **200**, **201** are connected together at their ends **203**, **204** by inducing magnetic fields in each other when the coils **207** are electrically energized. When an alternating electrical current is passed through at least one of the at least two coils **207** of the downhole tool string component **200**, the magnetic field from the electrical current may be concentrated by the annular trough **302**. The concentrated magnetic field inductively influences at least one of the at least two coils **207** in the adjacent tool string component **201** generating an electrical current in the at least one of the at least two coils **207** in the adjacent tool string component **201**. It is believed that the annular trough **302** may increase the efficiency of the electrical signal that is being transferred inductively between at least one of the at least two coils **207** in the downhole tool string component **200** and at least one of the at least two coils **207** in the adjacent downhole tool string component **201**. All of the at least two coils **207** may be electrically energized and each coil **207** may carry a different electrical current or signal than the other coils **207**. The annular trough **302** may concentrate the magnetic field from each electrical current of each energized coil **207**. The annular trough **302** may concentrate the magnetic field from each electrical current of less than all of the at least two coils **207**.

[0036] The first coil **303** of the at least two coils **207** may be housed within the annular trough **302** and may comprise at least two annular loops **401**. In the embodiment of FIG. **4**, the first coil **303** comprises six annular loops **401**. A magnetic current with a frequency of 35 kHz to 150 kHz may be emitted from the first coil **303** when the first coil **303** is electrically energized. More specifically, a magnetic current with a frequency of approximately 55 kHz may be emitted from the first coil **303** when the first coil **303** is electrically energized. The first coil **303** in the downhole tool string component **200** may inductively transfer an electrical power signal to the first coil **303** in the adjacent downhole tool string component **201**. The first coil **303** may comprise a single solid wire, litz wire, or combinations thereof.

[0037] The second coil **304** may also be housed within the annular trough **302**. The second coil **304** may comprise a single annular loop **402**. A magnetic current with a frequency of 2 MHz to 7 MHz may be emitted from the second coil **304** when the second coil **304** is electrically energized. More specifically, a magnetic current with a frequency of approximately 5 MHz may be emitted from the second coil **304** when the second coil **304** is electrically energized. The second coil **304** in the downhole tool string component **200** may inductively transfer an electrical data signal to the second coil **304** in the adjacent downhole tool string component **201**. The second coil **304** may be grounded to the at least one shoulder **205** of the downhole tool string component **200**. The second coil **304** may comprise a single solid wire.

[0038] The annular trough **302** may comprise two side walls **403** and a bottom **404** of uniform thickness **405**. It is believed that an annular trough **302** with side walls **403** and a bottom **404** of uniform thickness **405** may maximize the magnetic saturation limits of the annular trough **302** thereby increasing the efficiency of the annular trough's **302** ability to concentrate the magnetic field of the electrical current of at least one of the at least two coils **207**.

[0039] The magnetic properties of the annular trough may be optimized such that it works synergistically with only select coils. For instance, in downhole applications, the transfer of sufficient power across a few joints may be more difficult to achieve than the transfer of data across the same number of joints. It is believed that a larger volume of magnetic material in the annular trough of an optimized composition improves the power transfer. However, the thickness of the trough is limited by the shoulder width of the tool string component. Thus, in some embodiments all of the available shoulder width may be tailored to optimize the power signal by providing a trough composition optimized for only the first coil. In some embodiments, the data transfer provided by the second coil may actually be transparent to the annular trough, but the data will still transfer without the trough's aid. In some embodiments, the annular trough may be optimized for the second coil instead of the first. Generally, in most embodiments, the annular trough will concentrate all signals from all of the coils to some degree regardless of whether the trough's composition being optimized for one coil over the others as long as the other coils are located within the trough. However, a hybrid composition may be provided that concentrates the magnetic fields of both coils, while not being optimized for either.

[0040] FIGS. **5***a* and **5***b* respectively disclose a perspective view and an exploded view of an embodiment of the at least two coils **207** and the annular trough **302**. The at least two electrically conducting coils **207** and the annular trough **302** may be part of a modular unit that plugs into an electrical circuit disposed in the downhole tool string component **200**. A steel housing **305** may be disposed within the annular recess **301** and may house the annular trough **302**. The first coil **303** may comprise a positive lead **501** and a negative lead **502** that connects the first coil into the electrical circuit disposed in the downhole tool string component **200**. The second coil **304** may comprise a lead **503** that connects the first coil **304** into the electrical circuit disposed in the downhole tool string component **200**. To complete the circuit, the other end of the second coil may be grounded through a solder, braze, bond, or otherwise to the steel housing, which in turn is in direct electrical contact with the pipe. Cables **209** may connect the leads **501**, **502**, **503** to the electrical circuit of the downhole tool string component **200**. The electrical circuit may include pressure sensors, strain sensors, flow sensors, acoustic sensors, temperature sensors, torque sensors, position sensors, vibration sensors, geophones, hydrophones, electrical potential sensors, nuclear sensors, drill instruments, logging-while drilling tool, measuring-while drilling tool, computational board, drill string steering tools, downhole hammers, motors, downhole electrical generators, or combinations thereof. The electrical circuit may comprise an electronic amplifier disposed in the downhole tool string component that amplifies the electrical signal of at least one of the at least two electrically conducting coils **207**.

[0041] Referring now to FIGS. **6***a* through **6***d*, the second coil **304** may be disposed outside of the annular trough **302**. FIG. **6***a* discloses an embodiment wherein one of the side walls **403** of the annular trough **302** may be shortened to accommodate the second coil **304**. FIG. **6***b* discloses an embodiment wherein the second coil **304** is disposed in the annular recess **301** outside the annular trough **302** and intermediate the at least one shoulder **205** and the annular trough **302**. FIG. **6***c* discloses an embodiment wherein the second coil **304** is disposed outside the annular trough **302** and proximate a top of the annular recess **301**. The second coil **304** may also be disposed intermediate the steel housing **305** and the annular trough **302**. FIG. **6***d* discloses an embodiment wherein the second coil **304** is disposed inside the annular trough and proximate the top of the annular recess **301**. The first coil **303** may be disposed inside the annular trough **302** and intermediate the second coil **304** and the bottom **404** of the annular trough **302**.

[0042] Referring to FIGS. **7***a* through **7***c*, the annular trough **302** may be segmented where the segments **701** comprise different compositions. The different segments **702**, **703** may alternate between each other. The at least two different ferrite alloys may be manganese zinc ferrite and nickel zinc ferrite. Each segment's composition may be optimized for a signal produced by different coils, thus providing assistance to more than one coil. It is believed that varying the composition of the annular trough **302** may enable the annular trough **302** to concentrate at least two different magnetic currents with differing frequencies simultaneously. The segments **701** may be arrayed such that segments of the same composition are aligned across from one another such as in the embodiment of FIG. **7***b*. The segments **701** may be arrayed such that segments of differing composition are aligned across from one another such as in the embodiment of FIG. **7***c*. In embodiments, where more than two coils are disposed within the trough additional segments with yet different compositions may or may not be added.

[0043] In the embodiment shown in FIG. **7***a*, only two coil leads **501**, **503** are shown coming off the steel housing. In this embodiment, both the first and second coil may be grounded to the steel ring to complete the electrical circuit.

[0044] Whereas the present invention has been described in particular relation to the drawings attached hereto, it should be understood that other and further modifications apart from those shown or suggested herein, may be made within the scope and spirit of the present invention.

What is claimed is:

1. A downhole tool string component, comprising:

a tubular body with at least one end adapted for threaded connection to an adjacent tool string component;

the end comprising at least one shoulder that abuts an adjacent shoulder of an adjacent end of the adjacent tool string component;

at least two electrically conducting coils disposed within an annular recess formed in the at least one shoulder;

an annular trough disposed in the annular recess houses at least one of the at least two electrically conducting coils; and

each coil is electrically insulated from each other.

2. The component of claim **1**, wherein the adjacent shoulder comprises at least two adjacent electrically conducting coils and an adjacent annular trough disposed in an adjacent annular recess formed in the adjacent shoulder configured similar to the at least two electrically conducting coils and the annular trough in the downhole tool string component and couple when the downhole components are connected together at their ends, wherein the at least two coils and the at least two adjacent coils induce magnetic fields in each other when the coils are electrically energized.

3. The component of claim **1**, wherein the at least two electrically conducting coils and the annular trough are part of a modular unit that plugs into an electrical circuit disposed in the downhole tool string component.

4. The component of claim **1**, wherein the annular trough concentrates a magnetic field generated by at least one of the at least two electrically conducting coils.

5. The component of claim **1**, wherein a first coil of the at least two electrically conducting coils comprises at least two annular loops.

6. The component of claim **5**, wherein the first coil is housed within the annular trough.

7. The component of claim **5**, wherein a magnetic current with a frequency of 35 kHz to 150 kHz is emitted from the first coil when the first coil is electrically energized.

8. The component of claim **5**, wherein the first coil comprises a positive lead and a negative lead that connects the first coil into an electrical circuit disposed in the downhole tool string component.

9. The component of claim **1**, wherein a second coil of the at least two electrically conducting coils comprises a single annular loop.

10. The component of claim **9**, wherein the second coil is grounded to the at least one shoulder.

11. The component of claim **9**, wherein the second coil is housed within the annular trough.

12. The component of claim **9**, wherein the second coil is disposed outside of the annular trough.

13. The component of claim **9**, wherein a magnetic current with a frequency of 2 MHz to 7 MHz is emitted from the second coil when the second coil is electrically energized.

14. The component of claim **1**, wherein the annular trough comprises segments with a composition alternated between at least two different ferrite alloys.

15. The component of claim **1**, wherein an electronic amplifier is disposed in the downhole tool string component that amplifies an electrical signal of at least one of the at least two electrically conducting coils.

16. The component of claim **1**, wherein the annular trough comprises a material comprising a composition selected from the group consisting of ferrite, Ni, Fe, Cu, Mo, Mn, Co, Cr, V, C, Si, Zn alloys and combinations thereof.

17. The component of claim **1**, wherein the annular trough comprises two side walls and a bottom of uniform thickness.

18. The component of claim **1**, wherein a steel housing is disposed within the annular recess and houses the annular trough.

19. The component of claim **21**, wherein one of the at least two electrically conducting coils is disposed intermediate the steel housing and the annular trough.

20. An inductive coupler, comprising:

at least two electrically conducting coils disposed within an annular recess;

an annular trough disposed in the annular recess houses at least one of the at least two electrically conducting coils; and

each coil is electrically insulated from each other.

* * * * *