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(54) **DISPOSITIF D'ELECTROPOLISSAGE DE LA SURFACE INTERNE D'UN TUBE DOTE D'UN REGULATEUR D'ELECTROLYTE**

(54) **TUBE INNER SURFACE ELECTROPOLISHING DEVICE WITH ELECTROLYTE DAM**

(57) The tube inner surface electropolishing device includes an electrolyte delivery system to cause electrolyte to flow through the tube whose inner surface must be electropolished. An electrical cable having an electrode engaged to its distal end is slowly moved through the tube while an electrical current from a power supply passes through the electrode and the tube wall and the electrolyte flowing therebetween. Several electrode embodiments are disclosed including electrodes that include a chain of elements having alternating insulator and electrode elements, an electrode including a quantity of metallic wool enclosed in a permeable insulating member, and a flexible insulating member formed from a cylindrical tubular section which is axially compressible to produce a series of projecting flexible arms, so that any one section can be compressed to enter a smaller opening than the tube to be polished. An electrolyte dam is coupled to the electrode and controls the flow rate of electrolyte through the tube. The electrolyte dam includes a body, a channel formed in a top portion of the body, and ballast disposed in a bottom portion of the body. The channel facilitates the flow of electrolyte past the dam and the escape of gasses that are evolved during the electropolishing process. The ballast maintains the dam in an upright position as it is drawn through the tube.

ABSTRACT

The tube inner surface electropolishing device includes an electrolyte delivery system to cause electrolyte to flow through the tube whose inner surface must be electropolished. An electrical cable having an electrode engaged to its distal end is slowly moved through the tube while an electrical current from a power supply passes through the electrode and the tube wall and the electrolyte flowing therebetween. Several electrode embodiments are disclosed including electrodes that include a chain of elements having alternating insulator and electrode elements, an electrode including a quantity of metallic wool enclosed in a permeable insulating member, and a flexible insulating member formed from a cylindrical tubular section which is axially compressible to produce a series of projecting flexible arms, so that any one section can be compressed to enter a smaller opening than the tube to be polished. An electrolyte dam is coupled to the electrode and controls the flow rate of electrolyte through the tube. The electrolyte dam includes a body, a channel formed in a top portion of the body, and ballast disposed in a bottom portion of the body. The channel facilitates the flow of electrolyte past the dam and the escape of gasses that are evolved during the electropolishing process. The ballast maintains the dam in an upright position as it is drawn through the tube.

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TUBE INNER SURFACE ELECTROPOLISHING DEVICE WITH ELECTROLYTE DAM

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RELATED APPLICATIONS

This application is a continuation-in-part of co-pending U.S. Patent Application Serial No. 08/862,148, filed on May 22, 1997 by the same inventors, which is incorporated herein by reference in its entirety, as if fully set forth herein.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to devices for electropolishing the inner surface of metal tubes and more particularly to such devices which utilize flexible electrodes drawn through the tube.

Description of the Prior Art

Metal tubing that is to be utilized in high purity applications is preferably cleaned by electropolishing prior to installation. Additionally, subsequent to installation, metal tubing utilized in many industrial applications may be attacked on the inner tubular surfaces by chemicals passing through the tubing. This may result in the need to replace the tubing, at great cost. Significant cost savings can be accomplished in many industrial equipment applications, if the interior surface of the metal tubing can be cleaned, such that the tubing can be reused.

Prior art devices are known that can clean the inner surface of straight tubing sections; however, tubing with a plurality of bends can pose a difficult problem. One such prior art device is described in U.S. Patent 4,645,581, Apparatus for Electropolishing the Inner Surface of U-shaped Heat Exchanger Tubes, issued February 24, 1987 to Voggenthaler et al. The present invention provides improved results.

Another problem which presents in the electropolishing of bent tubing, as well as tubing with extended straight runs, is keeping the tubing full of electrolyte solution during the electropolishing process. Gasses evolved by the electropolishing process accumulate and displace the electrolyte solution, thereby preventing the uniform electropolishing of the inner surface of the tubing. What is needed is a device that retains the electrolyte solution in the tubing, while facilitating the escape of the evolved gasses.

SUMMARY OF THE INVENTION

The tube inner surface electropolishing device includes an electrolyte delivery system to cause electrolyte to flow through the tube whose inner surface must be electropolished. An electrical cable having an electrode engaged to its distal end is slowly moved through the tube while an electrical current from a power supply passes through the electrode and the tube wall and the electrolyte flowing therebetween. Several electrode embodiments are disclosed including electrodes that include a chain of elements having alternating insulator and electrode elements, an electrode including a quantity of metallic wool enclosed in a permeable insulating member, and a flexible insulating member formed from a cylindrical tubular section which is axially compressible to produce a series of projecting flexible arms. The various electrode embodiments generally function such that the insulator members prevent electrically powered electrode elements from touching the sidewall and producing an electrical short.

The problem of keeping the tube full of electrolyte solution while facilitating the escape of trapped gasses is overcome in a particular embodiment of the present invention by attaching an electrolyte dam to the electrode. The electrolyte dam includes a body with a top and a bottom portion, a ballast fixed to the bottom portion, and a channel in the top portion. The body of the dam substantially occludes the lumen of the tube, keeping the tube full of electrolyte solution. The ballast maintains the upright position of the dam as it is drawn through the tubing, such that trapped gasses can escape through the channel in the top of the dam.

It is an advantage of the present invention that metal tubular components having a plurality of bends can be effectively, economically electropolished.

It is another advantage of the present invention that electrode embodiments are disclosed which are easy to manufacture and utilize.

It is a further advantage of the present invention that the various electrode embodiments are flexible to pass through a plurality of bends in a tubular member, such that complex tubular configurations can be effectively electropolished.

It is yet another advantage of the present invention that it provides an electrode embodiment that is compressible to allow it to pass through smaller openings, and then expand to process generally larger tubing.

These and other features and advantages of the present invention will be well understood by those skilled in the art upon review of the following detailed description. Further, those skilled in the art will recognize that various embodiments of the present invention may achieve one or more, but not necessarily all, of the above-described advantages. Accordingly, the listed advantages are not essential elements of the invention, and should not be construed as limitations on the scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 depicts one embodiment of the tube electropolishing device and method of the present invention;

Fig. 2 is a schematic diagram depicting an electrolyte transfer system of the present invention;

Fig. 3 is a partially cut away view depicting a flexible electrode embodiment of the present invention disposed within a tube;

Fig. 4 is an enlarged partially cross-sectional side elevational view of the flexible electrode embodiment of Fig. 3 of the present invention;

Fig. 5 is a side elevational view of an alternative flexible electrode embodiment of the present invention;

Fig. 6 is an end elevational view of the alternative flexible electrode embodiment of Fig. 5 of the present invention;

Fig. 7 is a side elevational view of another alternative flexible electrode embodiment of the present invention;

Fig. 8 is a side elevational view of a further alternative flexible electrode embodiment of the present invention;

Fig. 9 is a side elevational view of yet another alternative flexible electrode embodiment of the present invention;

Fig. 10 is a side cross-sectional view of the electrode embodiment of Fig. 9 disposed within a section of metal tubing;

Fig. 11 is a side elevational view of yet a further alternative flexible electrode embodiment of the present invention;

Fig. 12 is a side cross-sectional view of the electrode embodiment of Fig. 11, depicted within a section of metal tubing;

Fig. 13 shows an electropolishing system including an electrolyte dam;

Fig. 14 a side view of the electrolyte dam of Fig. 13;

Fig. 15 a front view of the electrolyte dam of Fig. 13;

Fig. 16 is a side view of an alternate electrolyte dam;

Fig. 17 is a front view of the alternate electrolyte dam of Fig. 16;

Fig. 18 is a side view of another alternate electrolyte dam; and

Fig. 19 is a front view of the alternate electrolyte dam of Fig. 18.

DETAILED DESCRIPTION

Fig. 1 is a generalized depiction of a tube electropolishing system 10 of the present invention. As depicted in Fig. 1, a tube 14 having a flexible electrode 18 movably disposed therewithin, is engaged at its upstream end 22 to an electrolyte flow tube 26 utilizing a suitable connector 28. The tube 26 may be stabilized by a support bracket 30. The downstream end 32 of the tube 14 is engaged to a T fitting 36 utilizing an appropriate connector 40. The T fitting 36 is utilized for inletting cleansing water 44 utilizing a valve 46, and clean air 48 utilizing a valve 50, into the tube 14. The T fitting 36 is connected to a shut off valve 54 utilizing a suitable connector 56, and the shut off valve 54 is connected to a further T fitting 58 utilizing a suitable connector 60. The T fitting 58 is fixedly engaged to an adjustable stand 68, such that the top cross member 70 of the T fitting 58 is disposed at an angle of at least 15° degrees from the horizontal for up to approximately a 4 inch diameter tube 14, and the leg 72 of the T fitting 58 depends downwardly. The downstream end 64 of the T fitting 58 is open. An electrolyte return tube 74 is engaged to the leg 72 of the T fitting 58 utilizing an appropriate connector 76. The downstream end 78 of the electrolyte return tube 74 opens into a drain receptacle 79. An electrolyte return line 118 is engaged from the drain 79 to a liquid transfer system 150 which functions to cause electrolyte to flow through the tube electropolishing system 10 from the input electrolyte flow tube 26 to the electrolyte return tube 74. A preferred embodiment of the liquid transfer system 150 is shown and described in copending U.S. patent application serial number 08/777,681, although other liquid transfer systems that can produce appropriate liquid flow rate parameters can provide adequate results.

The flexible electrode 18 is engaged to a flexible cable 80 which is routed through the T fitting 36, valve 54 and T fitting 58. The cable 80 exits through the open downstream end 64 of the T fitting 58. The cable 80 is engaged to a cable pulling pulley 84 that is driven by a variable speed motor 88, to pull the cable 80 through the tube 14. Electrical power is provided to the cable 80 utilizing a direct current power source 92, and the tube 14 is also connected to the power source 92. The cable 80 is insulated throughout its length (up to the flexible electrode 18) to avoid unwanted shorting out of the cable against the walls of the tube 14. In the preferred embodiment, the power source 92 provides pulsed direct current, the cable 80 is connected to the negative terminal of the power source 92 and the tube 14 is connected to the positive terminal, such that an electropolishing current will be created between the flexible electrode 18 and the inner surface of the tube 14 through the electrolyte flowing within the tube 14, such that the inner surface of the tube 14 will be electropolished.

An apparatus support table 100 having legs 104 and a top surface drain pan 108 is utilized to support the stand 68, drain 79 and the electrolyte supply tube support bracket 30. The drain 79 is piped 118 into an electrolyte holding tank 120 supported by a table shelf 122. The drain pan 108 includes a drain outlet 124 which is piped 128 into a waste liquid holding tank 132 that is supported by table shelf 122.

In the preferred liquid transfer system 150, which is described more fully below with the aid of Fig. 2, the electrolyte is air pressure driven through the electropolishing apparatus 10 utilizing two pressurizable electrolyte supply vessels 140 and 144 that are supported by a stainless steel containment tray 148. The electrolyte supply vessels 140 and 144 receive electrolyte from the electrolyte holding tank 120 through an electrolyte control valve system. Electrolyte from vessels

140 or 144 is driven through a feed line 156, through filters 160 a sensor 164 and a control valve 168 to the electrolyte flow tube 26. Electrolyte flow control devices, including a flow meter 170 and a pH/temperature meter 174, operate through sensor 164 and valve 168 to control the temperature, pH and flow rate of the electrolyte through the system. It is therefore to be understood that electrolyte is caused to flow through the tube 14 from the supply vessels 140 or 144, and that the electrolyte returns through the return tube 74 to the electrolyte holding tank 120.

The device of Fig. 1 is utilized by firstly, fishing the electrode 18 and its attached cable 80 through the tube 14 to the upstream end 22 of the tube 14. Thereafter, the connector 28 is utilized to engage the electrolyte flow tube 26 to the tube end 22. Following engagement of the electrolyte flow tube 26 to the tube 14, the liquid transfer system 150 is activated to cause electrolyte to fill and flow through the tube 14 and drain out into the drain 79.

The power source is next activated, such that a voltage potential is created between the electrode 18 and the inner surface of the tube 14. An electrical current then passes between the electrode 18 and the tube 14 through the electrolyte in the tube, and the inner surface of the tube is electropolished. Utilizing the cable pulling pulley 84, and the variable speed motor 88, the cable is pulled such that the electrode 18 is slowly pulled through the tube 14, electropolishing the interior surface of the tube 14 as it is pulled therethrough.

After the electrode 18 has been pulled entirely through the tube 14 the electrode power is turned off. The electrode 18 is withdrawn past the shut off 54, and the shut off 54 is closed. The electrolyte control valve 68 is open. Thereafter, the air flow valve 50 is opened and air is caused to flow through the tube 14 to push back the remaining electrolyte. Following the electrolyte purge, the water valve 46 is opened and an air valve 50 is closed, such that pressurized water flows through the tube 14 to flush out all remaining electrolyte. Thereafter, air is again caused to flow through tube 14 using valve 50 to dry out the tube. In this manner, the interior surface of the tube is electropolished, cleaned and dried, such that the tube 14 is made available for future use.

Fig. 2 is a detailed depiction of a preferred electrolyte delivery valve system 150 of the present invention, wherein gas pipes are shown as a single line and electrolyte pipes are shown as a double line. As depicted in Fig. 2, an electrolyte drain line 118 delivers electrolyte from the drain receptacle 79 through a valve 202 to the electrolyte holding tank 120. The holding tank 120 is disposed in an elevated position relative to the two supply vessels 140 and 142. An electrolyte supply line 206 is connected from the holding tank 120 to a valve 210 (also identified by the letter A), and the inlet end 208 of line 206 is disposed towards the bottom of tank 120. A liquid sensor 212 in line 206 is used to indicate the presence of liquid in line 206. The valve 210 may be activated to supply electrolyte to vessel 140 through line 214 or to vessel 142 through line 218. Electrolyte from vessel 140 is deliverable to a valve 222 (also identified by the letter B) through line 226, whereas electrolyte from vessel 142 is deliverable to the valve 222 through line 230. Electrolyte from the valve 222 is delivered to electrolyte flow line 234 to a valve 238 (also identified by the letter F). Electrolyte normally flows through the valve 238 to the electrolyte feed line 156 to electrolyte filters 160, but if valve 238 is activated the electrolyte flows to a drain line 240. In the preferred embodiment, two filters 160 are placed in parallel in line 156 to remove unwanted impurities from the electrolyte. An electrolyte bypass line 242 that is accessible utilizing bypass valves 246, can be utilized to recirculate electrolyte from the filters back to the holding tank 120. Electrolyte passing through filters 160 is piped through parallel lines 250 to the electrolyte flow control valve 168 and sensor 164, as has been discussed hereinabove.

The flow of electrolyte from the vessels, 140 and 142 is controlled by gas pressure, preferably but not necessarily using an inert gas such as nitrogen. As depicted in Fig. 2, nitrogen from a source 260 is fed through delivery line 264 to a valve 268 (also identified by the letter E). In a first gating from valve 268, pressurized gas is fed through a line 272 that is controlled by a regulator 276 to a valve 280 (also identified by the letter D). Pressurized gas can then be gated from valve 280 to vessel 140 through gas line 284 or to vessel 142 through gas line 288.

Returning to valve 268, the left hand gating from valve 268 delivers pressurized gas through regulator 292 and line 300 to a gas control valve 304 (also identified by the letter G). Activation of valve 304 allows replacement gas to pass through line 308, through regulator valve 312 to tank 120. It is therefore to be understood that when electrolyte is present in tank 120 and in line 206 and when valve 210 is opened to either vessel 140 or 142, that a siphon effect will cause electrolyte to flow from tank 120 into vessels 140 or 142, and that as valve 268 and 304 are appropriately activated, replacement gas will be inlet into tank 120 to facilitate the siphon flow of electrolyte from tank 120 through line 206 to vessels 140 or 142, thus filling tanks 140 or 142 with electrolyte.

In order to fill vessels 140 or 142 with electrolyte, it is necessary to outlet any gas present in vessels 140 and 142 that is displaced by inletted electrolyte. To accomplish the outletting of gas from vessels 140 and 142, a valve 320 (also identified by the letter C) is engaged by gas lines 324 and 328 to lines 284 and 288 respectively. The valve 320 is preferably connected to the suction orifice 332 of a venturi valve 336 which is connected to a gas exhaust 340. Pressurized gas to operate the venturi valve 336 is delivered through gas line 350 which is connected through a control valve 354 to pressurized gas line 300 that is connected to valve 268. Therefore, when valve 320 is opened it permits the outletting of gas from vessels 140 or 142 during the electrolyte filling of those vessels. Additionally, if the venturi valve 336 is activated, a suction force can be applied through valve 320 to facilitate the removal of displaced gas from vessels 140 and 142. A drain line gas exhaust line 356 is connected between the drain line 240 and the exhaust 340.

The primary means for initiating a siphon from tank 120 is through a vacuum from the line 206. To initiate the vacuum, gas valve 268 is opened and valve 304 is closed to cause pressurized gas to flow through line 350 to the venturi 336. This causes a vacuum to be created from the suction orifice 332 of the venturi valve 336 back to the valve 320. Valve 320 may be opened to either vessel 140 or 142 through line 324 or 328, and when valve 210 is opened to the appropriate line 214 or 218 from vessels 140 or 142 respectively, the vacuum will be created through vessels 140 or 142 to line 206 and back to tank 120. Once a siphon flow is initiated the vacuum effect is discontinued as the gravity induced flow of the siphon will continue to cause fluid movement from tank 120 when required in the system.

An alternating fill-empty process is utilized to transfer electrolyte from the vessels 140 and 142 through valve 222 to line 156. To transfer electrolyte from vessel 140, valves 268 and 280 are appropriately opened to cause pressurized gas to flow through line 284 into vessel 140, and valve 222 is opened to permit electrolyte flow from vessel 140. When vessel 140 is nearly empty, valve 280 is activated to cause pressurized gas to flow through line 288, into vessel 142. Simultaneously, valve 222 is operated to permit electrolyte to flow from vessel 142 into line 156. While electrolyte from vessel 142 is being emptied through line 156, electrolyte from tank 120 is simultaneously caused to fill vessel 140, as has been discussed hereabove. When vessel 142 is nearly empty, valve 280 is activated to cause pressurized gas to flow through line 284, to cause electrolyte to flow from vessel 140, with valve 222 having been appropriately activated to allow electrolyte to flow from vessel 140. While electrolyte flows from vessel 140, vessel 142 is filled. It is therefore to be understood that electrolyte can be constantly transferred through line 156 by alternately filling and emptying vessels 140 and 142. Through appropriate control of the various valves of the liquid transfer system 150, the electrolyte flow rate through line 156 can be constantly maintained. It is to be further appreciated that the electrolyte transfer system 150 does not use reciprocating pumps or other devices that cause a pulsating pressurized electrolyte flow. Rather, the electrolyte transfer system 150 provides a constant electrolyte flow rate that is very controllable at low flow rates through control valve 168.

For gas control and safety reasons a 5 psi check valve 360 is engaged through gas line 364 to the gas delivery line 308 for tank 120. For added safety, a pressure release valve 370 in line 372 provides a safety release across regulator 312, and a pressure release valve 380 in line 382 having regulator 384 disposed therein is also provided.

To provide a fuller understanding of the operation of the electrolyte transfer system 150, a valve table is presented in Table 1 herebelow wherein "O" means open and "C" means closed and wherein "A" refers to valve 210, "B" refers to valve 220, "C" refers to valve 230, "D" refers to valve 280, "E" refers to valve 268, "F" refers to valve 238, and "G" refers to valve 304. The comprehension of the valve settings as set forth in Table 1 will be well understood by those skilled in the art in contemplation of Fig. 2, and a detailed description thereof is therefore unnecessary.

TABLE 1

	1A	1B	1C	1D	2A	2B	2C	2D	2E	1G	1F	No Drum Pressure 1E	Drum Press. 1E
To Fill PV140	o	c	o	c	c	c	c	c	o	c	c	c	o
Fill PV140	o	c	o	c	c	c	c	c	c	c	c	c	o
Press PV140	c	o	c	o	c	c	c	c	o	c	c	c	c
To Fill PV142	c	c	c	c	o	c	o	c	o	c	c	c	o

Fill PV142	c	c	c	c	o	c	o	c	c	c	c	c	o
Press PV142	c	c	c	c	c	o	c	o	o	c	c	c	c
To Rest	c	c	c	c	c	c	o	o	c	o	c	o	c
At Rest	c	c	c	c	c	c	c	c	c	o	c	o	c

□ DEPENDS ON OTHER PRESSURE VESSEL STATUS
c Closed
o Open

Fig. 3 is a partially cut away view depicting a first flexible electrode embodiment 500 of the present invention disposed within a metal tube 14 having a 90° bend. As depicted therein, the flexible electrode 500 includes a plurality of spherical insulator members 504 disposed upon an electrical cable 80 having an insulator sheath 508. In the preferred embodiment, the spherical insulators are made from Teflon balls having a bore formed therethrough to slide over the cable 80. A plurality of electrode members 512 are disposed upon the cable 80 in an alternating relationship between the insulator balls 504, such that a chain of alternating insulator, electrode members is created. The diameter of the insulator balls 504 is less than the inner diameter of the tube 14, such that electrolyte within the tube 14 can flow past the electrode 18. Alternatively, the balls 504 can have one or more grooves 516 cut into the surface to facilitate electrolyte flow passage. The size and shape of the electrodes 512 is controlled by several factors. Firstly, the closer that the outer surface of an electrode 512 is to the inner wall of the tube 14, the stronger will be the electropolishing current and effect. Secondly, the outer surface of an electrode 512 must not touch the wall of the tube 14 or an electrical short will occur. Thirdly, when the electrode embodiment 500 is drawn through a bend 520 in the pipe 14, the outer surface of each electrode, such as electrodes 524, passing through the elbow 528 in the bend 520 will more closely approach the inner wall of the tube 14. The diameter of the tube 14, radius of curvature of the centerline of the bend 520, coupled with the distance between adjacent insulators 532 and 536, as well as the diameters of the insulators 532 and 536, and the shape and diameter of the electrode 524, are all factors that will determine whether the electrode 524 will short out by touching the inner surface of the tube 14 in the elbow 528 of the bend 520.

Fig. 4 is an enlarged partially cross-sectional view of the flexible electrode 500 of Fig. 3, depicting the shape and attachment of the electrodes 512 and the spherical insulators 504 to the electrical cable 80. As depicted in Fig. 4, a cylindrical bore 540 projects diametrically through each spherical insulator 504, such that the electrical cable 80 passes therethrough. Each electrode member 512 has a generally thin walled cylindrical body portion 544 with outwardly flared ends 548 that approach the surface of the spherical insulators 504. A cable bore 552 projects through the body portion 544 such that the electrical cable 80 may pass therethrough. To hold the electrode 512 in position upon the cable 80 and pass electric current, a cable engagement pin 560 is passed through a hole 564 in the body portion 544 of the electrode 512, and through a bore 570 formed through the electrical cable 80. The end 574 of the pin 560 is then passed through a hole 580 in the electrode body portion 544 that is diametrically opposite hole 564. The ends of the pin 560 are flattened and/or soldered to maintain the pin 560 in position and to hold the electrode 512 in position on the cable 80. The flared ends 548 project more closely to the inner surface of the tube 14 to increase the electropolishing effect, while the "proximity of the spherical insulator to the flared ends prevents contact of the flared ends with the tube side wall when the electrode assembly 500 is drawn through a bend in the tube 14. The electrode embodiment 500 is generally suitable for electropolishing tubes having an inner diameter of at least 0.075 inches. A preferred embodiment for a 1.0 inch outer diameter tube having approximately an 0.875 inch inner diameter, comprises an electrode assembly 500 including spherical Teflon insulators having a diameter of approximately

0.75 inches and copper electrodes 512 having a center body 544 diameter of approximately 0.50 inches and a flared portion diameter of approximately 0.65 inches, where the distance between center points of the insulators is approximately 2.0 inches.

Figs. 5 and 6 depict a second flexible electrode embodiment 600 of the present invention, wherein Fig. 5 is a side elevational view and Fig. 6 is an end elevational view. The significant differences between flexible electrode 600 and flexible electrode 500 depicted in Figs. 3 and 4 is the replacement of the spherical insulator members 504 of embodiment 500 with star-shaped insulating washers 604 of embodiment 600, and the replacement of the flared ended cylindrical electrodes 512 with straight walled cylindrical electrodes 606, as shown in Figs. 5 and 6. As is seen in Fig. 5, a star-shaped insulating washer 604 is disposed between each electrode member 606. In the preferred embodiment, each star-shaped insulator 604 has six points 608, however, insulators with more or less points are certainly utilizable in place thereof. The outer diameter or distance from opposing points 608 of the star-shaped insulator 604 may more closely approach the inner diameter of the tube 14, in that electrolyte will flow past the star-shaped electrode in the spaces between the electrode points 608, whereas an appropriate clearance must be provided between the spherical insulators 504 and the inner wall of the tube 14 to allow electrolyte to flow in the embodiment 500 depicted in Fig. 3. The cylindrical electrodes 606 are formed with thin side walls that define a central passageway for the cable 80. A cable engagement pin 612 is passed through holes formed in the side wall of the electrode 606 and through the cable 80, in a similar manner to the engagement of electrodes 512 to the cable 80 depicted and described hereabove with the aid of Fig. 4. The embodiment 600 is generally suitable for electropolishing tubes having an inner diameter that is greater than 0.75 inches, and it has dimensions that generally approximate those of embodiment 500.

Fig. 7 is a side elevational view depicting a third flexible electrode embodiment 700 of the present invention. As depicted therein, a plurality of spherical insulators 504, that are identical to insulators 504 described hereinabove with regard to electrode embodiment 500, are disposed upon an electrical cable 80. Electrically conductive wire 706 is wound in a spiral fashion upon the cable 80 between each spherical insulator 504. The spiral wound wire 706 makes electrical contact with the cable 80, and serves both as an electrode that is disposed between each spherical insulator 504 and as a spacer to maintain proper spacing between the insulators 504. Owing to the flexible nature of the spiral wrapped electrode 706, the electrode 700 will retain good flexibility in passage through bends in a tube such as tube 14 depicted in Fig. 3. The electrode embodiment 700 is particularly suited for smaller tubes having an outer diameter of approximately 0.25 inches. A preferred embodiment for a 0.25 inch outer diameter tube having a 0.18 inch inner diameter comprises an electrode assembly 700 including spherical Teflon insulators having a diameter of approximately 0.156 inches and wound copper wire electrodes having a diameter of approximately 0.10 inches, where the distance between center points of the insulators is approximately 0.45 inches.

Still another flexible electrode embodiment is depicted in a side elevational view in Fig. 8. As depicted in Fig. 8, electrode embodiment 800 includes a plurality of cup-shaped cylindrical electrodes 812. Each electrode 812 includes a base wall 844 and generally cylindrical side walls 848, and a hole 852 is formed through the base wall 844 to permit the passage of the electrical cable 80 therethrough. A cable engagement pin 860 is passed through cable 18 and is soldered to base wall 844 to fixedly engage the electrode 812 to the cable 80. A plurality of insulating members 870 having broadened heads 874 project outwardly from the side walls 848. The heads of the insulator members 870 act as spacers to prevent the side wall 848 of the electrode 812 from touching the inner surface of a tube, such as to tube 14 depicted in Fig. 3. This electrode embodiment 800 is particularly suited to larger tubes having a diameter of approximately 1.5 inches or more.

Still a further flexible electrode embodiment 900 is depicted in Figs. 9 and 10, wherein Fig. 9 is a side elevational view and Fig. 10 is a cross-sectional view of the embodiment 900 disposed within a metal tube 14. As depicted in Figs. 9 and 10, the electrode embodiment 900 is formed with a flexible covering 904 which encloses a quantity of electrically conductive metallic wool material 908, which is copper wool in the preferred embodiment. The metallic wool 908 is electrically interconnected with the exposed end 912 of the electrical cable 80 which is covered with an insulating sheath 916 throughout its length except for the exposed end 912. The flexible covering 904 is preferably formed from a thin walled Teflon sock, and a plurality of perforations 920 are formed through the wall of the flexible covering 904. The forward end 924 of the flexible covering 904 is engaged to the cable 80 by a means such as a tightly wound thin wire 928. While the preferred flexible covering 904 is a perforated Teflon sock, other expanded or perforated covering materials may be utilized that can survive the electro-chemical and thermo-chemical reactions which occur during the tube electropolishing process. The perforations 920 are significant in that they facilitate the ingress and egress of electrolyte through the flexible covering 904 to accomplish the electropolishing effect of the electrode embodiment 900. It is significant to note that the flexible nature of the covering 904 and metallic wool 908 permits the electrode 900 to travel through bends in the tube 14 without the concern of the previously disclosed embodiments that the electrically active components of the electrode might touch the side of the tube 14 and cause an electrical short. This embodiment 900 is particularly suitable for tubes having a diameter that is greater than approximately 0.5 inches.

Figs. 11 and 12 depict yet another flexible electrode embodiment 1000 of the present invention, wherein Fig. 11 is a side elevational view of a cylindrical insulator a member 1004 before it is compressed and mounted on an electrode cable 80, and Fig. 12 is a cross-sectional view depicting the electrode 1000 disposed within a tube 14 for electropolishing purposes. As depicted in Figs. 11 and 12, the electrode embodiment 1000 comprises a generally cylindrical insulating member 1004 disposed upon the exposed distal end 1024 of an electrical cable 80. The insulating member 1004 is defined by a flexible, thin sidewall 1006 and having several sets of slits 1008, 1010, 1012, 1014 and 1016 formed through the sidewall 1006. Each of the sets of slits, such as set 1010, includes several slits that are parallel to the central axis of the cylindrical sidewall 1006 and circumferentially disposed around the surface of the sidewall 1006. An engagement hole 1018 is formed through the sidewall 1006 at each end of the insulating member 1004.

Fig. 12 depicts the insulating member 1004 engaged with a electrode cable 80 and disposed within a tube 14. As is seen in Fig. 12, the insulating member 1004 is mounted upon the exposed end 1024 of the cable 80 in an axially compressed manner. Mounting pins 1028, that are preferably non-electrically conductive, are passed through the mounting holes 1018 and through the exposed cable end 1024 to hold the member 1004 in a fixed, compressed position. As can be seen in Fig. 12, when the member 1004 is axially compressed, the sidewall material 1032 within the slits in each slit set 1008-1016 is caused to project outwardly, whereas the material in the unslitted sidewall portions 1036 between the slit sets 1008-1016 remains generally cylindrical. It is therefore to be understood that the axial compression of the slitted member 1004 produces a plurality of outwardly projecting portions 1032 around the circumference of the member 1004. The insulating member 1004 is formed from an electrically non-conductive material that can withstand the electro-chemical and thermo-chemical conditions of the electropolishing reaction, and an expanded Teflon tube has been found to produce good results. This embodiment 1000 is particularly suited to tubes having a diameter of approximately 1.0 inches or more. In a preferred electrode embodiment 1000, for a 2 gage cable and a 1.5 inch diameter metal tube, a Teflon insulating member 1004 is preferably formed utilizing a Teflon tube having a length of approximately 17 inches, an outside diameter of approximately 0.5 inches, a wall thickness of 0.065 inches, and 6 sets of slits, wherein each set of slits is approximately 2.5 inches long, 8 slits are formed circumferentially around the member 1004, and a spacing of 0.5 inches is made between each set of slits. In use, the length of the insulating member 1004 is compressed to approximately 14 inches. A specific utilization of the embodiment 1000 in a 1.5 inch diameter metal tube includes an electrolyte flow rate of approximately 2 gallons per minute with the application of a 300 amp. current and an electrode pull rate of approximately 5 inches per minute.

As will be appreciated by those skilled in the art, when the electrode embodiment 1000 is pulled through a bend in a tube 14, the various flexible members 1032 are free to flex and to move axially to some degree, such that the exposed cable end 1024 can be pulled through a bend without electrical contact between the cable end 1024 and the sidewall of the tube 14, thus preventing the electrical shorting of the electrode against the inner wall of the tube 14 when the electrode 1000 passes through a bend in the tube 14. Additionally, the flexible nature of the members 1032 permits the device 1000 to pass through smaller openings of component parts that are found in many tubular systems. After the electrode 1000 and its collapsed flexible members 1032 are pulled through a small opening, the flexible members 1032 will expand into a larger diameter section of the tubing.

Fig. 13 shows an alternate electropolishing system 1300 for electropolishing the interior surface of a tube 1302. System 1300 includes an electrolyte solution source 1304 with a supply line 1306 and a return line 1308, an adapter 1310, a cable 1312, an electropolishing electrode 1314, an electrolyte dam 1316, a power supply 1318, a cable puller 1320, and a feed-through valve 1322. Tube 1302 is coupled to system 1300 by attaching one end of tube 1302 to supply line 1306 of electrolyte solution source 1304, via adapter 1310, and attaching the opposite end of tube 1302 to return line 1308 of electrolyte solution source 1304.

System 1300 is shown in abbreviated fashion in Fig. 13 to illustrate the use of electrolyte dam 1316, but is understood to be substantially similar in both structure and function to electropolishing system 10 described above, except that the electrolyte flow through tube 1302 is in a direction opposite to the direction that electrode 1314 is drawn through tube 1302. Further, those skilled in the art will recognize that other electropolishing electrodes, including but not limited to all of those described herein, may be substituted for electrode 1314.

In this particular embodiment, adapter 1310 is a "T" fitting. The openings of adapter 1310 are coupled to supply line 1306, tube 1302, and valve 1322, respectively. While the particular shape of adapter 1310 is not essential to the practice of the present invention, coupling tube 1302 and valve 1322 to opposite ends of a straight run, as shown in Fig. 13, allows cable 1312 to be drawn straight through adapter 1310.

Valve 1322 opens to allow the insertion of electrode 1314 and dam 1316, through adapter 1310, into tube 1302, and then closes around cable 1312 to prevent the escape of electrolyte solution as cable 1312 is drawn from tube 1302. In a particular embodiment, valve 1322 is a manually operated Series AD Iris Diaphragm Valve, manufactured by Kemutec, Inc., having a place of business in Bristol, PA, U.S.A.. Those skilled in the art will recognize, however, that the particular design of valve 1322 is not an essential element of the present invention. In fact, in particular embodiments, valve 1322 may be omitted completely, for example, by redirecting the opening of adapter 1310 upwardly and controlling the flow rate of electrolyte solution into tube 1302, thus using gravity to prevent the flow of electrolyte out of the open end of adapter 1310.

Electrolyte dam 1316 is coupled to electrode 1314 by a tether 1324, which includes a swivel 1326. Swivel 1326 facilitates the free movement of dam 1316 within tube 1302, and is unnecessary if tether 1324 is otherwise sufficiently flexible. Dam 1316 keeps the portion of tube 1302 surrounding electrode 1314 full of electrolyte solution by partially blocking the flow of electrolyte solution through tube 1302, while advantageously reducing the required electrolyte flow rate.

Dam 1316 further includes a channel 1328 through its top portion and ballast 1330 in its bottom portion. Channel 1328 allows a small amount of electrolyte solution to flow past dam 1316, facilitating the supply of fresh electrolyte solution during the electropolishing process. Ballast 1330 maintains dam 1316 in its upright position as it is drawn through tube 1302, so that evolved gasses can escape through channel 1328. Keeping the portion of tube 1302 surrounding electrode 1314 full of electrolyte solution and free of trapped gasses results in a more uniform electropolishing of the inner surface of tube 1302.

Fig. 14 and Fig. 15 show an enlarged side view and front view, respectively, of one particular embodiment of dam 1316. The body of dam 1316 is formed as a hollow spherical shell 1402, and channel 1328 is formed by cutting a narrow slot through the top portion of shell 1402.

Ballast 1330 is formed in the bottom, interior portion of shell 1402, by pouring a solidifying liquid (e.g., low melting point metal) into the interior of shell 1402, and allowing the liquid to solidify and adhere to the bottom of shell 1402.

The slot that forms channel 1328 extends along the top surface of shell 1402, nearly half way around the circumference shell 1402. This extension of channel 1328 insures that at least a portion of channel 1328 will be open, to permit the escape of trapped gasses, even when dam 1316 is being drawn through an upward or downward sloping portion of a tube. Additionally, though slot 1328 permits electrolyte solution to enter the interior of shell 1402, the solution entering shell 1402 does not hinder the operation of dam 1316, but rather reduces the buoyancy of dam 1316 and is therefore advantageous in some applications.

Tether 1324 is attached to dam 1316 by way of a retaining member (e.g., a small bead) 1404 fixed to the end of tether 1324. A portion of tether 1324 adjacent retaining member 1404 is engaged in a small slit 1406 in shell 1402, extending downward from channel 1328. Retaining member 1404 prevents tether 1324 from being pulled through slit 1406.

A prototype electrolyte dam was constructed from a conventional ping-pong ball using a low melting point metal as ballast, and functioned well. Those skilled in the art will recognize however, that other materials may be used to form the body and ballast of dam 1316. For example, the body shell may be formed of a rigid material (e.g., plastic, TEFLON®, etc.) or a flexible material (e.g., soft rubber, condensed foam, etc.), so long as the material is fairly resistant to the electrolyte solution in use. In fact, forming shell 1402 from a flexible material provides an advantage that shell 1402 may be deformed for insertion into a system through a small opening, or when passing through an unusually narrow portion of a tube (e.g., a bend).

Fig. 16 and Fig. 17 show a side view and front view, respectively, of an alternate electrolyte dam 1600 according to the present invention. Dam 1600 includes a solid spherical body 1602, a channel 1604 formed in the top portion of body 1602, and ballast 1606 fixed to the bottom portion of body 1602. Channel 1604 is cut or ground into body 1602, to extend nearly half way around body 1602, so as to permit the escape of trapped gasses, even when dam 1600 is being drawn through an upward or downward sloping portion of a tube. Dam 1600 is fastened to tether 1324 by a fastener 1608, for example a common screw.

Ballast 1606 is formed from a more dense material than the upper portion of body 1602, in order to maintain dam 1602 in an upright position while being drawn through a tube during the electropolishing process. The upper portion of body 1602 and ballast 1606 can be constructed by any number of processes well known to those skilled in the art. For example, ballast 1606 and the upper portion of body 1602 may be integrally formed by a two step molding process. Alternatively, ballast 1606 and the upper portion of body 1602 may be formed separately, and then be fastened together. According to yet another alternative construction, the entire spherical body is formed from a first material. Then, a bottom portion of the body is machined out and filled with a second, denser material.

Fig. 18 and Fig. 19 show a side and front view, respectively, of another alternate electrolyte dam 1800 according to the present invention. Dam 1800 includes a body 1802, ballast 1804 disposed in the bottom portion of body 1802, and a channel 1806 formed in the top portion of body 1802. Channel 1806 is simply a flat strip formed along the top circumference of body 1802. Flat channel 1806, together with the inner wall of tube 1302 (Fig. 13), forms a passageway 1808 for electrolyte flow and for the escape of trapped gasses.

Dam 1800 further includes a bore 1810 through body 1802, which facilitates coupling dam 1800 directly to cable 1312. Dam 1800 is coupled to cable 1312 by inserting cable 1312 through bore 1810, and then fixing a retaining member 1812 to the end of cable 1312. Bore 1810 is formed sufficiently large to permit dam 1800 to freely rotate about cable 1312, so that ballast 1804 can function to maintain dam 1800 in an upright position during the electropolishing process. In this particular embodiment, retaining member 1812 is a ring with a set screw 1814 for engaging cable 1312, but any type of suitable retaining member may be employed for this purpose. In fact, the need for a retaining member may be eliminated in some applications simply by bending over the end of cable 1312 after it has been inserted through bore 1810.

Because dam 1800 is fixed directly to cable 1312, care must be taken to insure the electrical isolation of cable 1312 and the inner wall of tube 1302 (Fig. 13). This can be accomplished in a number of ways, including forming or covering dam 1800 with an insulating material, or attaching dam 1800 to an insulated portion of cable 1312.

While the invention has been depicted and described with reference to several particular embodiments, it will be understood by those skilled in the art that many features may be modified, substituted or omitted, without departing from the scope of the invention. For example, each embodiment of the electrolyte dam of the present invention is shown with a spherical body, but other body shapes, including but not limited to pear-shaped, tear-drop, or ellipsoidal, may be substituted therefor.

I claim:

1. An electrolyte dam for controlling electrolyte flow during the electropolishing of the interior surface of a tube, said electrolyte dam comprising:

a body having a top portion, and a bottom portion;

ballast fixed at said bottom portion of said body; and

a channel defined by said top portion of said body, for allowing the passage of electrolyte solution and evolved gasses past said electrolyte dam.

2. An electrolyte dam according to Claim 1, wherein said body is comprises an insulating material.

3. An electrolyte dam according to Claim 1, wherein said body is spherical in shape.

4. An electrolyte dam according to Claim 1, wherein said channel is defined at least in part by a flat formed on said top portion of said body.

5. An electrolyte dam according to Claim 1, wherein said channel is defined at least in part by a groove formed in said top portion of said body.

6. An electrolyte dam according to Claim 1, wherein said ballast is formed integral with said body.

7. An electrolyte dam according to Claim 1, further comprising a connector for attaching said electrolyte dam to an electropolishing electrode.

8. An electrolyte dam according to Claim 7, wherein said connector comprises a tether, said tether having a first end fixed to said electrolyte dam.

9. An electrolyte dam according to Claim 8, wherein said tether comprises a swivel connector.

10. An electrolyte dam according to Claim 7, wherein said connector comprises a bore through said body.

11. An electrolyte dam according to Claim 10, wherein said bore is adapted to receive an electropolishing electrode cable.

12. An electrolyte dam according to Claim 11, wherein said bore is adapted to loosely receive said electrode cable to facilitate the free rotation of said body about said electrode cable.

13. An electropolishing system for polishing the interior surface of a tube, said electropolishing system comprising:

an electrolyte solution source;

an adapter for coupling said electrolyte solution source to said tube;

an electropolishing electrode;

a cable coupled to said electropolishing electrode for drawing said electropolishing electrode through said tube; and

an electrolyte dam coupled to said electropolishing electrode for controlling the flow of electrolyte solution through said tube and to facilitate the escape of any evolved gases.

14. An electropolishing system according to Claim 13, wherein said electrolyte dam comprises:

a body having a top portion, and a bottom portion;

ballast fixed at said bottom portion of said body; and

a channel defined by said top portion of said body, for allowing the passage of electrolyte solution and evolved gasses past said electrolyte dam.

15. An electropolishing system according to Claim 13, further comprising a mechanical feed-through coupled to said adapter to facilitate drawing said cable through said adapter and to inhibit electrolyte leakage.

16. An electropolishing system according to Claim 15, wherein said mechanical feed-through comprises an iris valve.

17. An electropolishing system for polishing the interior surface of a tube, said electropolishing system comprising:

an electrolyte solution source connectable to said tube;

an electropolishing electrode;

a cable, coupled to said electropolishing electrode, for drawing said electropolishing electrode through said tube and for electrically coupling said electropolishing electrode to an electrical power supply; and

wherein said electropolishing electrode includes at least one electrode member electrically coupled to said cable, a first insulating member fixed to said cable on a first side of said electrode member, and a second insulating member fixed to said cable on a second side of said electrode member, at least one of said insulating members defining a passageway to facilitate electrolyte flow thereby.

18. An electropolishing system for polishing the interior surface of a tube, said electropolishing system comprising:

an electrolyte solution source connectable to said tube;

an electropolishing electrode;

a cable, coupled to said electropolishing electrode, for drawing said electropolishing electrode through said tube and for electrically coupling said electropolishing electrode to an electrical power supply; and

wherein said electropolishing electrode includes a quantity of electrically conductive fiber in electrical contact with said cable, and a perforated, insulating membrane enclosing said fiber and being fixed to said cable.

19. An electropolishing system for polishing the interior surface of a tube, said electropolishing system comprising:

an electrolyte solution source connectable to said tube;

an electropolishing electrode;

a cable, coupled to said electropolishing electrode, for drawing said electropolishing electrode through said tube and for electrically coupling said electropolishing electrode to an electrical power supply; and

wherein said electropolishing electrode includes an insulating cylindrical tube, having a set of slits defined in the wall thereof, fixed about an uninsulated portion of said cable.

20. An electropolishing electrode comprising:

a length of electrically conducting cable;

at least one electrode member electrically coupled to said cable;

a first insulating member fixed to said cable on a first side of said electrode member;

a second insulating member fixed to said cable on a second side of said electrode member; and

wherein at least one of said insulating members defines a passageway to facilitate electrolyte flow thereby.

21. An electropolishing electrode comprising:

a length of electrically conducting cable;

a quantity of electrically conductive fiber in electrical contact with said cable; and

a perforated, insulating membrane enclosing said fiber and being fixed to said cable.

22. An electropolishing electrode comprising :

a length of electrically conducting cable; and

an insulating cylindrical tube, having a set of slits defined in the wall thereof, fixed about an uninsulated portion of said cable

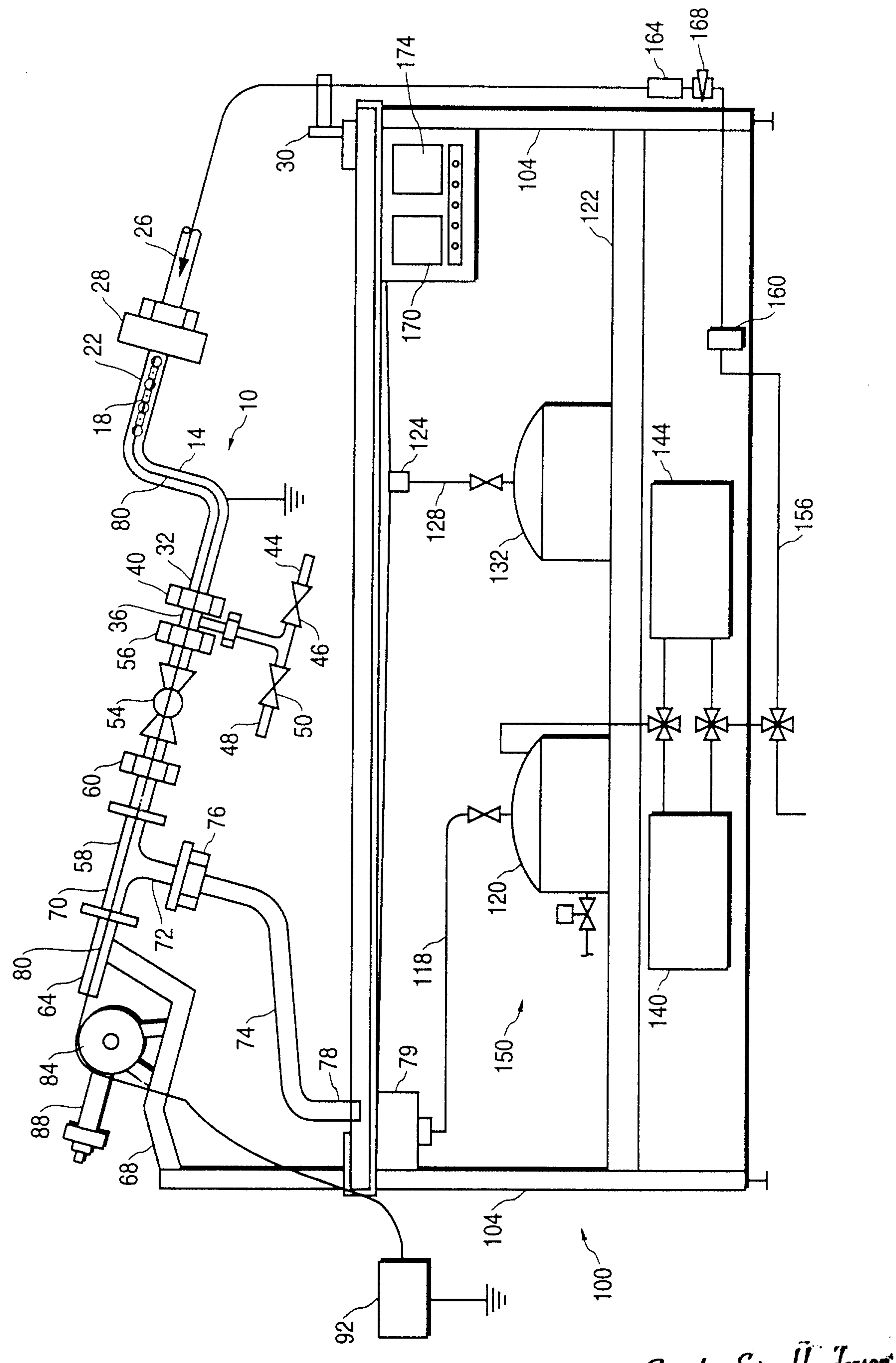

FIG.1

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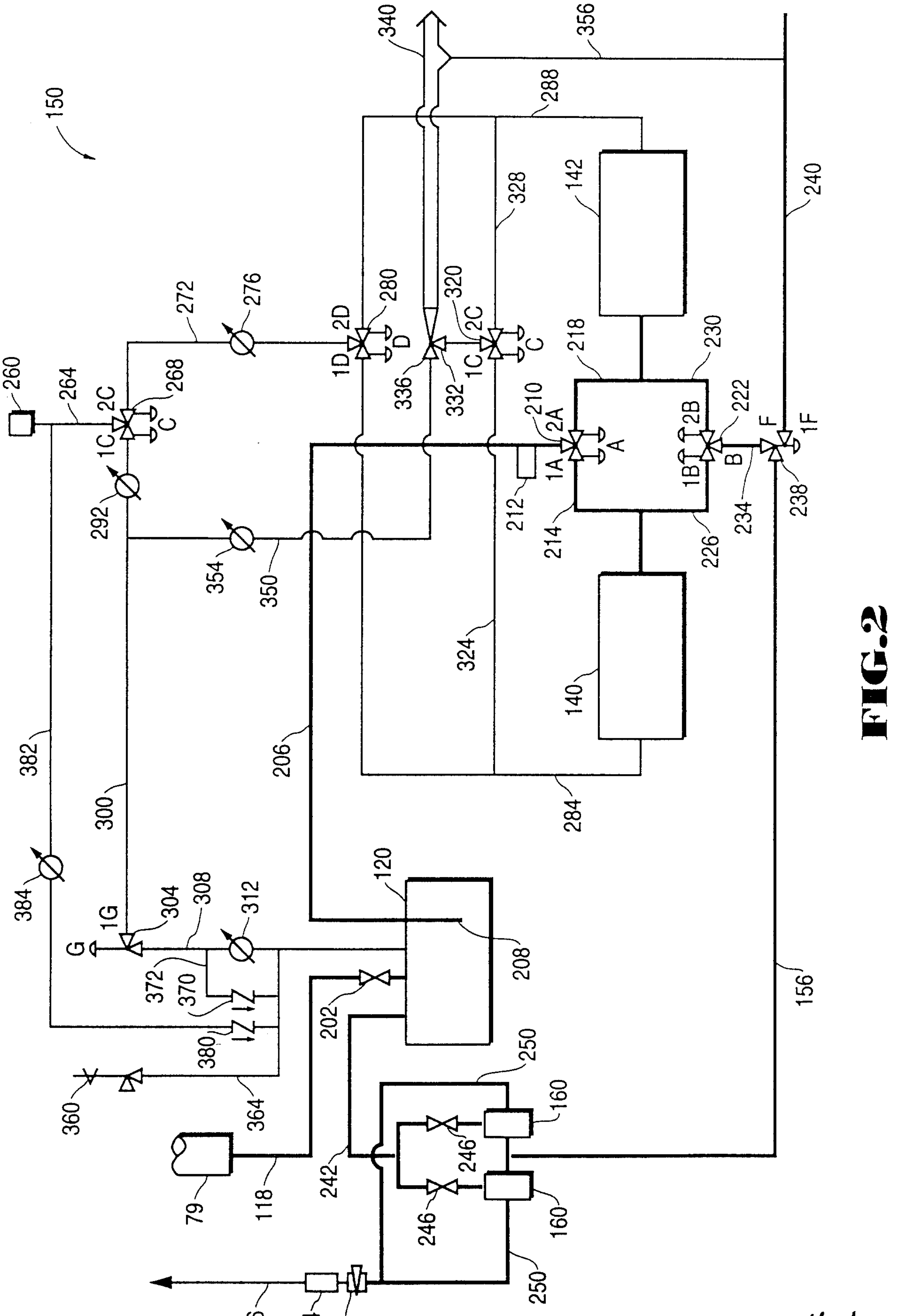

FIG.2

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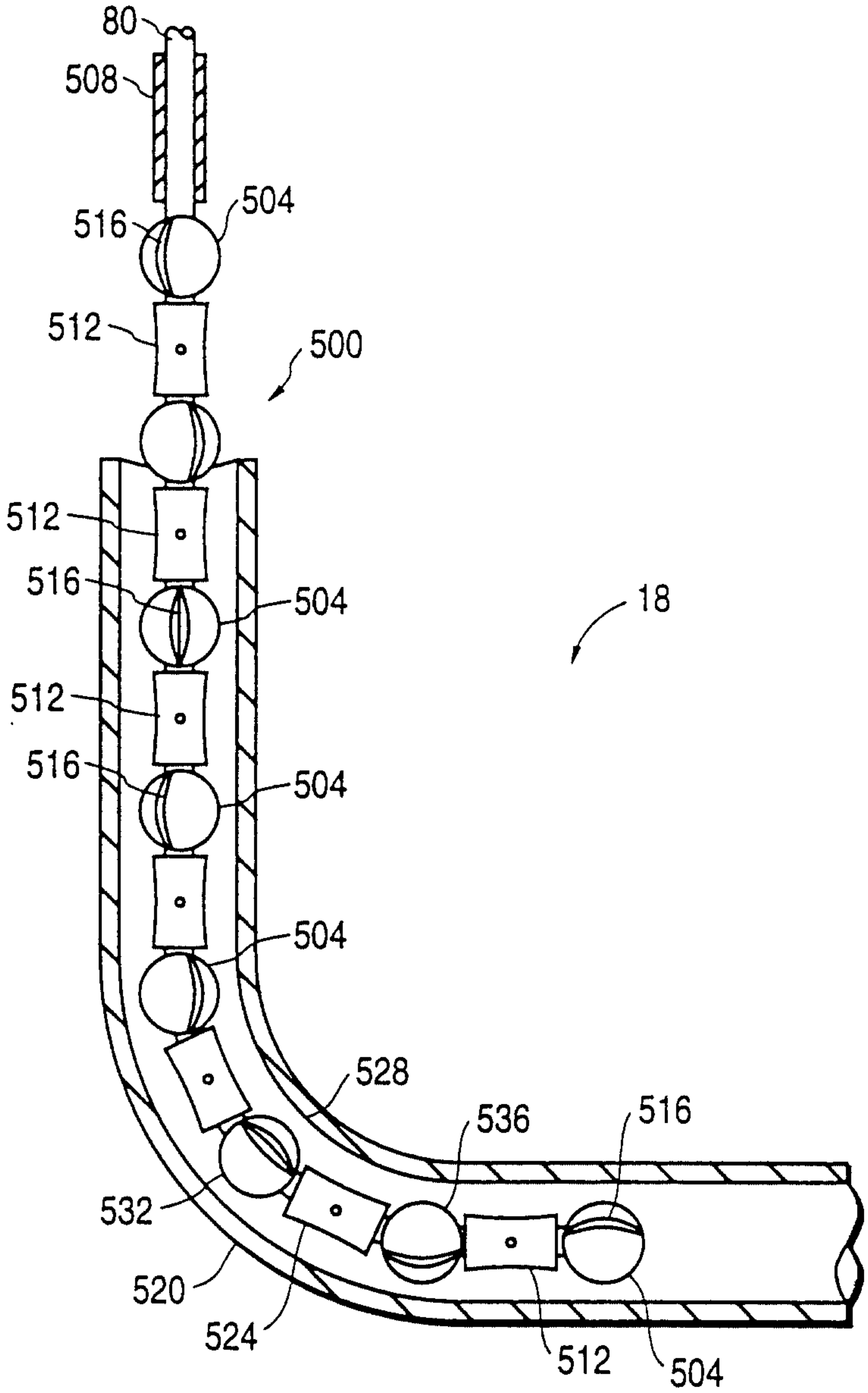

FIG.3

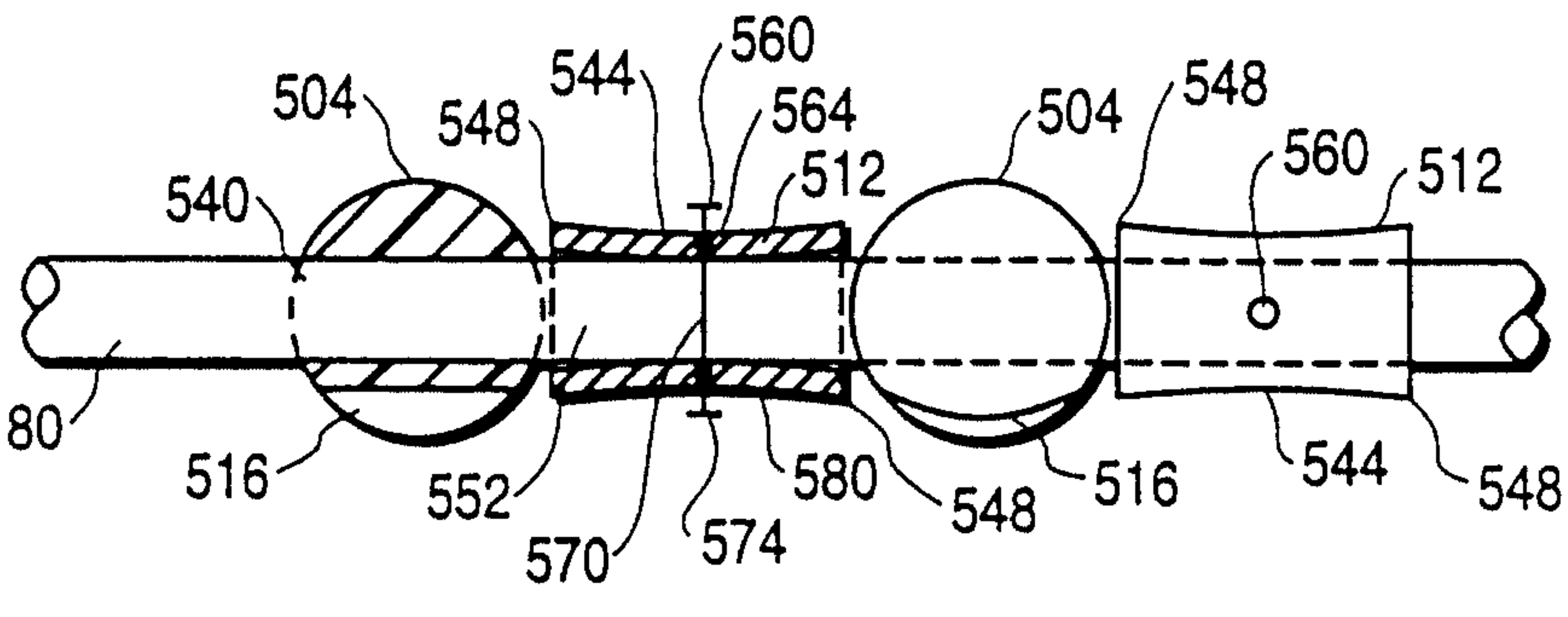

FIG.4

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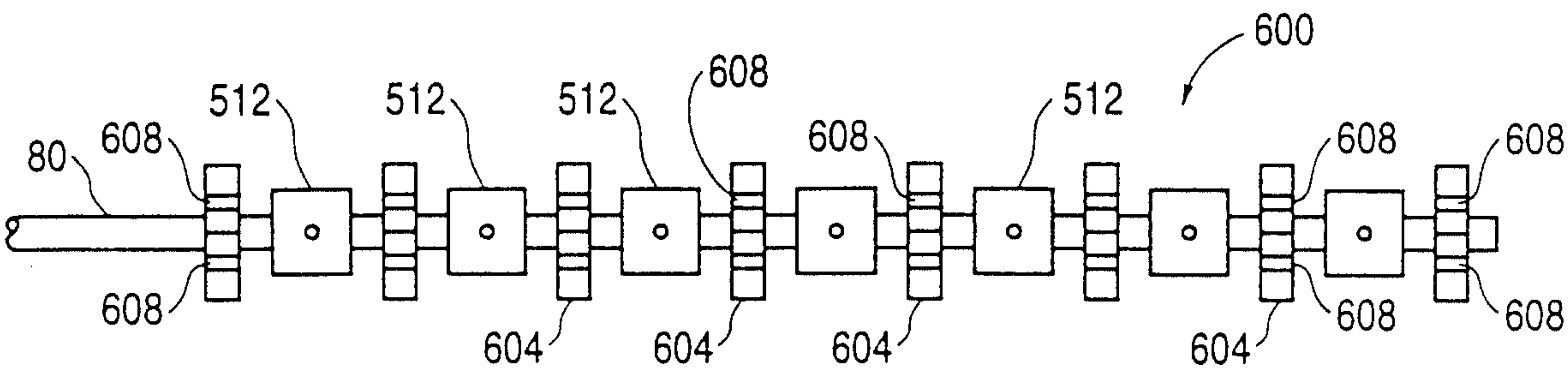

FIG.5

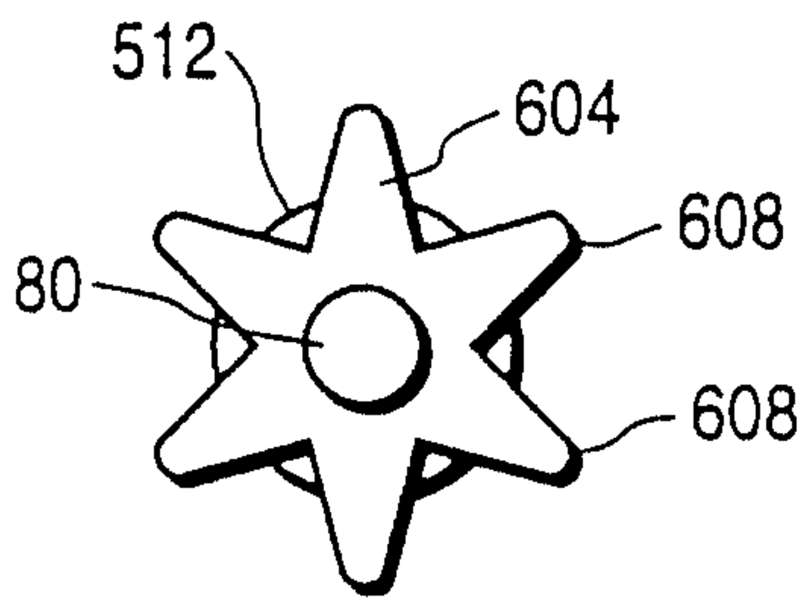

FIG.6

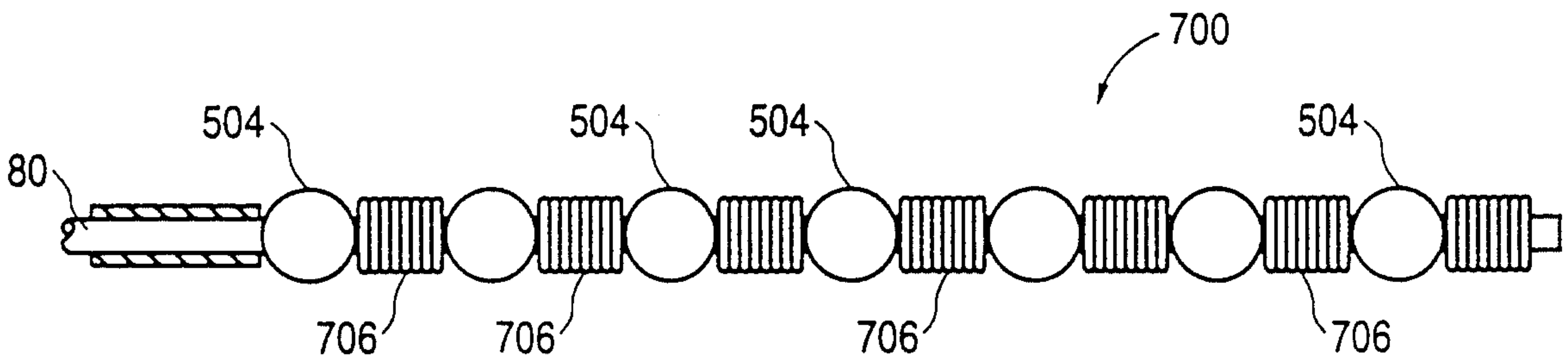

FIG.7

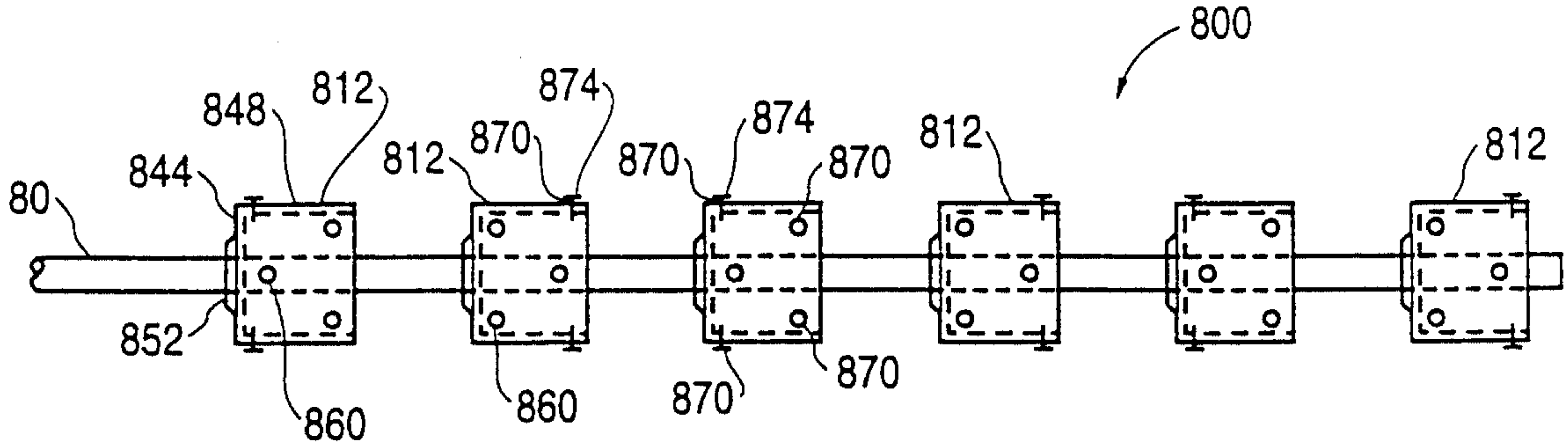

FIG.8

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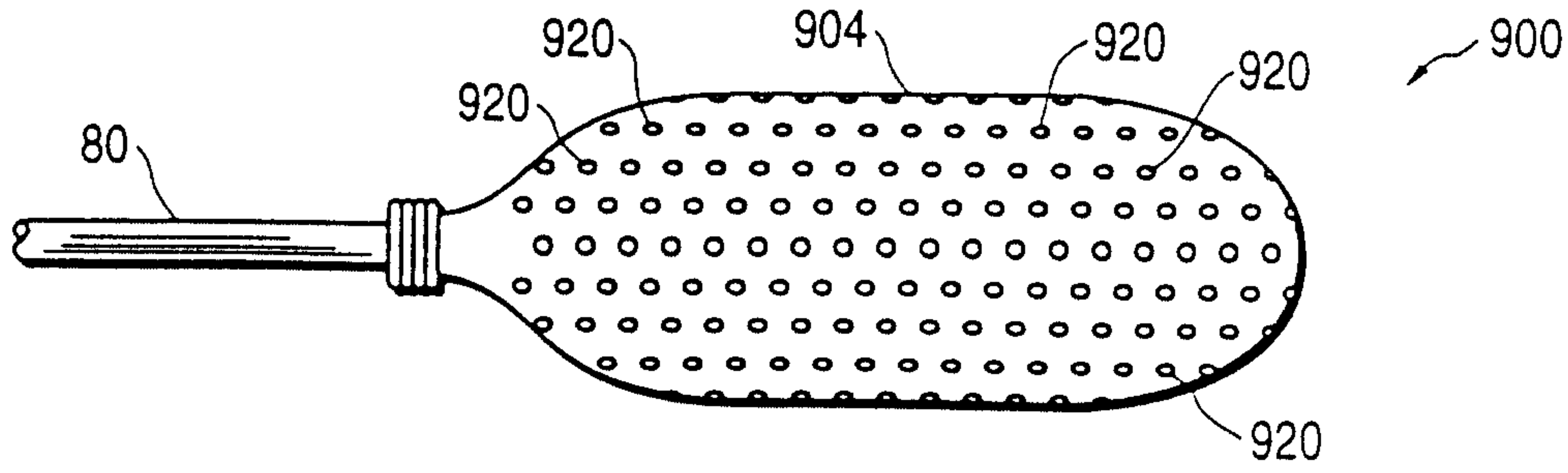

FIG.9

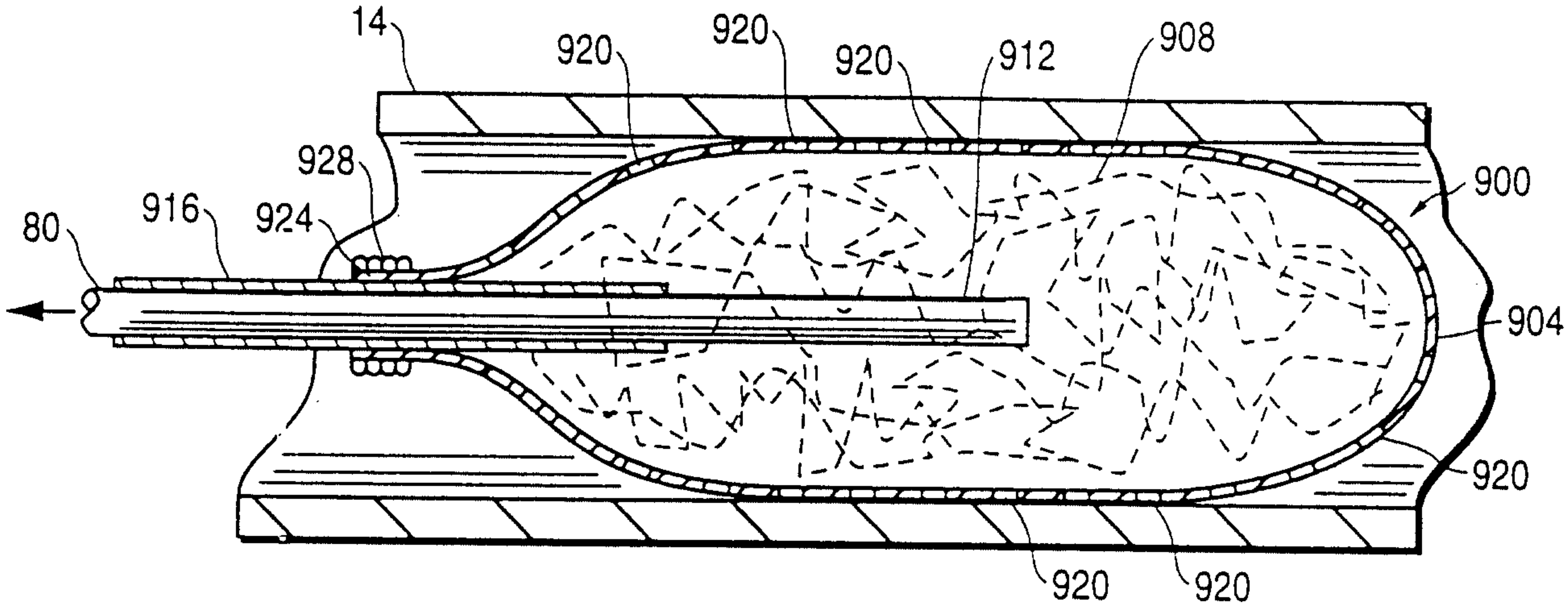

FIG.10

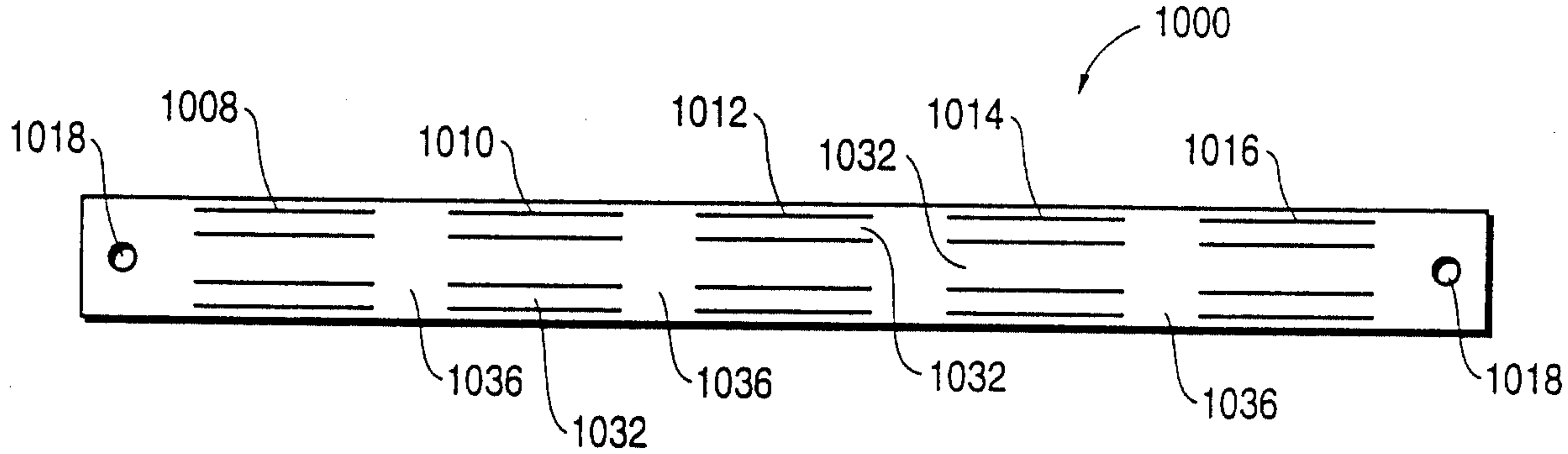

FIG.11

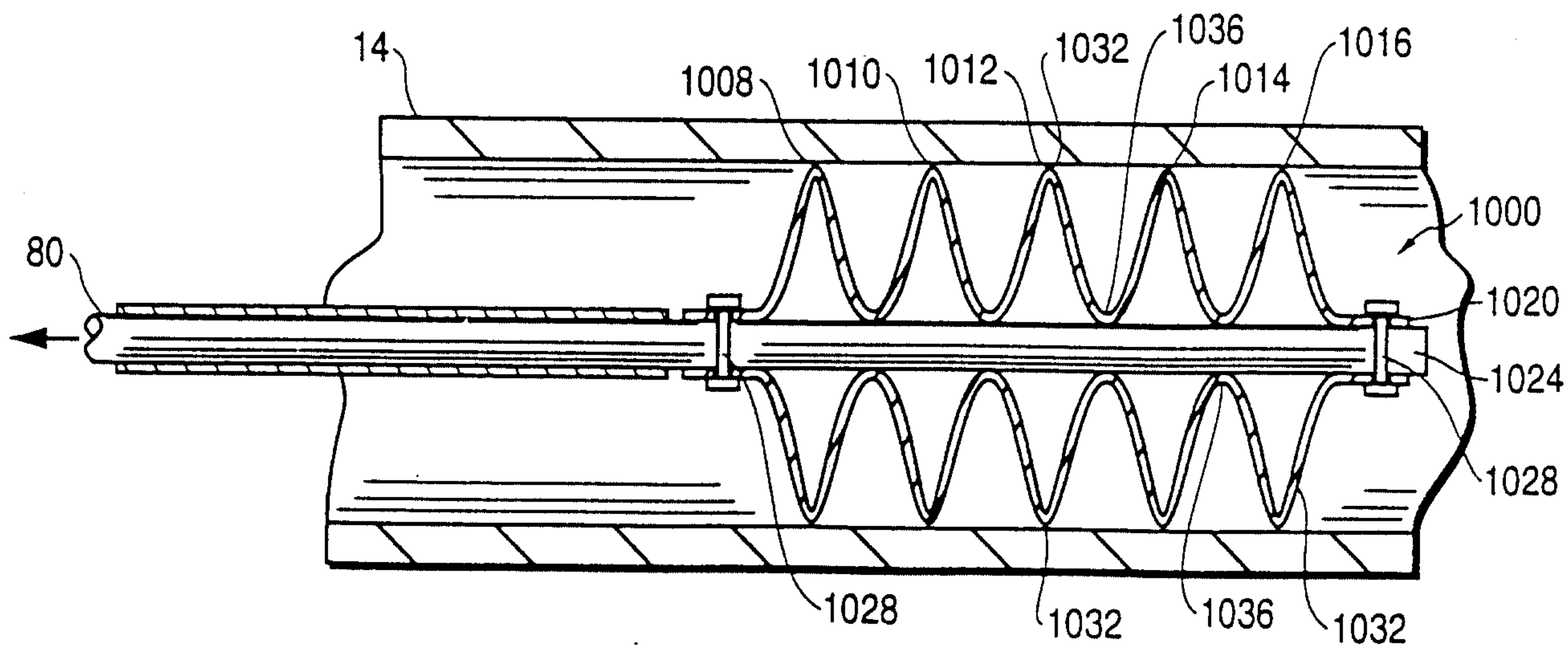

FIG.12

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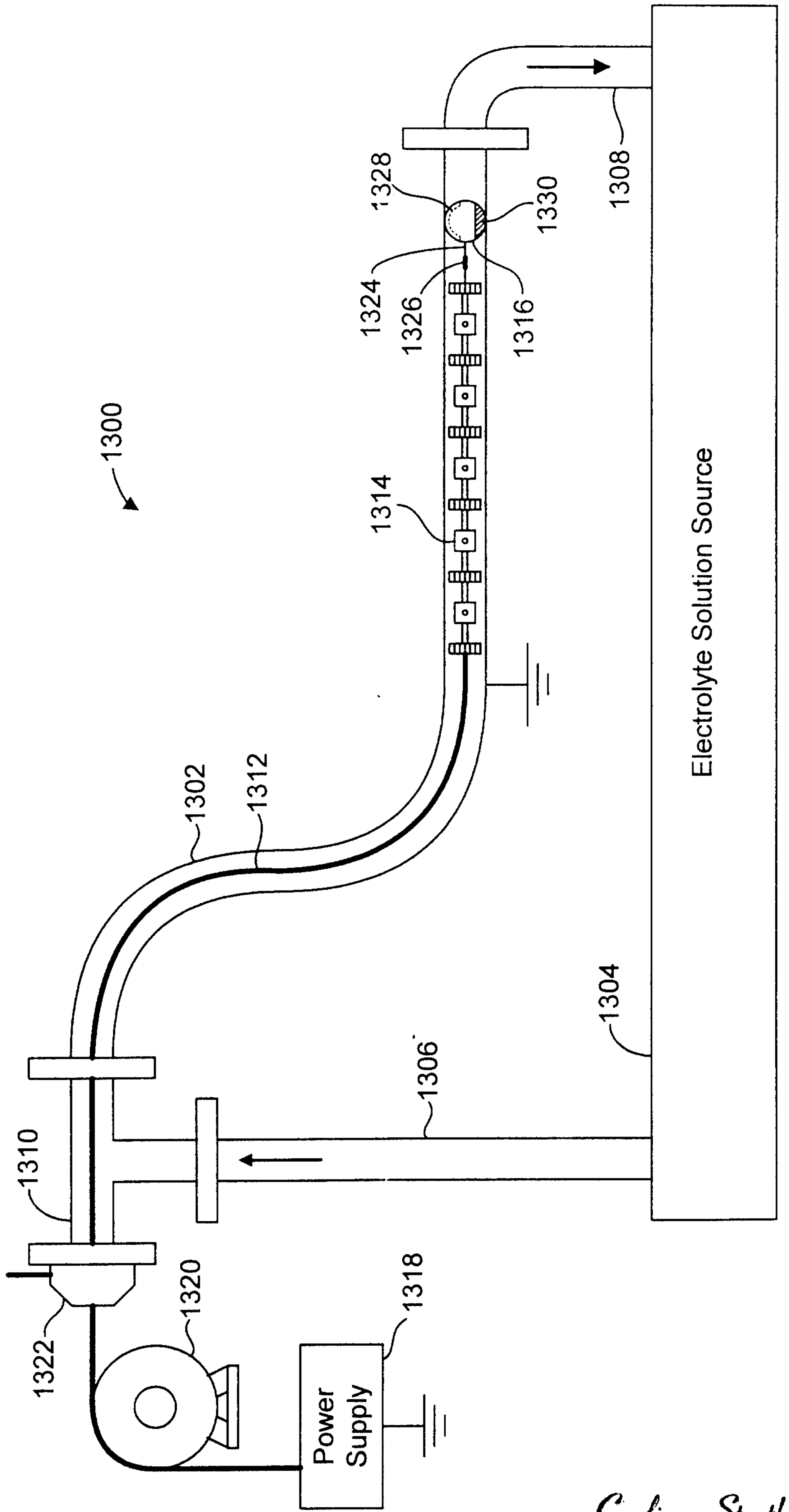

FIG. 13

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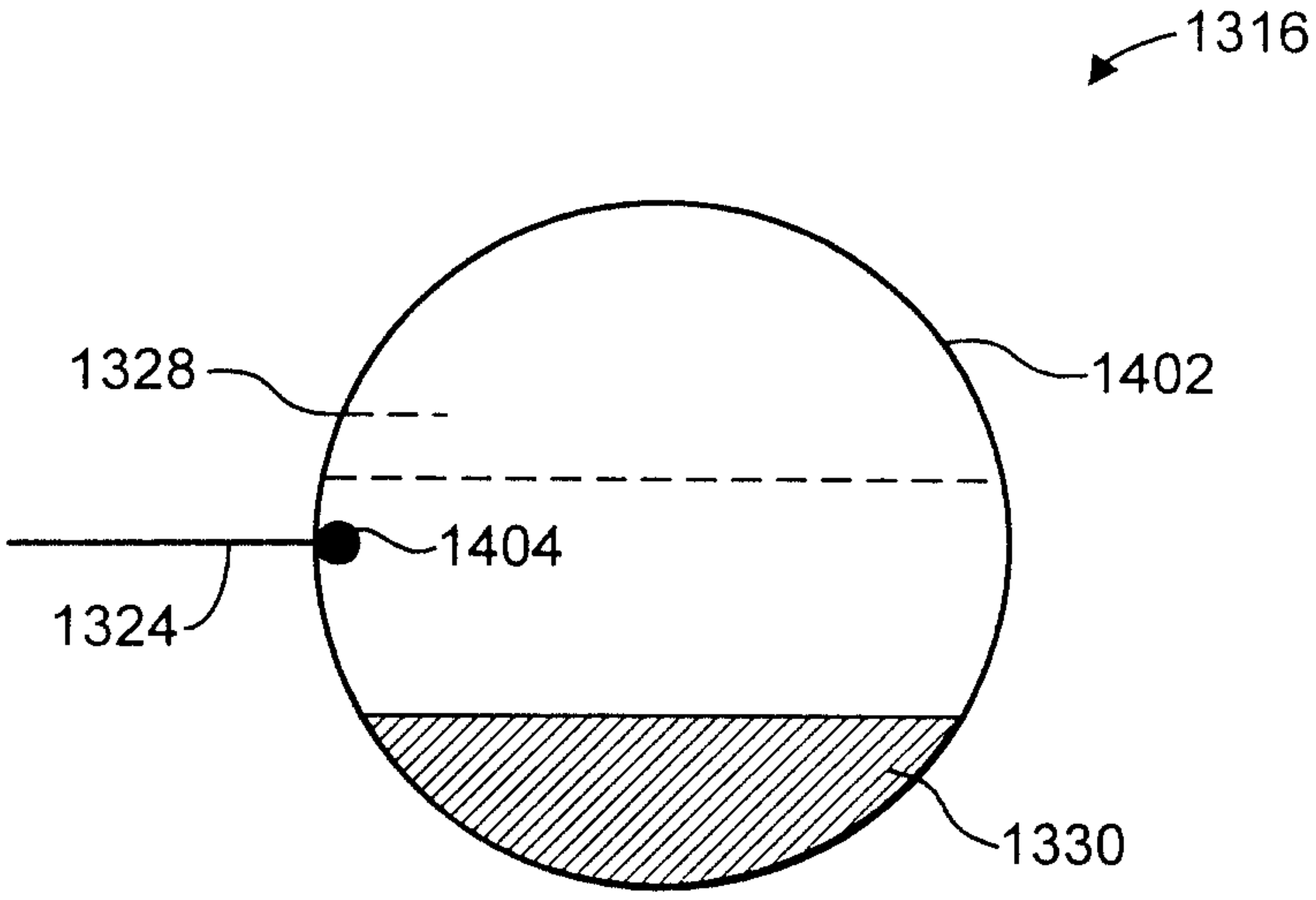

FIG. 14

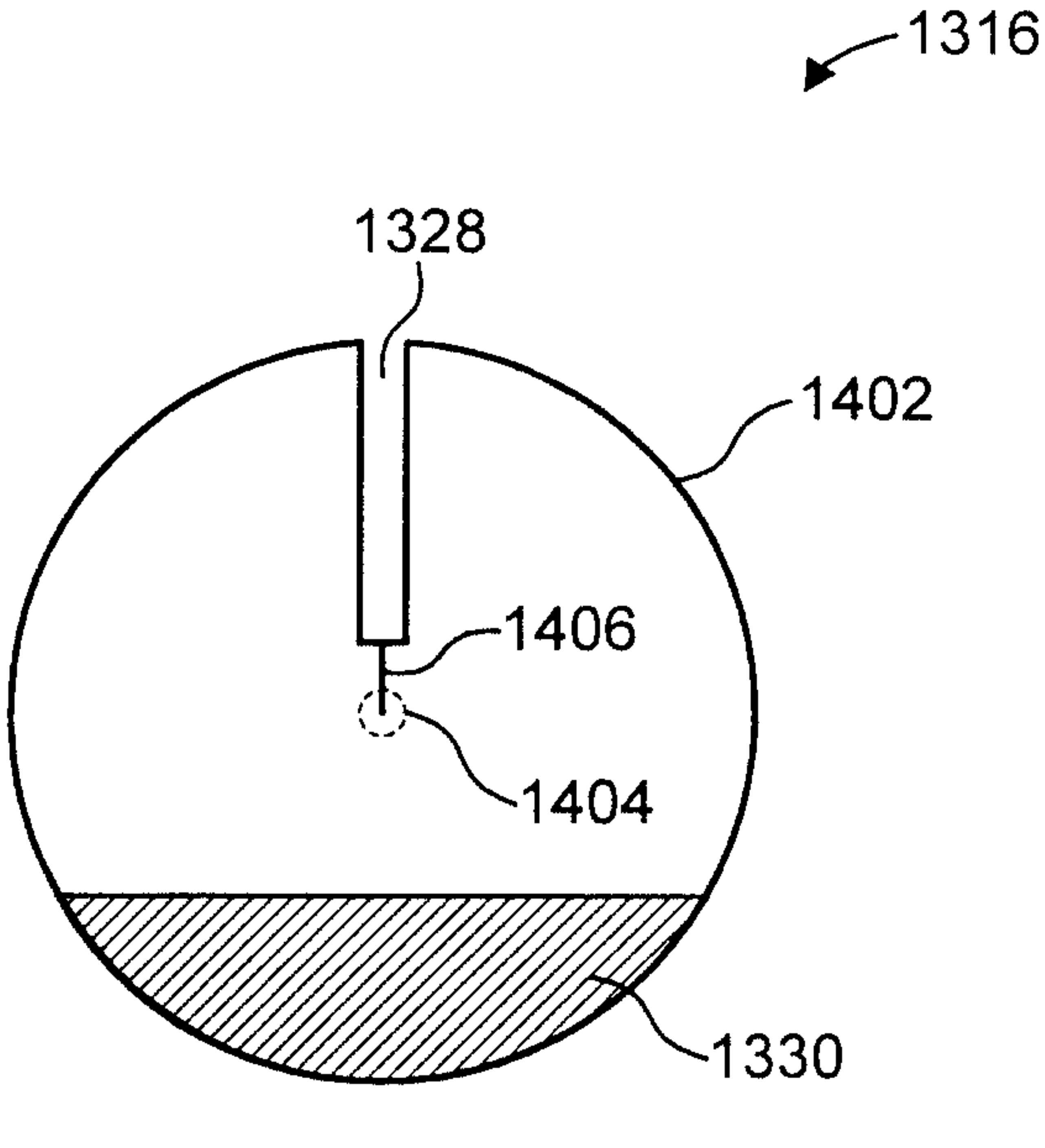

FIG. 15

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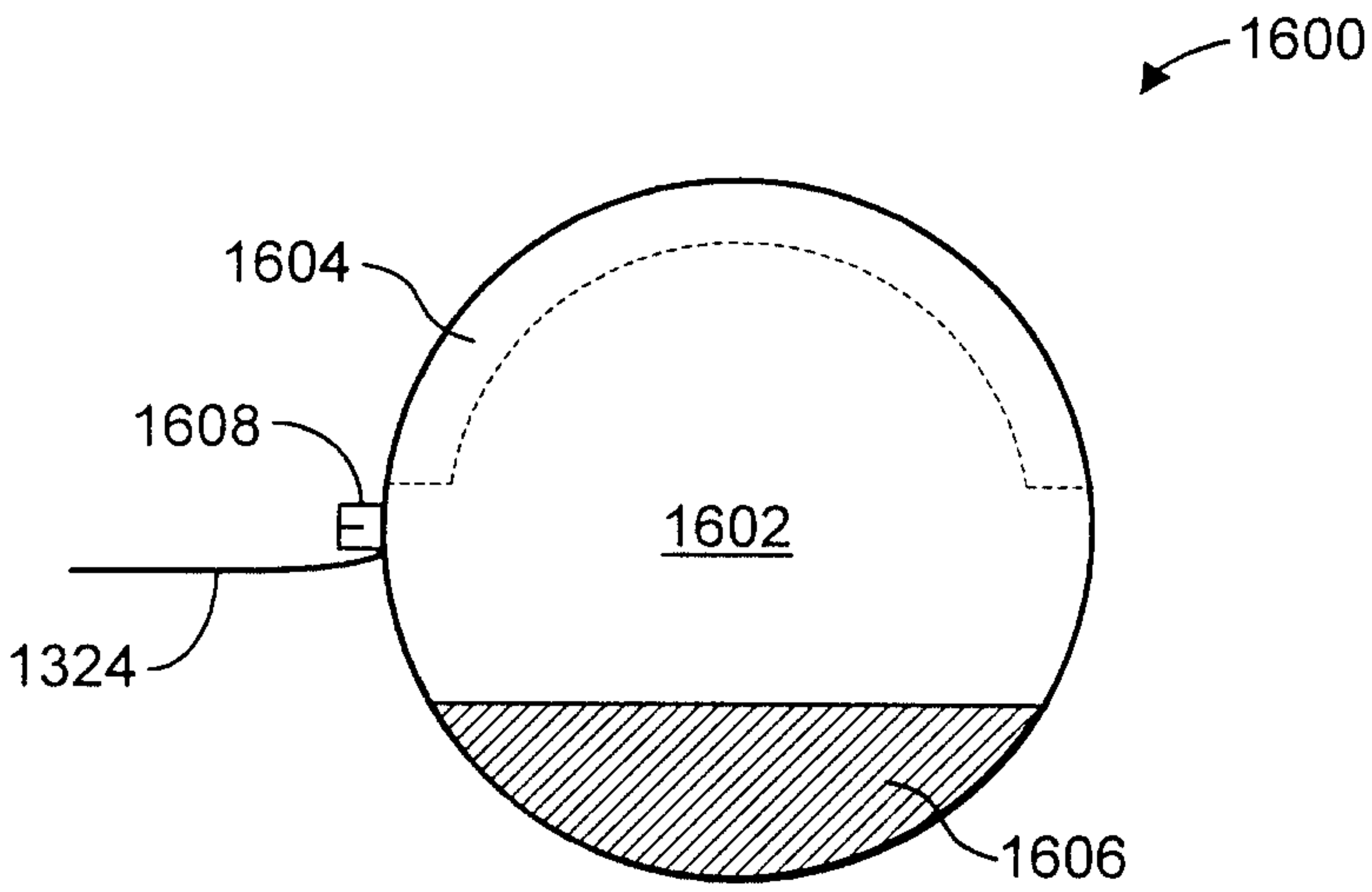

FIG. 16

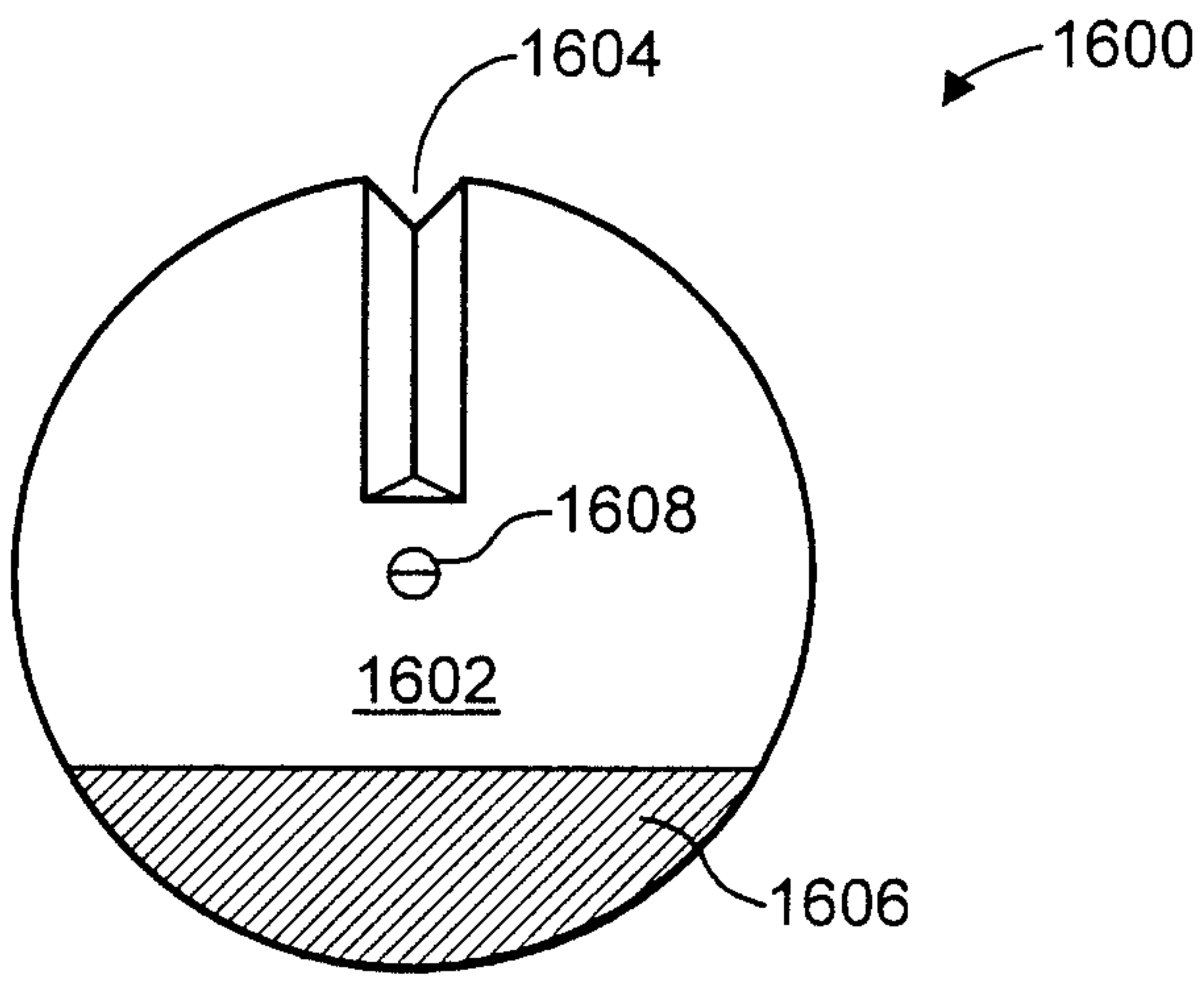

FIG. 17

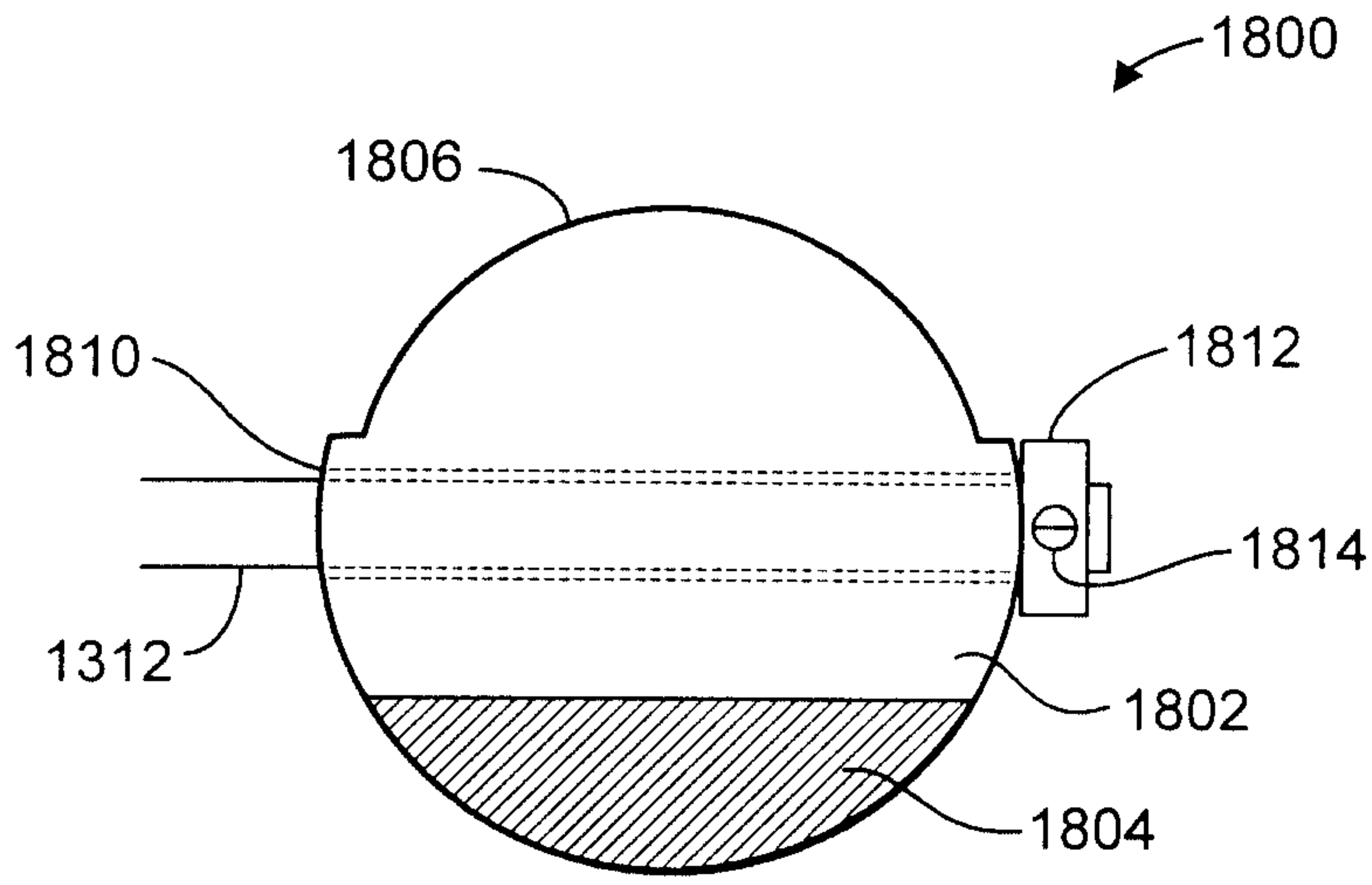

FIG. 18

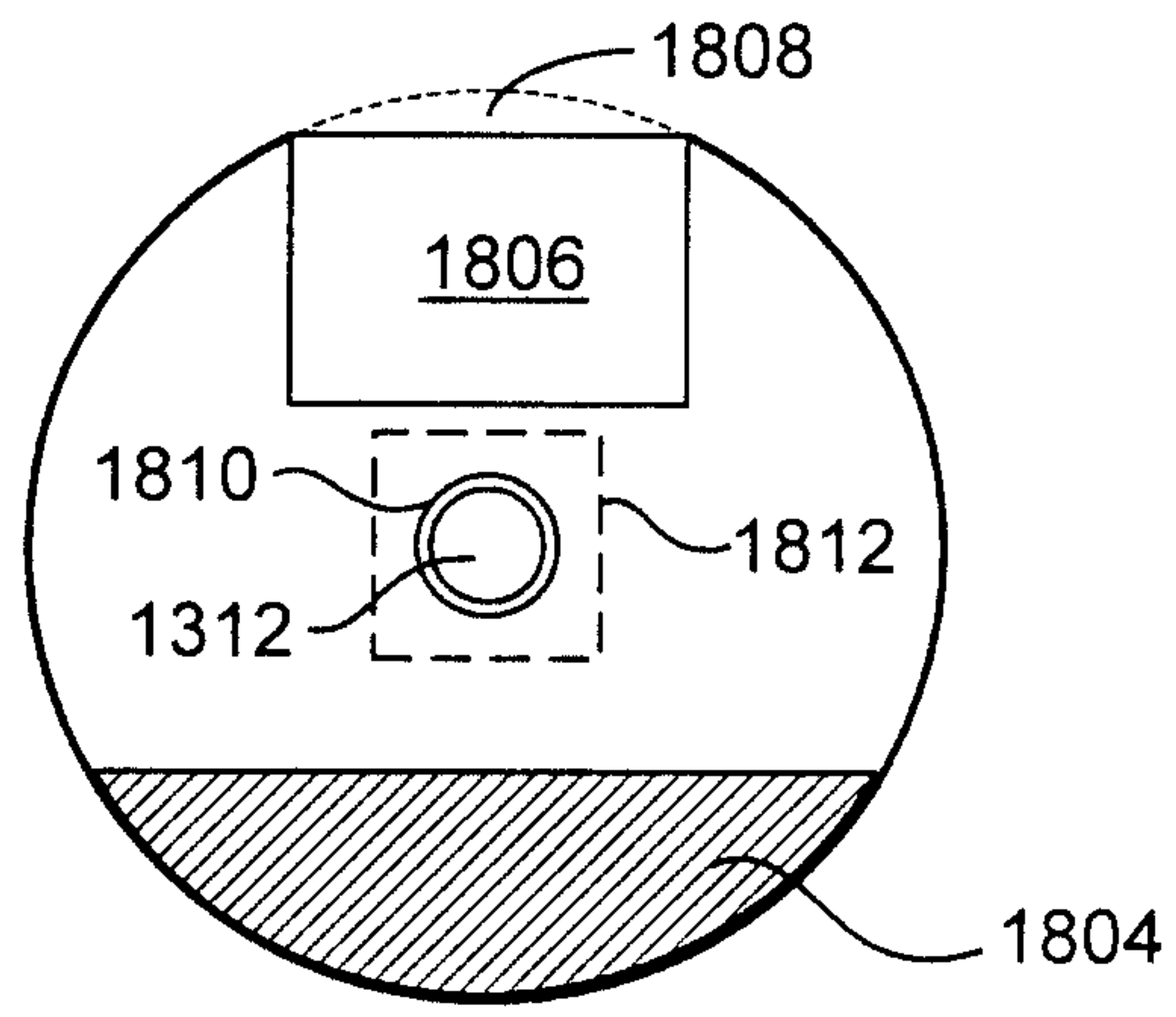

FIG. 19

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