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(54) **ELECTROSURGICAL METHODS AND SYSTEMS**

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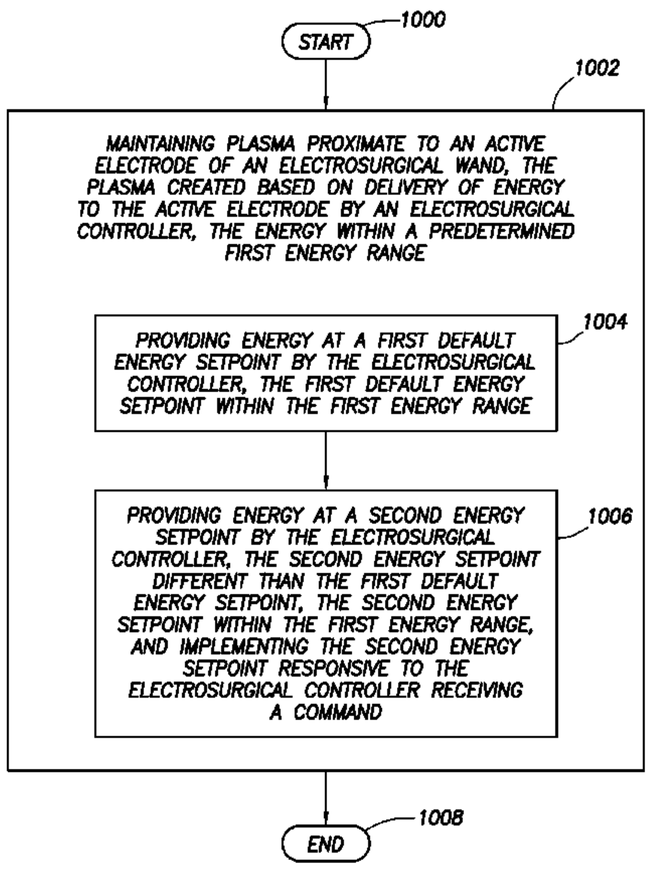
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(57) **ABSTRACT**

Electrosurgical methods and systems. At least some of the illustrative embodiments are methods including maintaining plasma proximate to an active electrode in a first energy range, and a second energy range. During periods when plasma is proximate to the active electrode, the illustrative method may include controlling flow of fluid drawn into an aperture of an electrosurgical wand, and in some situations increasing fluid flow drawing into the aperture responsive to the active electrode being in operational relationship with tissue, and in other cases decreasing fluid flow drawing into the aperture responsive to the active electrode being in operational relationship with tissue. Further, during periods when plasma is proximate to the active electrode, the illustrative method may include providing output energy at a default energy setpoint, and then providing output energy at a second energy setpoint.

14 Claims, 10 Drawing Sheets



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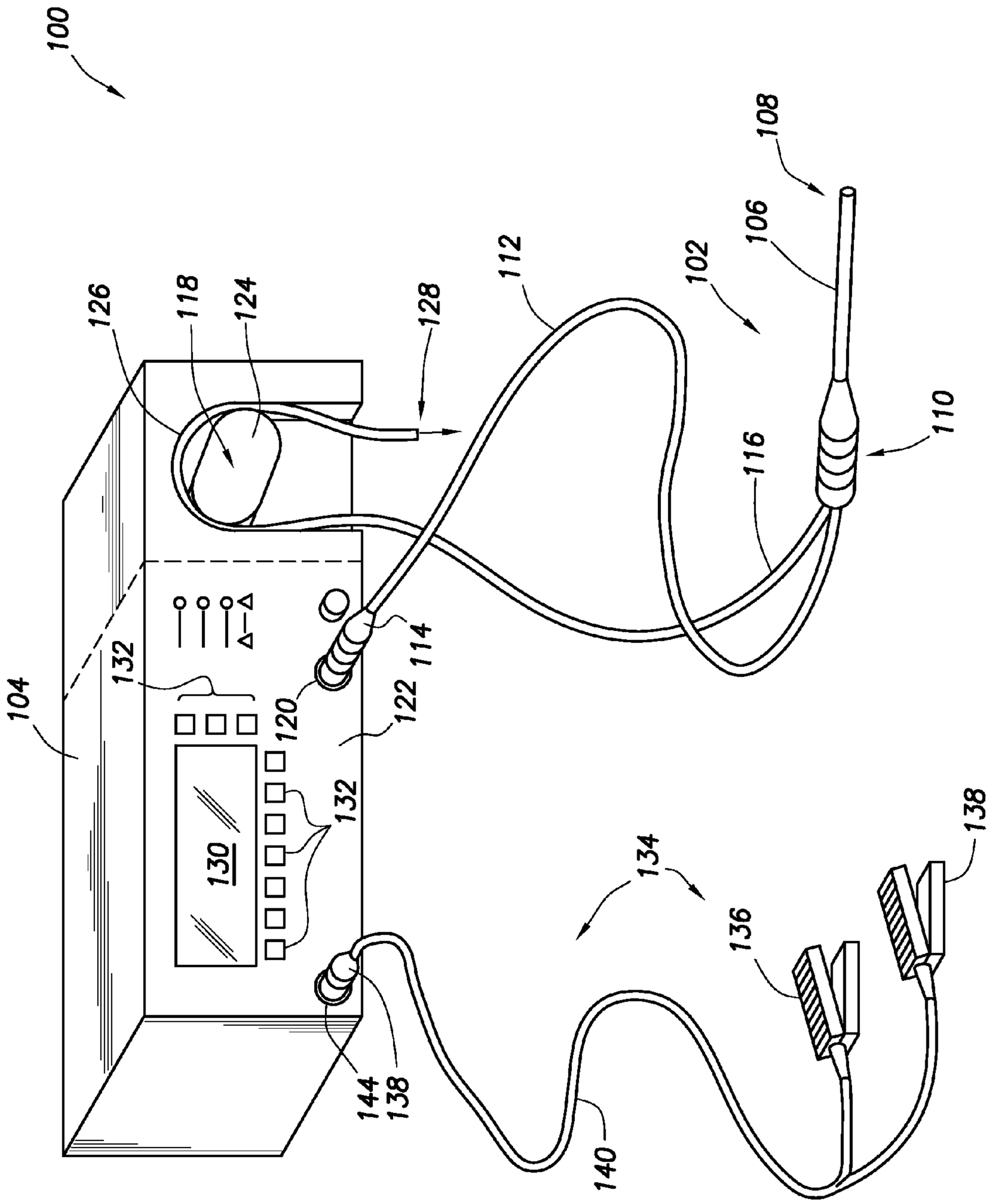

100
104
106
108
110
112
114
116
118
120
122
124
126
128
130
132
134
136
138
140
144

FIG. 1

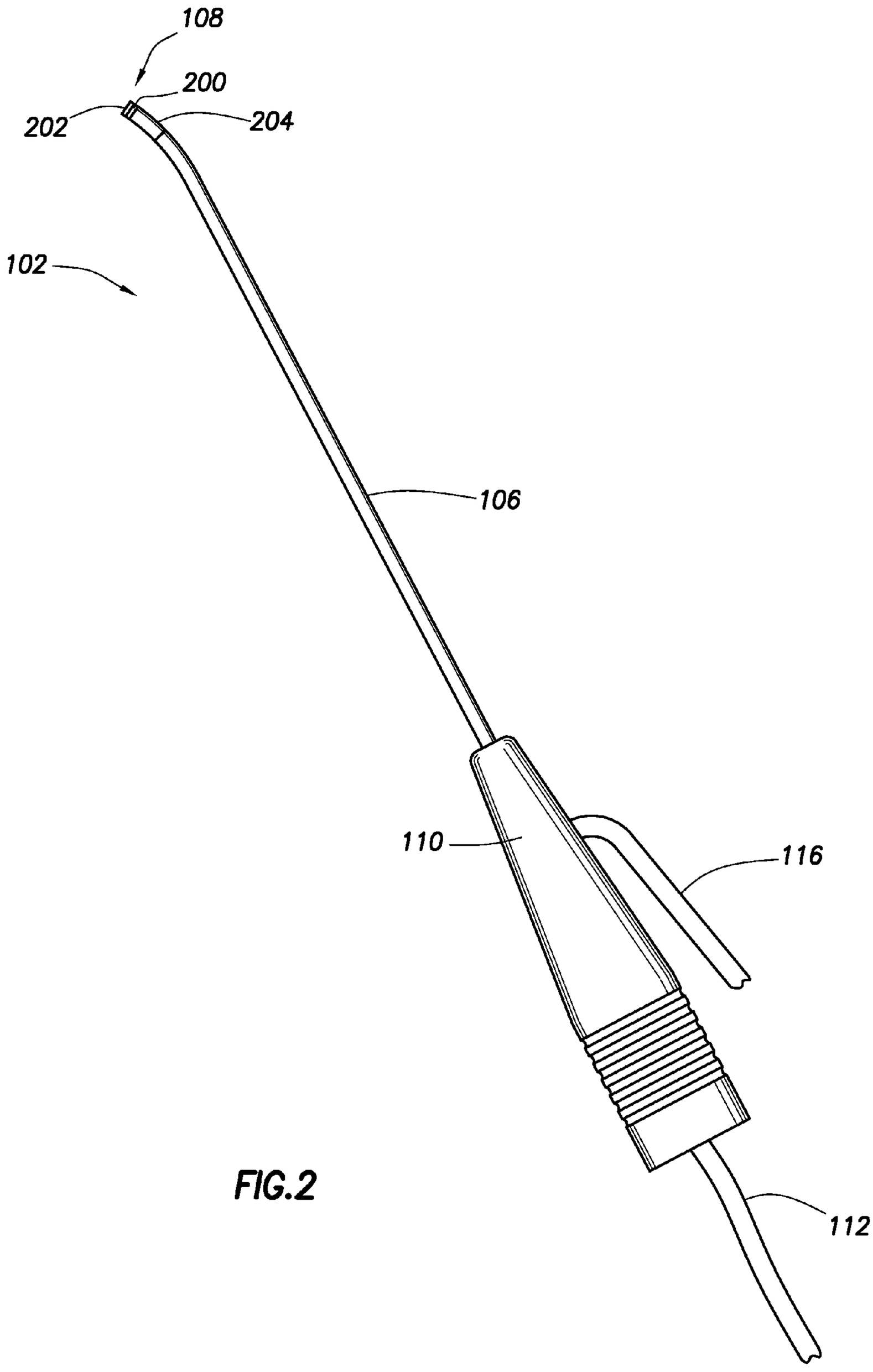


FIG.2

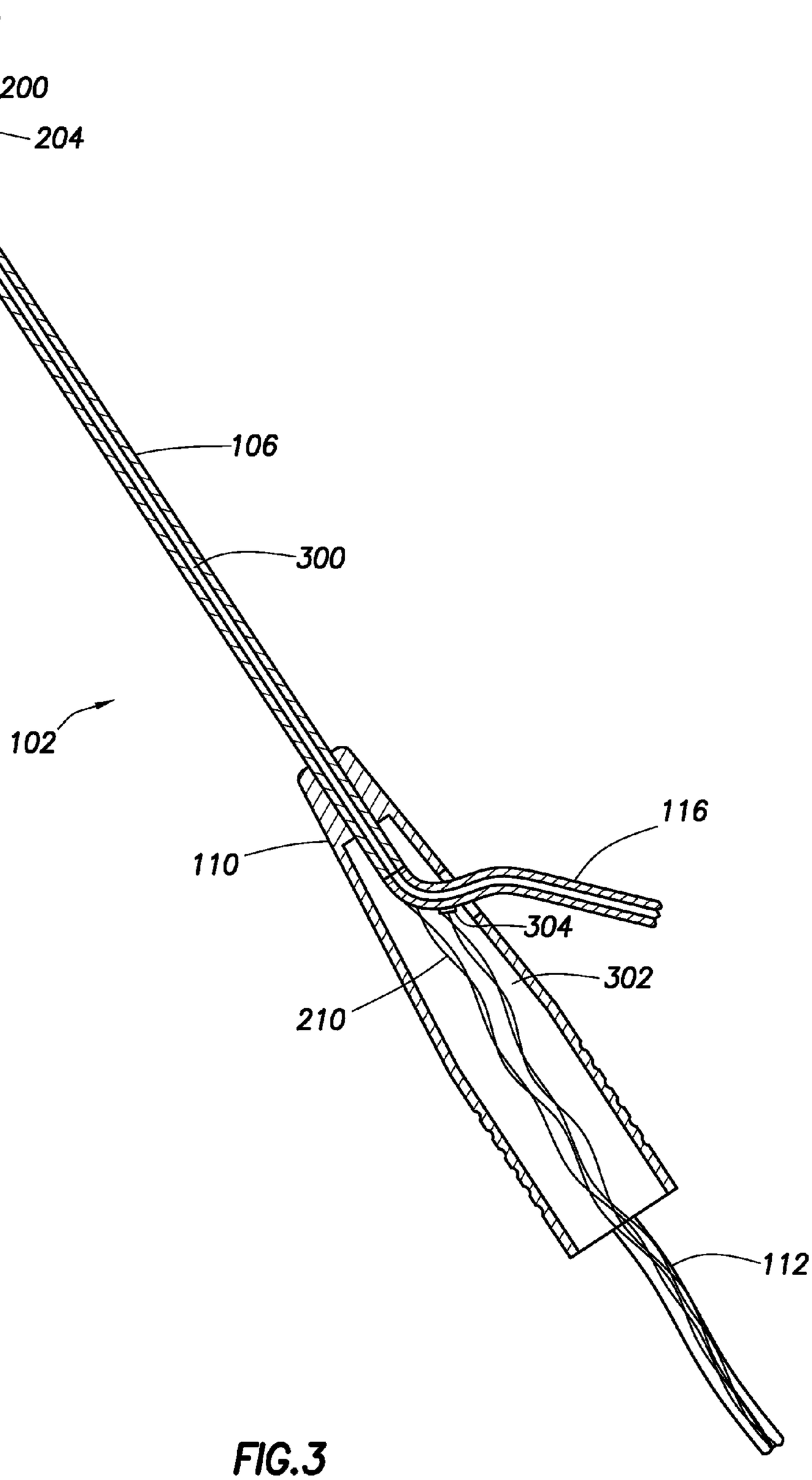


FIG.3

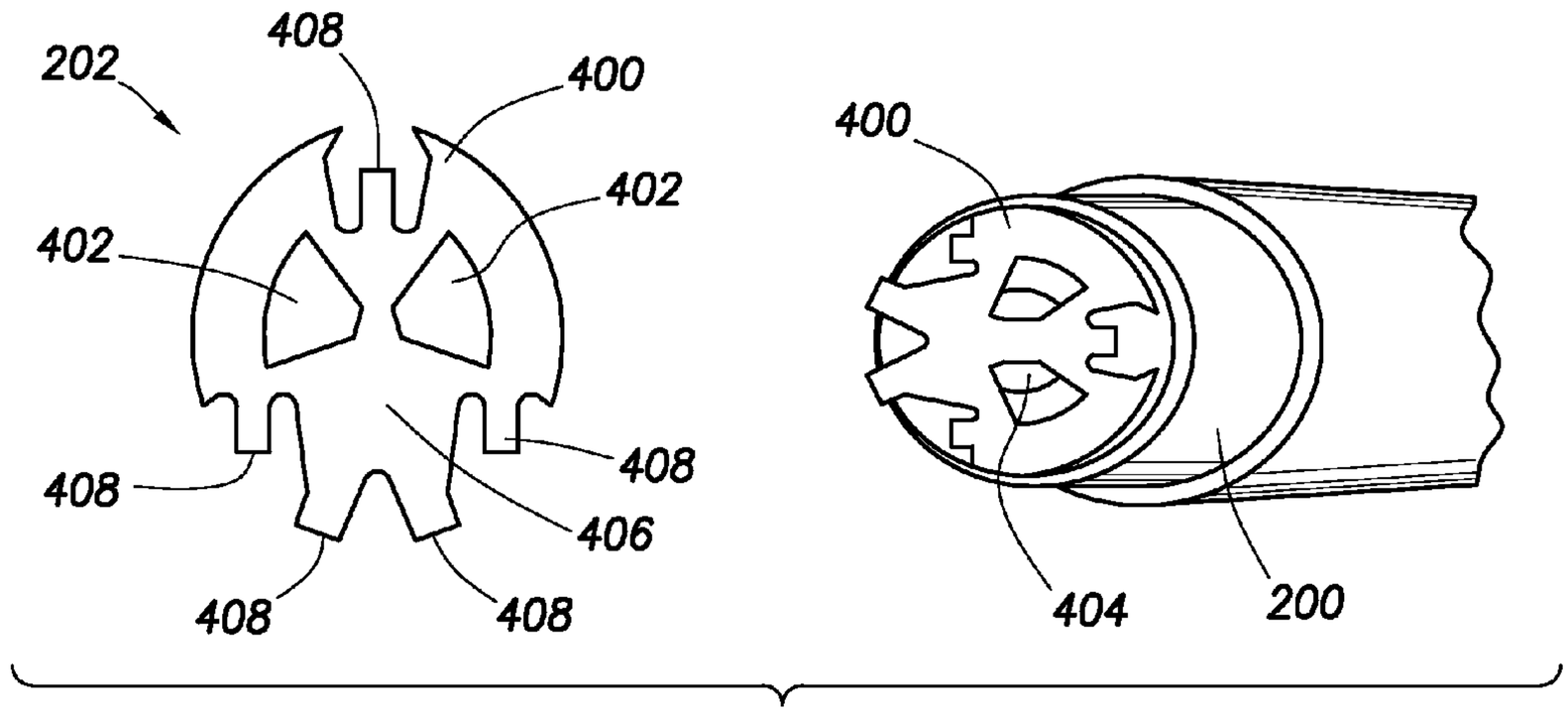

202
408
400
402
402
408
408
406
408
408
400
404
200

FIG.4

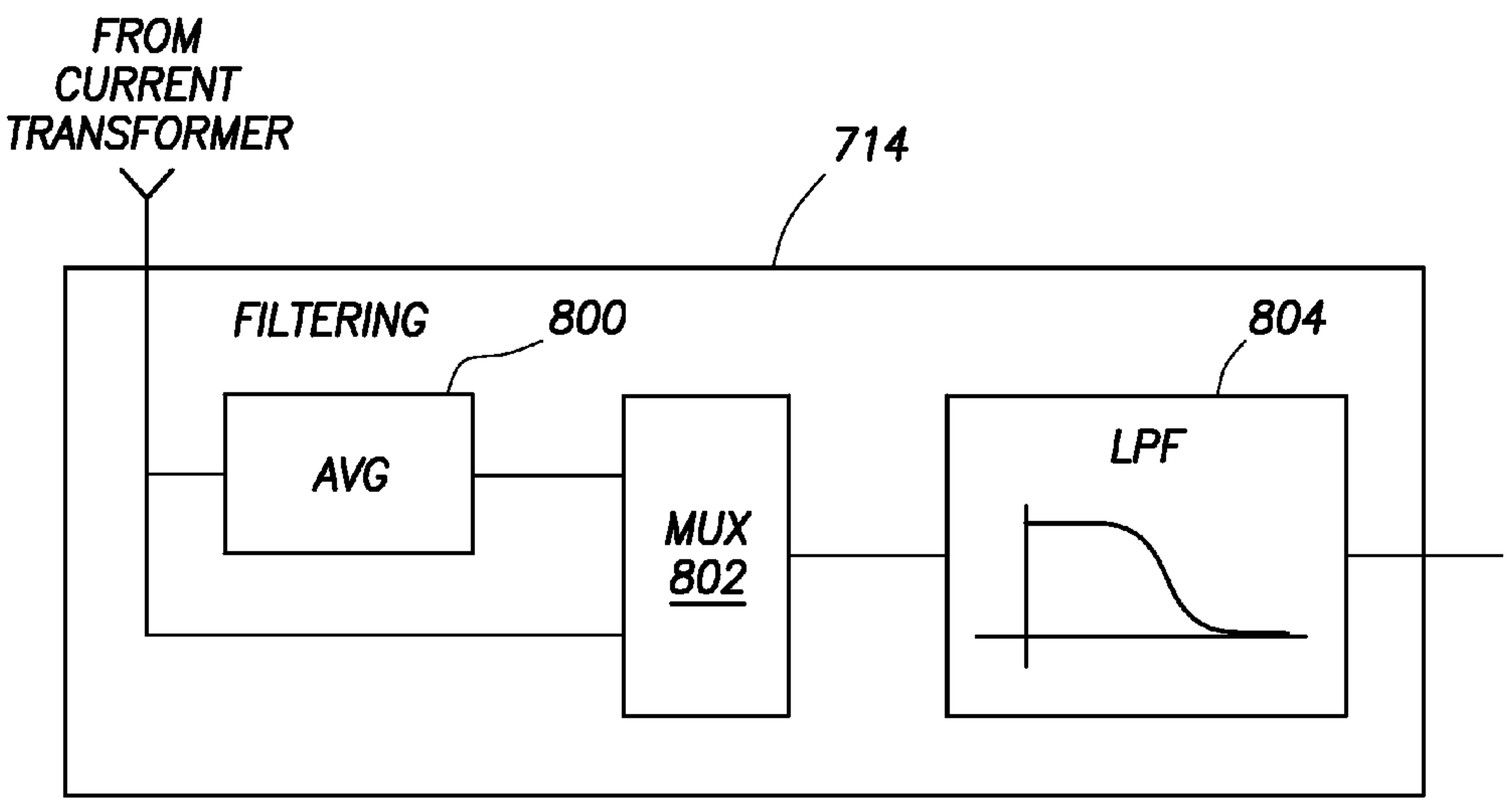

FROM CURRENT TRANSFORMER
714
FILTERING
800
804
AVG
MUX 802
LPF

FIG.8

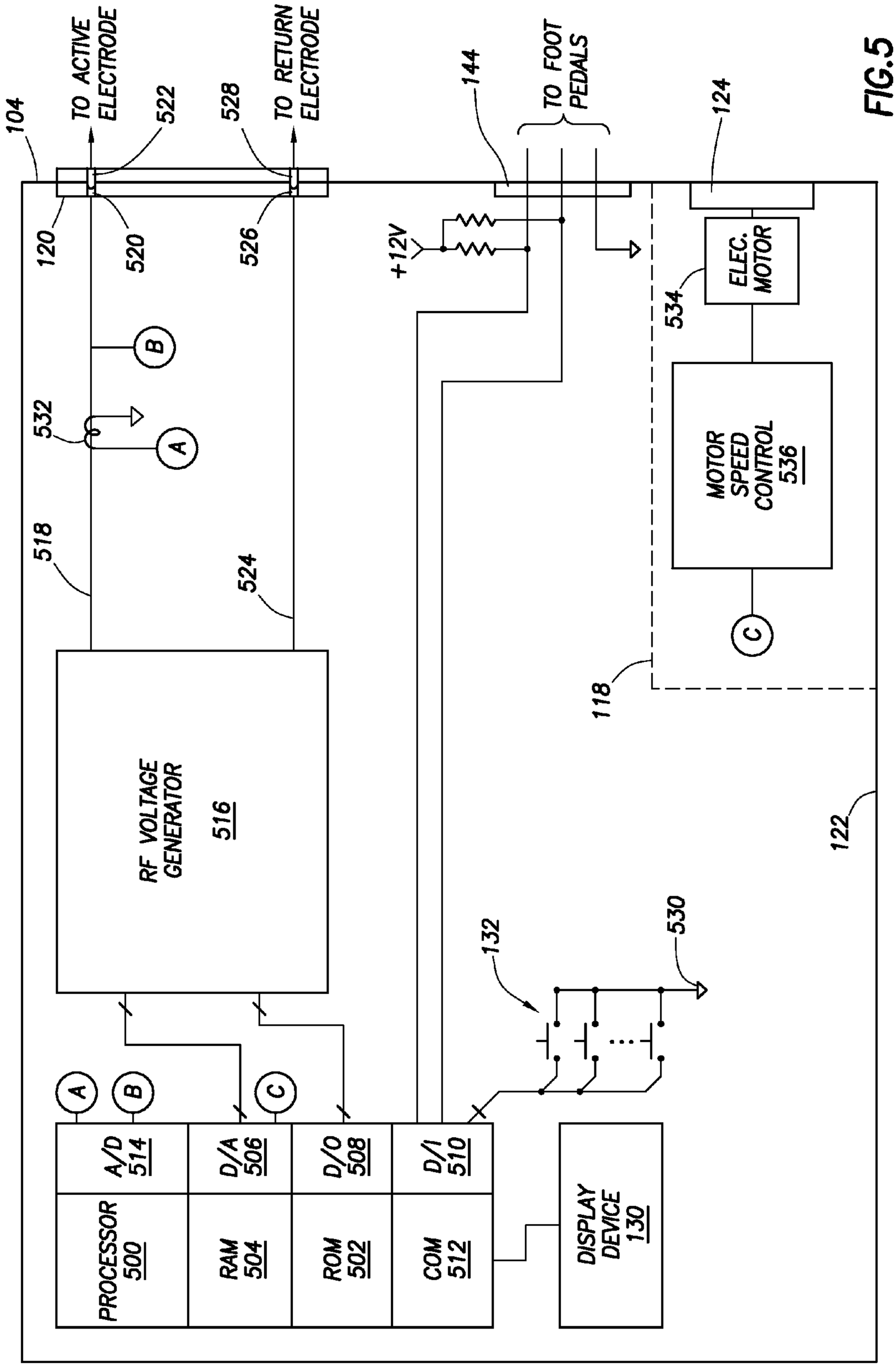

104
TO ACTIVE ELECTRODE
522
528
TO RETURN ELECTRODE
144
TO FOOT PEDALS
124
120
520
526
+12V
ELEC. MOTOR
534
B
532
A
518
524
MOTOR SPEED CONTROL 536
C
118
RF VOLTAGE GENERATOR 516
122
132
530
A
B
C
A/D 514
D/A 506
D/O 508
D/I 510
PROCESSOR 500
RAM 504
ROM 502
COM 512
DISPLAY DEVICE 130

FIG.5

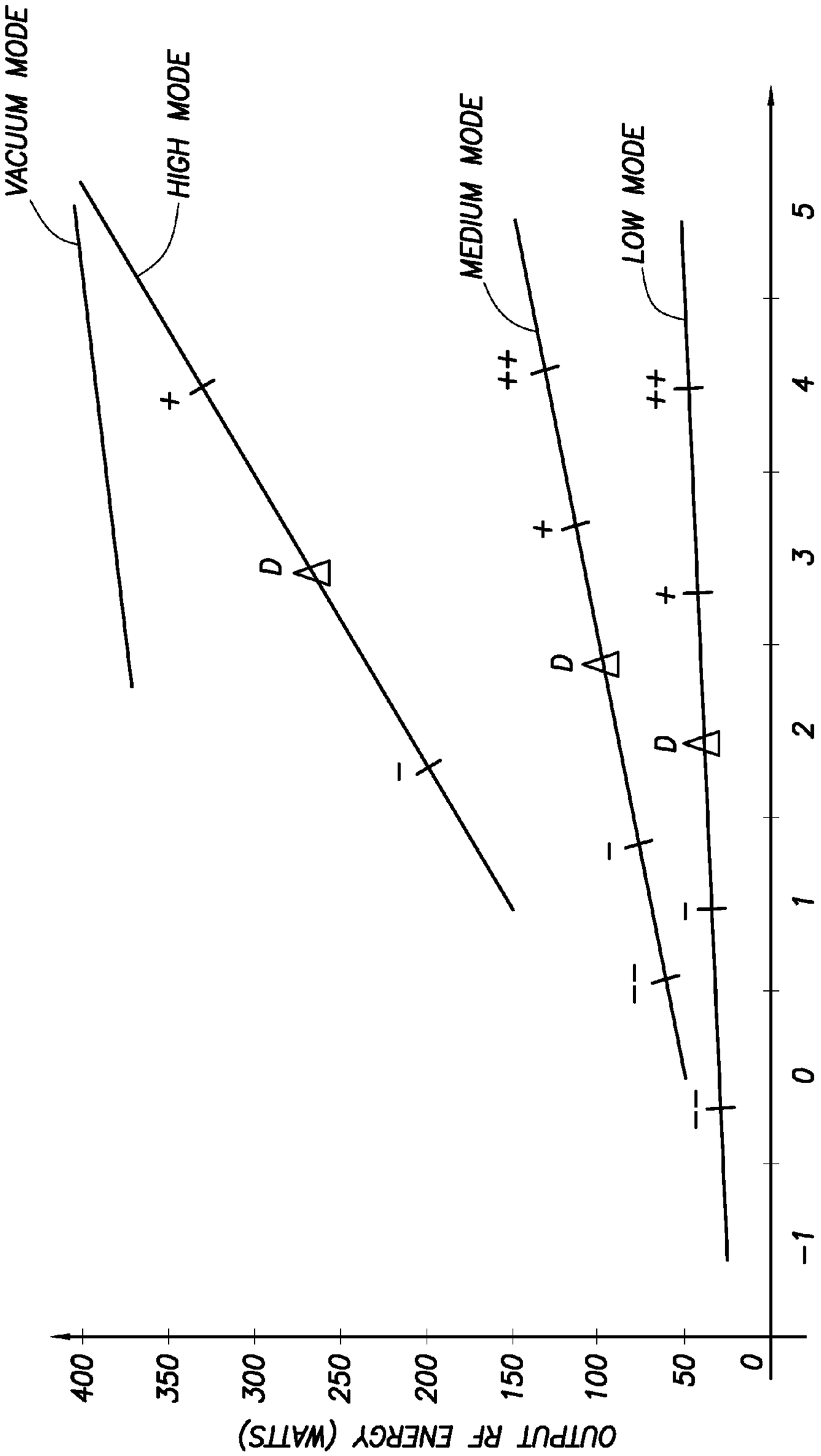

VACUUM MODE
HIGH MODE
MEDIUM MODE
LOW MODE
D
+
++
−
−−
5
4
3
2
1
0
−1
ASPIRATION FLOW RATE (PUMP SPEED SETTINGS)
400
350
300
250
200
150
100
50
0
OUTPUT RF ENERGY (WATTS)

FIG.6

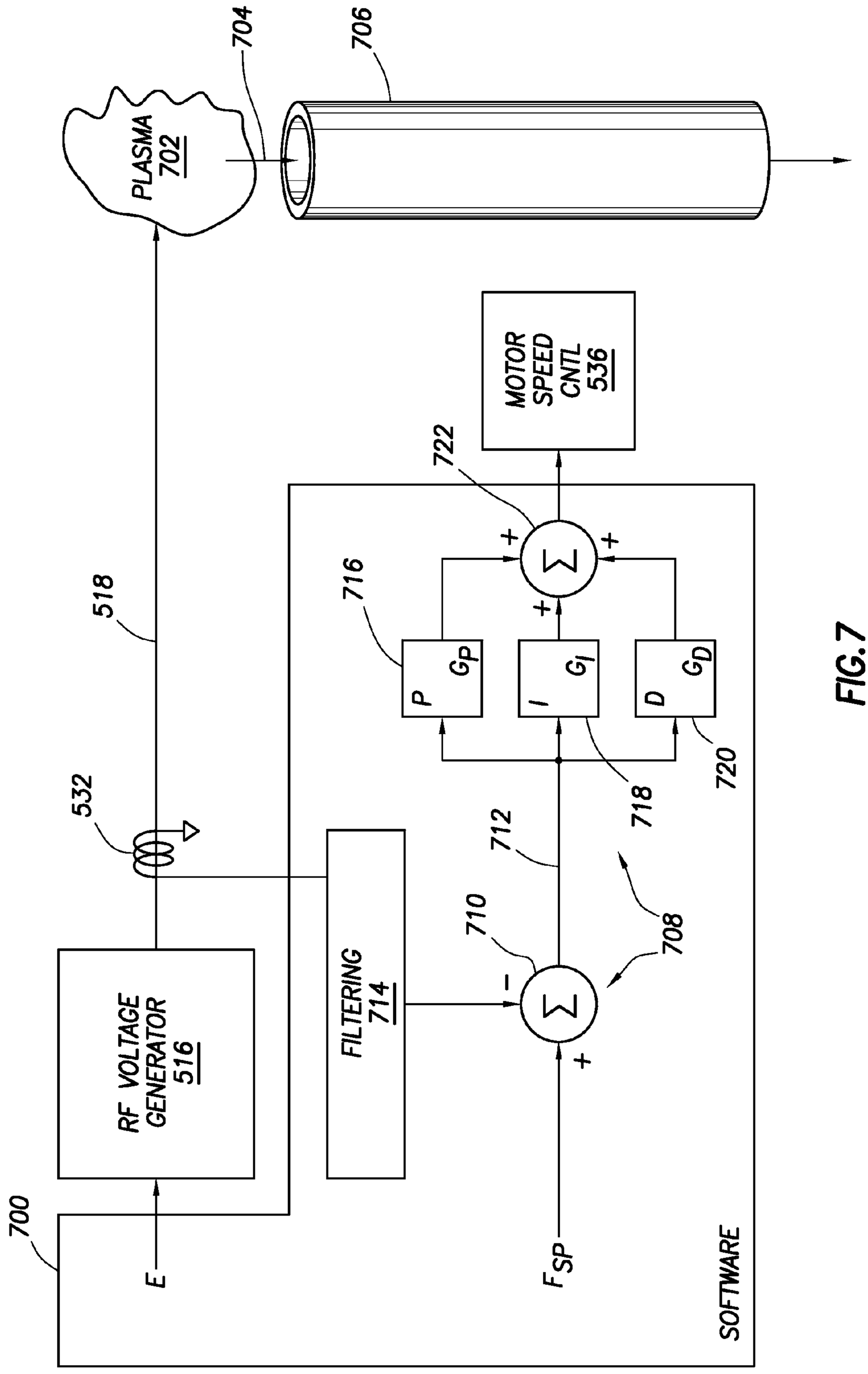

704
706
PLASMA
702
MOTOR
SPEED
CNTL
536
722
+
+
+
716
P
G_P
I
G_I
D
G_D
720
718
712
710
708
532
518
FILTERING
714
RF VOLTAGE
GENERATOR
516
700
E
F_{SP}
SOFTWARE

FIG.7

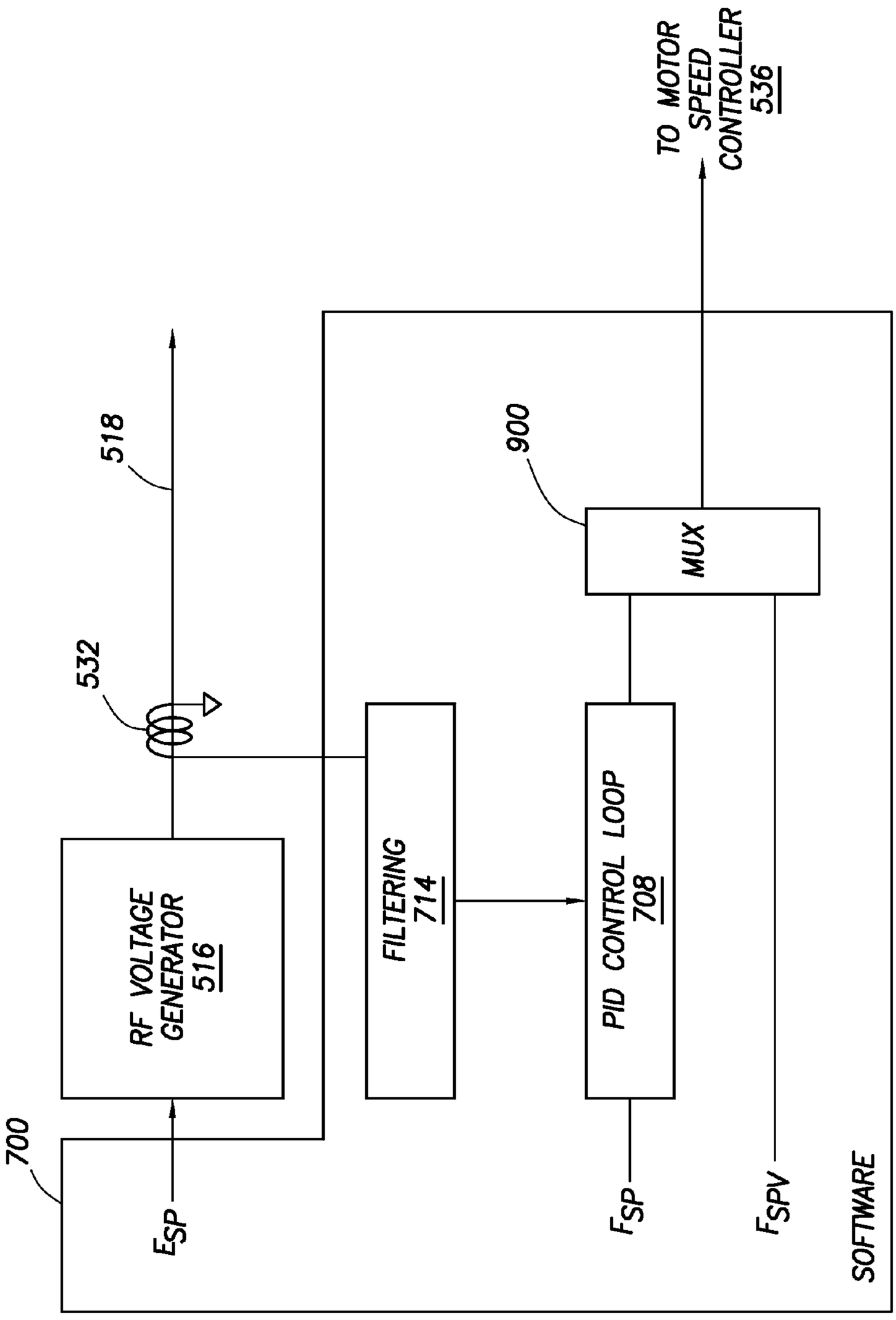

TO MOTOR SPEED CONTROLLER 536
518
900
MUX
532
RF VOLTAGE GENERATOR 516
FILTERING 714
PID CONTROL LOOP 708
700
E_{SP}
F_{SP}
F_{SPV}
SOFTWARE

FIG.9

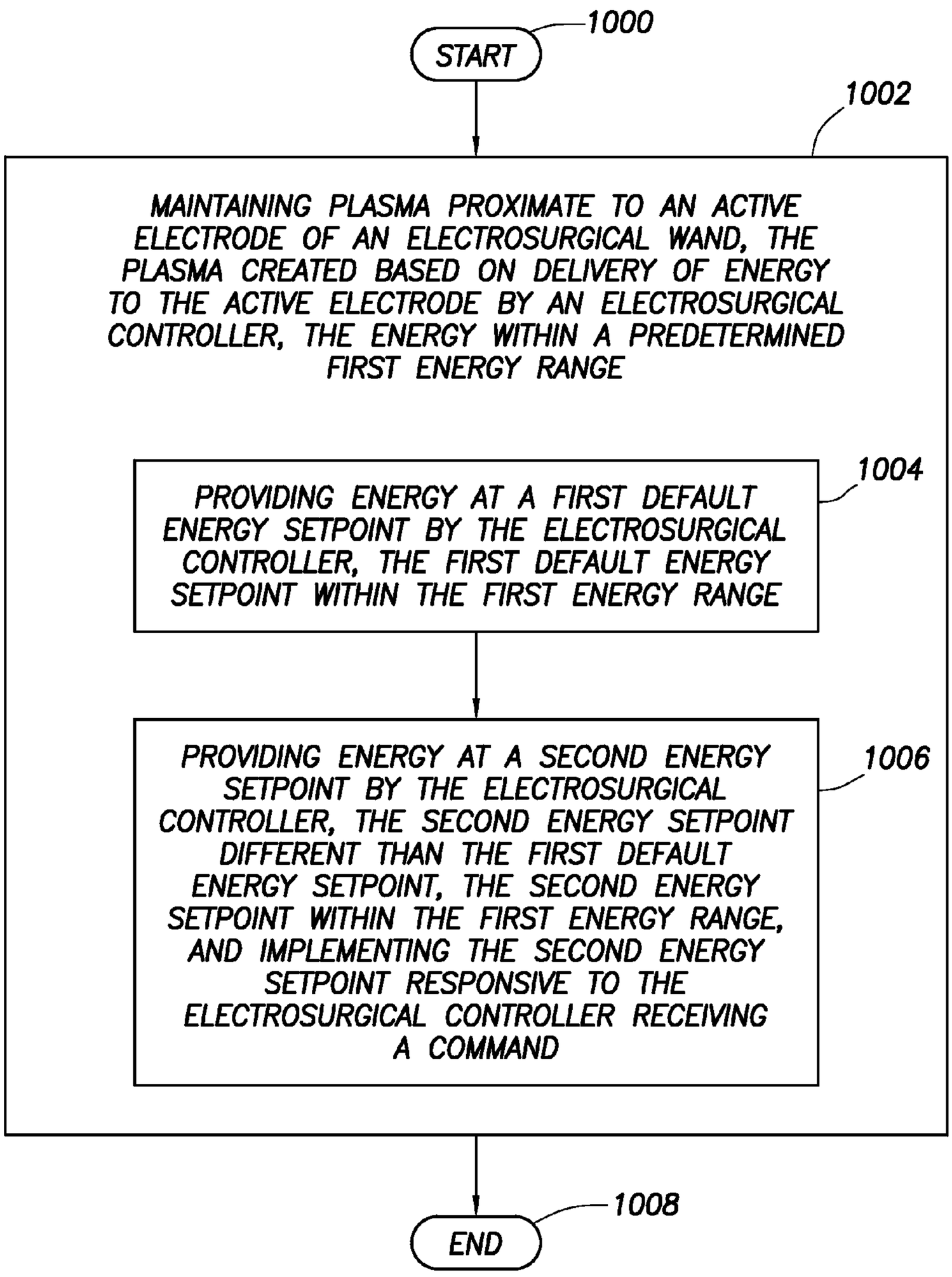
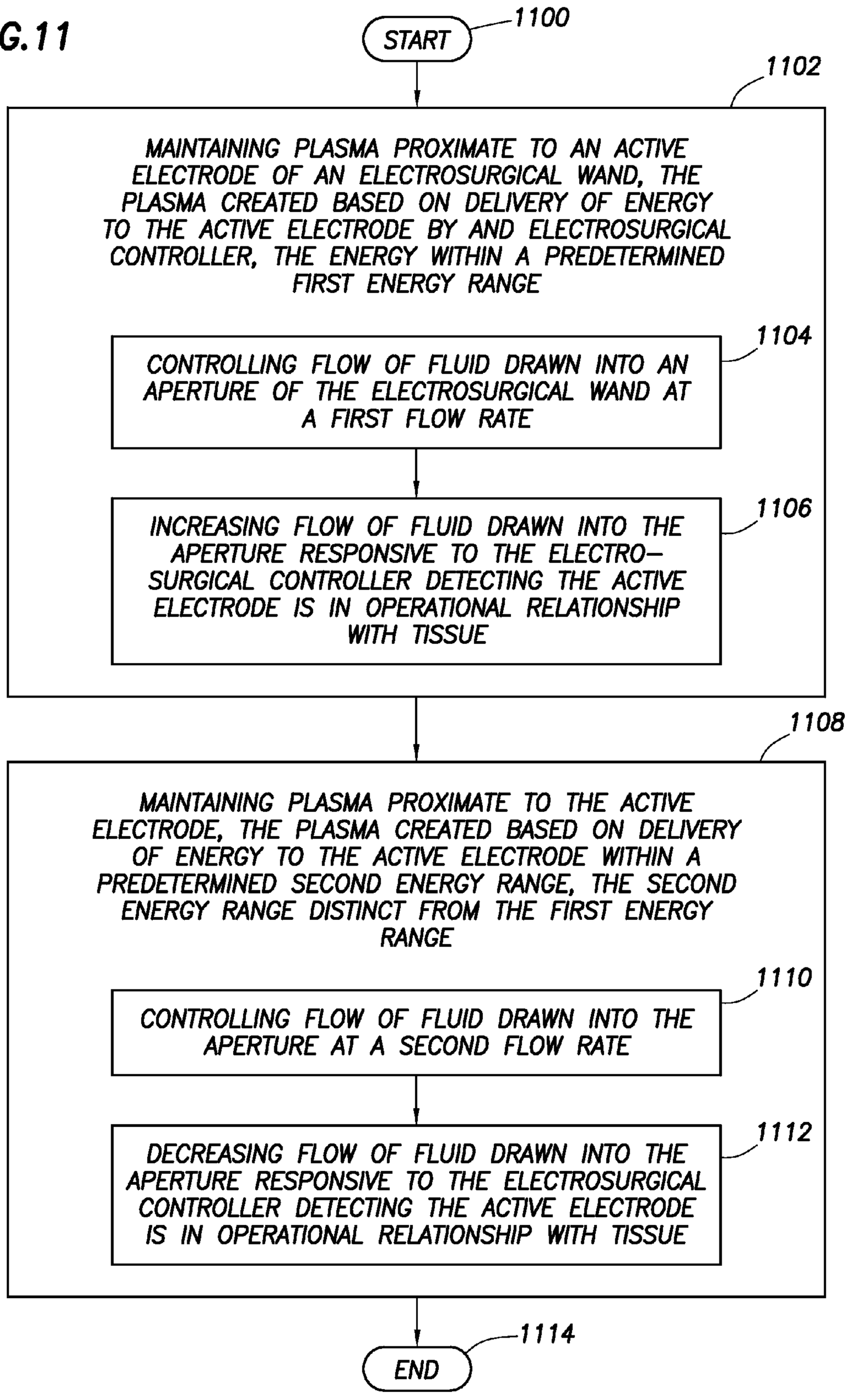

1000
START
1002
MAINTAINING PLASMA PROXIMATE TO AN ACTIVE ELECTRODE OF AN ELECTROSURGICAL WAND, THE PLASMA CREATED BASED ON DELIVERY OF ENERGY TO THE ACTIVE ELECTRODE BY AN ELECTROSURGICAL CONTROLLER, THE ENERGY WITHIN A PREDETERMINED FIRST ENERGY RANGE
1004
PROVIDING ENERGY AT A FIRST DEFAULT ENERGY SETPOINT BY THE ELECTROSURGICAL CONTROLLER, THE FIRST DEFAULT ENERGY SETPOINT WITHIN THE FIRST ENERGY RANGE
1006
PROVIDING ENERGY AT A SECOND ENERGY SETPOINT BY THE ELECTROSURGICAL CONTROLLER, THE SECOND ENERGY SETPOINT DIFFERENT THAN THE FIRST DEFAULT ENERGY SETPOINT, THE SECOND ENERGY SETPOINT WITHIN THE FIRST ENERGY RANGE, AND IMPLEMENTING THE SECOND ENERGY SETPOINT RESPONSIVE TO THE ELECTROSURGICAL CONTROLLER RECEIVING A COMMAND
1008
END

FIG. 10

FIG. 11


START
1100
1102
MAINTAINING PLASMA PROXIMATE TO AN ACTIVE ELECTRODE OF AN ELECTROSURGICAL WAND, THE PLASMA CREATED BASED ON DELIVERY OF ENERGY TO THE ACTIVE ELECTRODE BY AND ELECTROSURGICAL CONTROLLER, THE ENERGY WITHIN A PREDETERMINED FIRST ENERGY RANGE
1104
CONTROLLING FLOW OF FLUID DRAWN INTO AN APERTURE OF THE ELECTROSURGICAL WAND AT A FIRST FLOW RATE
1106
INCREASING FLOW OF FLUID DRAWN INTO THE APERTURE RESPONSIVE TO THE ELECTRO-SURGICAL CONTROLLER DETECTING THE ACTIVE ELECTRODE IS IN OPERATIONAL RELATIONSHIP WITH TISSUE
1108
MAINTAINING PLASMA PROXIMATE TO THE ACTIVE ELECTRODE, THE PLASMA CREATED BASED ON DELIVERY OF ENERGY TO THE ACTIVE ELECTRODE WITHIN A PREDETERMINED SECOND ENERGY RANGE, THE SECOND ENERGY RANGE DISTINCT FROM THE FIRST ENERGY RANGE
1110
CONTROLLING FLOW OF FLUID DRAWN INTO THE APERTURE AT A SECOND FLOW RATE
1112
DECREASING FLOW OF FLUID DRAWN INTO THE APERTURE RESPONSIVE TO THE ELECTROSURGICAL CONTROLLER DETECTING THE ACTIVE ELECTRODE IS IN OPERATIONAL RELATIONSHIP WITH TISSUE
1114
END

ELECTROSURGICAL METHODS AND SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

None.

BACKGROUND

Electrosurgical systems are used by physicians to perform specific functions during surgical procedures. Particular electrosurgical procedures may remove several different tissue types. For example, procedures involving the knee or shoulder may remove portions of cartilage, meniscus, and free floating and/or trapped tissue. In some cases, the removal may be a very slight removal, such as tissue sculpting, and in other cases the more aggressive removal of tissue is used. Removing each different tissue type, and/or aggressiveness, represents a different amount of applied energy, and in the related-art involves the use of different electrosurgical wands and different electrosurgical controllers. In some cases, a surgeon may forgo use of the correct wand, applied energy, and/or electrosurgical controller to reduce expenses of the procedure, when better clinical results may have been achieved using multiple electrosurgical wands, energies, and/or controllers.

Any advance that makes treatment easier for the surgeon, and achieves better results, would provide a competitive advantage.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of exemplary embodiments, reference will now be made to the accompanying drawings in which:

FIG. **1** shows an electrosurgical system in accordance with at least some embodiments;

FIG. **2** shows an elevation view of an electrosurgical wand in accordance with at least some embodiments;

FIG. **3** shows a cross-sectional elevation view of an electrosurgical wand in accordance with at least some embodiments;

FIG. **4** shows both an elevation view of screen electrode, and a perspective view of a distal end of an electrosurgical wand comprising the screen electrode, in accordance with at least some embodiments;

FIG. **5** shows an electrical block diagram of a controller in accordance with at least some embodiments;

FIG. **6** shows an example graph relating output RF energy and aspiration flow of various modes, including setpoints within each mode, in accordance with at least some embodiments;

FIG. **7** shows, in block diagram form, various control algorithms in accordance with at least some embodiments;

FIG. **8** shows, in block diagram form, filter algorithms in accordance with at least some embodiments;

FIG. **9** shows, in block diagram form, various control algorithms in accordance with at least some embodiments;

FIG. **10** shows a method in accordance with at least some embodiments; and

FIG. **11** shows a method in accordance with at least some embodiments.

NOTATION AND NOMENCLATURE

Certain terms are used throughout the following description and claims to refer to particular system components. As one skilled in the art will appreciate, companies that design and manufacture electrosurgical systems may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function.

In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to . . . ." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection or through an indirect connection via other devices and connections.

Reference to a singular item includes the possibility that there are plural of the same items present. More specifically, as used herein and in the appended claims, the singular forms "a," "an," "said" and "the" include plural references unless the context clearly dictates otherwise. It is further noted that the claims may be drafted to exclude any optional element. As such, this statement serves as antecedent basis for use of such exclusive terminology as "solely," "only" and the like in connection with the recitation of claim elements, or use of a "negative" limitation. Lastly, it is to be appreciated that unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

"Plasma" shall mean a low temperature gas formed of vapor bubbles or a vapor layer that is capable of emitting an ionized discharge.

"Ablation" shall mean removal of tissue based on tissue interaction with a plasma.

"Mode of ablation" shall refer to one or more characteristics of an ablation. Lack of ablation (i.e., a lack of plasma) shall not be considered a "mode of ablation." A mode which performs coagulation shall not be considered a "mode of ablation."

"Active electrode" shall mean an electrode of an electrosurgical wand which produces an electrically-induced tissue-altering effect when brought into contact with, or close proximity to, a tissue targeted for treatment.

"Return electrode" shall mean an electrode of an electrosurgical wand which serves to provide a current flow path for electrical charges with respect to an active electrode, and/or an electrode of an electrical surgical wand which does not itself produce an electrically-induced tissue-altering effect on tissue targeted for treatment.

"Electric motor" shall include alternating current (AC) motors, direct current (DC) motors, as well as stepper motors.

"Controlling flow of fluid" shall mean controlling a volume flow rate. Control of applied pressure to maintain a set point pressure (e.g., suction pressure) independent of volume flow rate of liquid caused by the applied pressure shall not be considered "controlling flow of fluid." However, varying applied pressure to maintain a set point volume flow rate of liquid shall be considered "controlling flow of fluid".

"Output energy" and "output RF energy" shall refer to the rate at which electrical energy is provided, transferred, or used over time.

"Energy range" shall refer to a lower limit output energy, upper limit output energy, and all the intervening output energies between the lower limit and the upper limit. A first energy range and a second energy range may overlap (e.g., the lower limit of the second energy range may be an intervening energy in the first energy range), but so long as at least a portion of each energy range is mutually exclusive,

the two energy ranges shall be considered distinct for purposes of the specification and claims.

"Energy setpoint" shall refer to a specific output energy that falls within an energy range.

A proximity that is in "operational relationship with tissue" shall mean a proximity wherein the tissue interacting with a plasma affects the impedance presented by the plasma and surrounding fluid to electrical current flow through the plasma and surrounding fluid.

A fluid conduit said to be "within" an elongate shaft shall include not only a separate fluid conduit that physically resides within an internal volume of the elongate shaft, but also situations where the internal volume of the elongate shaft is itself the fluid conduit.

Where a range of values is provided, it is understood that every intervening value, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the invention. Also, it is contemplated that any optional feature of the inventive variations described may be set forth and claimed independently, or in combination with any one or more of the features described herein.

All existing subject matter mentioned herein (e.g., publications, patents, patent applications and hardware) is incorporated by reference herein in its entirety except insofar as the subject matter may conflict with that of the present invention (in which case what is present herein shall prevail). The referenced items are provided solely for their disclosure prior to the filing date of the present application. Nothing herein is to be construed as an admission that the present invention is not entitled to antedate such material by virtue of prior invention.

DETAILED DESCRIPTION

Before the various embodiments are described in detail, it is to be understood that this invention is not limited to particular variations set forth herein as various changes or modifications may be made, and equivalents may be substituted, without departing from the spirit and scope of the invention. As will be apparent to those of skill in the art upon reading this disclosure, each of the individual embodiments described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other several embodiments without departing from the scope or spirit of the present invention. In addition, many modifications may be made to adapt a particular situation, material, composition of matter, process, process act(s) or step(s) to the objective(s), spirit or scope of the present invention. All such modifications are intended to be within the scope of the claims made herein.

The various embodiments are directed to electrosurgical methods and related electrosurgical systems. In particular, the various embodiments are directed to an electrosurgical system having multiple modes of ablation that are configured for treatment of a specific targeted tissue type or electrosurgical effect desired, and implemented by a single electrosurgical wand and a single electrosurgical controller. In example embodiments, the multiple modes of ablation are implemented by a single active electrode on the electrosurgical wand, and within each mode multiple energy setpoints may be implemented. The specification first turns to an illustrative system to orient the reader.

FIG. **1** illustrates an electrosurgical system **100** in accordance with at least some embodiments. In particular, the electrosurgical system **100** comprises an electrosurgical wand **102** (hereinafter "wand **102**") coupled to an electrosurgical controller **104** (hereinafter "controller **104**"). The wand **102** comprises an elongate shaft **106** that defines distal end **108**. The elongate shaft **106** further defines a handle or proximal end **110**, where a physician grips the wand **102** during surgical procedures. The wand **102** further comprises a flexible multi-conductor cable **112** housing one or more electrical leads (not specifically shown in FIG. **1**), and the flexible multi-conductor cable **112** terminates in a wand connector **114**. As shown in FIG. **1**, the wand **102** couples to the controller **104**, such as by a controller connector **120** on an outer surface of the enclosure **122** (in the illustrative case of FIG. **1**, the front surface).

Though not visible in the view of FIG. **1**, in some embodiments the wand **102** has one or more internal fluid conduits coupled to externally accessible tubular members. As illustrated, the wand **102** has a flexible tubular member **116**, used to provide aspiration at the distal end **108** of the wand. In accordance with various embodiments, the tubular member **116** couples to a peristaltic pump **118**, which peristaltic pump **118** is illustratively shown as an integral component with the controller **104** (i.e., residing at least partially within the enclosure **122** of the controller **104**). In other embodiments, an enclosure for the peristaltic pump **118** may be separate from the enclosure **122** for the controller **104** (as shown by dashed lines in the figure), but in any event the peristaltic pump is operatively coupled to the controller **104**.

The peristaltic pump **118** comprises a rotor portion **124** (hereafter just "rotor **124**") as well as a stator portion **126** (hereafter just "stator **126**"). The flexible tubular member **116** couples within the peristaltic pump **118** between the rotor **124** and the stator **126**, and movement of the rotor **124** against the flexible tubular member **116** causes fluid movement toward the discharge **128**. While the illustrative peristaltic pump **118** is shown with a two-head rotor **124**, varying types of peristaltic pumps **118** may be used (e.g., a five-head peristaltic pump). In the context of the various embodiments, the peristaltic pump **118** creates a volume-controlled aspiration from a surgical field at the distal end **108** of the wand **102**, with the control based on a speed of the rotor **124**, as commanded by the controller **104**.

Still referring to FIG. **1**, a display device or interface device **130** is visible through the enclosure **122** of the controller **104**, and in some embodiments a user may select operational modes of the controller **104** by way of the interface device **130** and related buttons **132**. For example, using one or more of the buttons **132** the surgeon may select among modes of ablation, such as: a low mode which may be used for removal of portions of cartilage; a medium mode which may be used for removal of meniscus; a high mode for aggressive removal of tissue; and a vacuum mode for removal free floating and/or trapped tissue. The various modes of ablation are discussed more thoroughly below.

In some embodiments the electrosurgical system **100** also comprises a foot pedal assembly **134**. The foot pedal assembly **134** may comprise one or more pedal devices **136** and **138**, a flexible multi-conductor cable **140** and a pedal connector **142**. While only two pedal devices **136** and **138** are shown, one or more pedal devices may be implemented. The enclosure **122** of the controller **104** may comprise a corresponding connector **144** that couples to the pedal connector **142**. A physician may use the foot pedal assembly **134** to control various aspects of the controller **104**, such as the mode of ablation. For example, pedal device **136** may be used for on-off control of the application of radio frequency (RF) output energy to the wand **102**, and more specifically for control of output energy in a mode of ablation. Further,

pedal device **138** may be used to control and/or set the mode of ablation of the electrosurgical system. For example, actuation of pedal device **138** may switch between energy levels created by the controller **104** and aspiration volume created by the peristaltic pump **118**. In certain embodiments, control of the various operational or performance aspects of controller **104** may be activated by selectively depressing finger buttons located on handle **110** of wand **102** (the finger buttons not specifically shown so as not to unduly complicate the figure).

The electrosurgical system **100** of the various embodiments may have a variety of modes of ablation which employ Coblation® technology. In particular, the assignee of the present disclosure is the owner of Coblation® technology. Coblation® technology involves the application of a radio frequency (RF) signal between one or more active electrodes and one or more return electrodes of the wand **102** to develop high electric field intensities in the vicinity of the target tissue. The electric field intensities may be sufficient to vaporize an electrically conductive fluid over at least a portion of the one or more active electrodes in the region between the one or more active electrodes and the target tissue. The electrically conductive fluid may be inherently present in the body, such as blood, or in some cases extracelluar or intracellular fluid. In other embodiments, the electrically conductive fluid may be a liquid or gas, such as isotonic saline. In some embodiments, such as surgical procedures involving a knee or shoulder, the electrically conductive fluid is delivered in the vicinity of the active electrode and/or to the target site by a delivery system separate and apart from the system **100**.

When the electrically conductive fluid is heated to the point that the atoms of the fluid vaporize faster than the atoms recondense, a gas is formed. When sufficient energy is applied to the gas, the atoms collide with each other causing a release of electrons in the process, and an ionized gas or plasma is formed (the so-called "fourth state of matter"). Stated otherwise, plasmas may be formed by heating a gas and ionizing the gas by driving an electric current through the gas, or by directing electromagnetic waves into the gas. The methods of plasma formation give energy to free electrons in the plasma directly, electron-atom collisions liberate more electrons, and the process cascades until the desired degree of ionization is achieved. A more complete description of plasma can be found in Plasma Physics, by R. J. Goldston and P. H. Rutherford of the Plasma Physics Laboratory of Princeton University (1995), the complete disclosure of which is incorporated herein by reference.

As the density of the plasma becomes sufficiently low (i.e., less than approximately 1020 atoms/cm^3 for aqueous solutions), the electron mean free path increases such that subsequently injected electrons cause impact ionization within the plasma. When the ionic particles in the plasma layer have sufficient energy (e.g., 3.5 electron-Volt (eV) to 5 eV), collisions of the ionic particles with molecules that make up the target tissue break molecular bonds of the target tissue, dissociating molecules into free radicals which then combine into gaseous or liquid species. By means of the molecular dissociation (as opposed to thermal evaporation or carbonization), the target tissue is volumetrically removed through molecular dissociation of larger organic molecules into smaller molecules and/or atoms, such as hydrogen, oxygen, oxides of carbon, hydrocarbons and nitrogen compounds. The molecular dissociation completely removes the tissue structure, as opposed to dehydrating the tissue material by the removal of liquid within the cells of the tissue and extracellular fluids, as occurs in related art electrosurgical desiccation and vaporization. A more detailed description of the molecular dissociation can be found in commonly assigned U.S. Pat. No. 5,697,882 the complete disclosure of which is incorporated herein by reference.

The energy density produced by electrosurgical system **100** at the distal end **108** of the wand **102** may be varied by adjusting a variety of factors, such as: the number of active electrodes; electrode size and spacing; electrode surface area; asperities and/or sharp edges on the electrode surfaces; electrode materials; applied voltage; current limiting of one or more electrodes (e.g., by placing an inductor in series with an electrode); electrical conductivity of the fluid in contact with the electrodes; density of the conductive fluid; and other factors. Accordingly, these factors can be manipulated to control the energy level of the excited electrons. Since different tissue structures have different molecular bonds, the electrosurgical system **100** may be configured to produce energy sufficient to break the molecular bonds of certain tissue but insufficient to break the molecular bonds of other tissue. For example, fatty tissue (e.g., adipose) has double bonds that require an energy level higher than 4 eV to 5 eV (i.e., on the order of about 8 eV) to break. Accordingly, the Coblation® technology in some modes of operation does not ablate such fatty tissue; however, the Coblation® technology at the lower energy levels may be used to effectively ablate cells to release the inner fat content in a liquid form. Other modes of operation may have increased energy such that the double bonds can also be broken in a similar fashion as the single bonds (e.g., increasing voltage or changing the electrode configuration to increase the current density at the electrodes). A more complete description of the various phenomena can be found in commonly assigned U.S. Pat. Nos. 6,355,032; 6,149,120 and 6,296,136, the complete disclosures of which are incorporated herein by reference.

The inventors now present a theoretical underpinning to explain how multiple modes of ablation may be implemented with a single wand **102** and a single controller **104**. However, the theoretical basis is presented merely as one possible explanation, and shall not be read as a limitation on the operation of the various embodiments. Another theoretical basis may be equivalently proffered, and attempting to explain operation of a device using a different theoretical basis shall not obviate whether such a device falls within the appended claims. In particular, the electrode circuit, including the plasma created and maintained in operational relationship to an active electrode of a wand, the fluid between the active and return electrode, and the electrode-fluid interface, has or presents a certain amount of impedance to the flow of output energy away from the active electrode toward a return electrode. The impedance presented by the electrode circuit may be dependent on many factors, including but not limited to the thickness and volume of the plasma itself, the surface area of the active electrode not covered by a vapor layer and directly in contact with the conductive fluid, and the volume flow of fluid and/or gasses away from the location of the plasma.

In related-art devices, only the vacuum pressure used for aspiration is controlled (e.g., the vacuum available at wall socket connections in a hospital operating room). However, the vacuum available at a wall socket connection may be highly variable from room to room, and in many cases within the same room over time. Moreover, control of vacuum pressure applied does not imply a controlled volume

of aspiration. Thus, while related-art devices may control vacuum pressure, they do not control volume flow rate of the aspiration.

The inventors have found that the relationship of the volume of flow of fluid of the aspiration to output energy dissipation is counter to the prevailing understanding. That is, related-art devices and methods operate under the assumption that a generally high flow rate more rapidly carries away output energy and thus reduces thermal aspects of the ablation. By contrast, the inventors have found that high volume flow of aspiration tends to cause higher output energy dissipation overall. With respect to the plasma, the inventors have found that higher volume flow rates drive both the impedance of the plasma and of the electrode circuit down, which increases the output energy dissipation. Moreover, higher volume flow rates cause the plasma to "flicker". Consider an analogy in the form of a candle. If a candle is burning in a room with very little air movement, the flame may be a steady shape, size, and location. However, in the presence of airflow (e.g., a ceiling fan), the flame tends to "flicker". If one considers that during periods of time of plasma collapse (i.e., absence of plasma) greater output energy is dissipated in a thermal mode through the surrounding fluid and tissue, "flickering" plasma caused by high volume flow rate may result in more output energy dissipation in the tissue and surrounding fluid, rather than less. That is, not only will the "flickering" plasma present a lower average impedance and thus higher output energy dissipation, but also the thermal mode that dominates during momentary plasma collapse present in "flicker" causes higher output energy dissipation than periods of time when plasma is present.

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Accordingly, the embodiments described herein are related to a system wherein the impedance at the electrode is (directly or indirectly) monitored and used as a parameter to control the volume flow rate of aspiration in order to control the plasma field in a way that is desirable for a specific tissue type or procedure. For example, in some modes of ablation if the impedance at the active electrode is observed to decrease at a point during a procedure (possibly indicating plasma instability), the system may direct the peristaltic pump to decrease the aspiration flow rate to enable the plasma field to stabilize. From another perspective, it may be desirable to measure the RF electrical current applied to the active electrode and adjust the peristaltic pump (and thus the fluid flow) in order to keep the RF electrical current at a certain predetermined and desired level associated with the mode of ablation. Reference is also made to commonly assigned U.S. Pat. No. 8,192,424, titled "ELECTROSURGICAL SYSTEM WITH SUCTION CONTROL APPARTUS, SYSTEM AND METHOD" the complete disclosure of which is incorporated herein by reference for all purposes. Conversely, it may be desirable in certain modes of ablation to trade off plasma field stability in order to have higher overall aspiration fluid flow volume in order to remove bubbles and debris from the surgical field.

Based on the theoretical underpinning in the paragraphs above, the various embodiments are directed to systems and related methods implementing at least two modes of ablation during an electrosurgical procedure, in some embodiments using a single wand (and in some cases a single active electrode) along with a single controller. In a particular embodiment, four different modes of ablation may be implemented, such as: a "low mode" which may be used for the treatment and removal of portions of sensitive tissue such as portions of articular cartilage; a "medium mode" which may be used for the treatment and removal of meniscus; a "high mode" for aggressive removal of tissue of any kind; and a "vacuum mode" for removal free floating and/or trapped tissue. Moreover, some example systems implement multiple energy/flow setpoints within a single mode of ablation. For example, the "low mode" of ablation may comprise a default setpoint energy/flow, but a surgeon may choose an increased energy/flow setpoint within the energy range associated with the "low mode" of ablation. Likewise, the surgeon may choose a decreased energy/flow setpoint in relation to the default setpoint yet still within the energy range associated with the "low mode" of ablation. More detail regarding the illustrative modes of ablation, and setpoints within each mode, is presented below, after a discussion of an illustrative wand **102** and internal components of the controller **104**.

FIG. **2** shows an elevation view of wand **102** in accordance with example systems. In particular, wand **102** comprises elongate shaft **106** which may be flexible or rigid, a handle **110** coupled to the proximal end of the elongate shaft **106**, and an electrode support member **200** coupled to the distal end of elongate shaft **106**. Also visible in FIG. **2** is the flexible tubular member **116** extending from the wand **102** and the multi-conductor cable **112**. The wand **102** comprises an active electrode **202** disposed on the distal end **108** of the elongate shaft **106**. Active electrode **202** may be coupled to an active or passive control network within controller **104** (FIG. **1**) by means of one or more insulated electrical connectors (not shown) in the multi-conductor cable **112**. The active electrode **202** is electrically isolated from a common or return electrode **204** which is disposed on the shaft proximally of the active electrode **202**, in some example systems within 1 millimeter (mm) to 25 mm of the distal tip. Proximally from the distal tip, the return electrode **204** is concentric with the elongate shaft **106** of the wand **102**. The support member **200** is positioned distal to the return electrode **204** and may be composed of an electrically insulating material such as epoxy, plastic, ceramic, silicone, glass or the like. Support member **200** extends from the

distal end **108** of elongate shaft **106** (usually about 1 to 20 mm) and provides support for active electrode **202**.

FIG. **3** shows a cross-sectional elevation view of the wand **102** in accordance with example embodiments. In particular, wand **102** comprises a suction lumen **300** defined within the elongate shaft **106**. In the example wand **102** of FIG. **3**, the inside diameter of the elongate shaft **106** defines the section lumen **300**, but in other cases a separate tubing within the elongate shaft **106** may define the suction lumen **300**. The suction lumen **300** may be used for aspirating excess fluids, bubbles, tissue fragments, and/or products of ablation from the target site proximate to the active electrode **202**. Suction lumen **300** extends into the handle **110** and fluidly couples to the flexible tubular member **116** for coupling to the peristaltic pump **118**. Handle **110** also defines an inner cavity **302** within which electrical conductors **210** may reside, where the electrical conductors **210** may extend into the multi-conductor cable **112** and ultimately couple to the controller **104**. The electrical conductors likewise extend through the elongate shaft and couple, one each, to the return electrode **204** and the active electrode **202**, but the electrical conductors **210** are not shown to reside within the elongate shaft **106** so as not to unduly complicate the figure.

In some systems, the wand **102** may further comprise a temperature measurement device **304** in operational relationship to the flexible tubular member **116**. As illustrated in FIG. **3**, the temperature measurement device resides within the inner cavity **302** defined by the handle **110**, but the temperature measurement device may be placed at any suitable location. The temperature measurement device **304** is used to directly or indirectly measure the temperature of the fluid within the tubular member **116**. As illustrated, the temperature measurement device **304** abuts an outer surface of the tubular member **116** such that as fluids travel within the tubular member **116** past the location of the temperature measurement device **304**, localized temperature changes can be read. The temperature measurement device **304** may take any suitable form, such as a resistive thermal device (RTD), a thermistor, an optical temperature probe, or a thermocouple. The temperature measurement device may be useful in a variety of operational circumstances, such as clog detection discussed more below.

FIG. **4** shows an elevation view of an example active electrode (on the left), as well as a perspective view of the distal end of wand **102** (on the right), in accordance with example systems. In particular, active electrode **202** may be an active screen electrode **400** as shown in FIG. **4**. Screen electrode **400** may comprise a conductive material, such as tungsten, titanium, molybdenum, platinum, or the like. Screen electrode **400** may have a diameter in the range of about 0.5 to 8 mm, in some cases about 1 to 4 mm, and a thickness of about 0.05 to about 2.5 mm, in some cases about 0.1 to 1 mm. Screen electrode **400** may comprise a plurality of apertures **402** configured to rest over an aperture or distal opening **404** of the suction lumen. Apertures **402** are designed to enable the passage of aspirated excess fluids, bubbles, and gases from the ablation site and are large enough to enable ablated tissue fragments to pass through into suction lumen **206** (FIG. **3**). As shown, screen electrode **400** has an irregular shape which increases the edge to surface-area ratio of the screen electrode **400**. A large edge to surface-area ratio increases the ability of screen electrode **400** to initiate and maintain a plasma layer in conductive fluid because the edges generate higher current densities, which a large surface area electrode tends to dissipate power into the conductive media.

In the representative embodiment shown in FIG. **4**, screen electrode **400** comprises a body **406** that rests over insulative support member **200** and the distal opening **404** to suction lumen **206**. Screen electrode **400** further comprises tabs **408**, in the example screen electrode **400** of FIG. **4**, five tabs **408** are shown. The tabs **408** may rest on, be secured to, and/or be embedded in insulative support member **200**. In certain embodiments, electrical connectors extend through insulative support member **200** and are coupled (i.e., via adhesive, braze, weld, or the like) to one or more of tabs **408** in order to secure screen electrode **400** to the insulative support member **200** and to electrically couple screen electrode **400** to controller **104** (FIG. **1**). In example systems, screen electrode **400** forms a substantially planar tissue treatment surface for smooth resection, ablation, and sculpting of the meniscus, cartilage, and other tissues. In reshaping cartilage and meniscus, the physician often desires to smooth the irregular and ragged surface of the tissue, leaving behind a substantially smooth surface. For these applications, a substantially planar screen electrode treatment surface provides the desired effect. The specification now turns to a more detailed description of the controller **104**.

FIG. **5** shows an electrical block diagram of controller **104** in accordance with at least some embodiments. In particular, the controller **104** comprises a processor **500**. The processor **500** may be a microcontroller, and therefore the microcontroller may be integral with read-only memory (ROM) **502**, random access memory (RAM) **504**, digital-to-analog converter (D/A) **506**, analog-to-digital converter (A/D) **514**, digital outputs (D/O) 508, and digital inputs (D/I) **510**. The processor **500** may further provide one or more externally available peripheral busses, such as a serial bus (e.g., I^2C), parallel bus, or other bus and corresponding communication mode. The processor **500** may further be integral with communication logic **512** to enable the processor **500** to communicate with external devices, as well as internal devices, such as display device **130**. Although in some embodiments the processor **500** may be implemented in the form of a microcontroller, in other embodiments the processor **500** may be implemented as a standalone central processing unit in combination with individual RAM, ROM, communication, A/D, D/A, D/O, and D/I devices, as well as communication hardware for communication to peripheral components.

ROM **502** stores instructions executable by the processor **500**. In particular, the ROM **502** may comprise a software program that, when executed, causes the controller to implement two or more modes of ablation, including increasing and decrease peristaltic pump speed responsive to various feedback parameters (discussed more below). The RAM **504** may be the working memory for the processor **500**, where data may be temporarily stored and from which instructions may be executed. Processor **500** couples to other devices within the controller **104** by way of the digital-to-analog converter **506** (e.g., in some embodiment the RF voltage generator **516**), digital outputs **508** (e.g., in some embodiment the RF voltage generator **516**), digital inputs **510** (e.g., interface devices such as push button switches **132** or foot pedal assembly **134** (FIG. **1**)), and communication device **512** (e.g., display device **130**).

Voltage generator **516** generates an alternating current (AC) voltage signal that is coupled to active electrode **202** of the wand **102** (FIG. **3**). In some embodiments, the voltage generator defines an active terminal **518** which couples to electrical pin **520** in the controller connector **120**, electrical pin **522** in the wand connector **114**, and ultimately to the active electrode **202** (FIG. **3**). Likewise, the voltage genera-

tor defines a return terminal **524** which couples to electrical pin **526** in the controller connector **120**, electrical pin **528** in the wand connector **114**, and ultimately to the return electrode **204** (also see FIG. **3**). Additional active terminals and/or return terminals may be used. The active terminal **518** is the terminal upon which the voltages and electrical currents are induced by the voltage generator **516**, and the return terminal **524** provides a return path for electrical currents. It would be possible for the return terminal **524** to provide a common or ground being the same as the common or ground within the balance of the controller **104** (e.g., the common **530** used on push-buttons **132**), but in other embodiments the voltage generator **516** may be electrically "floated" from the balance of the controller **104**, and thus the return terminal **524**, when measured with respect to the common or earth ground (e.g., common **530**) may show a voltage; however, an electrically floated voltage generator **516** and thus the potential for voltage readings on the return terminals **524** relative to earth ground does not negate the return terminal status of the terminal **524** relative to the active terminal **518**.

The AC voltage signal generated and applied between the active terminal **518** and return terminal **524** by the voltage generator **516** is RF energy that, in some embodiments, has a frequency of between about 5 kilo-Hertz (kHz) and 20 Mega-Hertz (MHz), in some cases being between about 30 kHz and 2.5 MHz, in other cases being between about 50 kHz and 500 kHz, often less than 350 kHz, and often between about 100 kHz and 200 kHz. In some applications, a frequency of about 100 kHz is useful because target tissue impedance is greater at 100 kHz.

The RMS (root mean square) voltage generated by the voltage generator **516** may be in the range from about 5 Volts (V) to 1800 V, in some cases in the range from about 10 V to 500 V, often between about 10 V to 400 V depending on the mode of ablation and active electrode size. The peak-to-peak voltage generated by the voltage generator **516** for ablation in some embodiments is a square waveform with a peak-to-peak voltage in the range of 10 V to 2000 V, in some cases in the range of 100 V to 1800 V, in other cases in the range of about 28 V to 1200 V, and often in the range of about 100 V to 320V peak-to-peak.

The voltage and current generated by the voltage generator **516** may be delivered in a series of voltage pulses or AC voltage with a sufficiently high frequency (e.g., on the order of 5 kHz to 20 MHz) such that the voltage is effectively applied continuously (as compared with, e.g., lasers claiming small depths of necrosis, which are pulsed about 10 Hz to 20 Hz). In addition, the duty cycle (i.e., cumulative time in any one-second interval that energy is applied) of a square wave voltage produced by the voltage generator **516** is on the order of about 50% for some embodiments as compared with pulsed lasers which may have a duty cycle of about 0.0001%. Although square waves are generated and provided in some embodiments, the AC voltage signal is modifiable to include such features as voltage spikes in the leading or trailing edges of each half-cycle, or the AC voltage signal is modifiable to take particular shapes (e.g., sinusoidal, triangular).

The voltage generator **516** delivers average power levels ranging from several milliwatts to hundreds of watts per electrode, depending on the mode of ablation and state of the plasma proximate to the active electrode. The voltage generator **516** in combination with the processor **500** are configured to initially set the output energy of the voltage generator **516** (e.g., by controlling output voltage) based on the mode of ablation selected by the surgeon, and in some cases the setpoint within the particular mode of ablation. Moreover, while in a selected mode of ablation and setpoint within the mode of ablation, the processor **500** and/or voltage generator **516** may make control changes to compensate for changes caused by use of the wand. The control changes are discussed more below after a further discussion of the peristaltic pump **118**. A description of various voltage generators **516** can be found in commonly assigned U.S. Pat. Nos. 6,142,992 and 6,235,020, the complete disclosure of both patents are incorporated herein by reference for all purposes. Reference is also made to commonly assigned U.S. Pat. No. 8,257,350, entitled "METHOD AND SYSTEM OF AN ELECTROSURGICAL CONTROLLER WITH WAVE-SHAPING", the complete disclosure of which is incorporated herein by reference as if reproduced in full below.

In some embodiments, the various modes of ablation implemented by the voltage generator **516** (along with the peristaltic pump **118**) may be controlled by the processor **500** by way of digital-to-analog converter **506**. For example, the processor **500** may control the output voltages by providing one or more variable voltages to the voltage generator **516**, where the voltages provided by the digital-to-analog converter **506** are proportional to the voltages to be generated by the voltage generator **516**. In other embodiments, the processor **500** may communicate with the voltage generator by way of one or more digital output signals from the digital output converter **508**, or by way of packet-based communications using the communication device **512** (the communication-based embodiments not specifically shown so as not to unduly complicate FIG. **5**).

Still referring to FIG. **5**, in some embodiment the controller **104** further comprises a mechanism to sense the electrical current provided to the active electrode. In the illustrative case of FIG. **3**, sensing current provided to the active electrode may be by way of a current sense transformer **532**. In particular, current sense transformer **532** may have a conductor of the active terminal **518** threaded through the transformer such that the active terminal **518** becomes a single turn primary. Current flow in the single turn primary induces corresponding voltages and/or currents in the secondary. Thus, the illustrative current sense transformer **532** is coupled to the analog-to-digital converter **514** (as shown by the bubble A). In some cases, the current sense transformer may couple directly to the analog-to-digital converter **514**, and in other cases additional circuitry may be imposed between the current sense transformer **532** and the analog-to-digital converter **514**, such as amplification circuits and protection circuits. For example, in one example system the current sense transformer **532** is coupled to an integrated circuit device that takes the indication of current from the current sense transformer **532**, calculates a root-mean-square (RMS) current value, and provides the RMS current values to the processor **500** through any suitable communication system (e.g., as an analog value applied the A/D **514**, as a digital value applied to the multiple inputs of the D/I **510**, as a packet message through the communication port **512**). The current sense transformer is merely illustrative of any suitable mechanism to sense the current supplied to the active electrode, and other systems are possible. For example, a small resistor (e.g., 1 Ohm, 0.1 Ohm) may be placed in series with the active terminal **518**, and the voltage drop induced across the resistor used as an indication of the electrical current.

Given that the voltage generator **516** is electrically floated, the mechanism to sense current is not limited to the just the active terminal **518**. Thus, in yet still further embodi-

ments, the mechanism to sense current may be implemented with respect to the return terminal **524**. For example, illustrative current sense transformer **532** may be implemented on a conductor associated with the return terminal **524**.

In some example systems, the feedback parameter used by the processor **500** regarding the voltage generator **516** is the electrical current flow. For example, in systems where the voltage generator can accurately produce an output voltage independent of the impedance of the attached load, the processor **500** having set point control for the voltage created by the voltage generator **516** may be sufficient (e.g., to calculate a value indicative of impedance of the electrode circuit and plasma proximate the active electrode). However, in other cases, voltage too may be a feedback parameter. Thus, in some cases the active terminal **518** may be electrically coupled to the analog-to-digital converter **514** (as shown by bubble B). However, additional circuitry may be imposed between the active terminal **518** and the analog-to-digital converter **514**, for example various step-down transformers, protection circuits, and circuits to account for the electrically floated nature of the voltage generator **516**. Such additional circuitry is not shown so as not to unduly complicate the figure. In yet still other cases, voltage sense circuitry may measure the voltage, and the measured voltage values may be provided other than by analog signal, such as by way of packet-based communications over the communication port **512** (not shown so as not to unduly complicate the drawing).

Still referring to FIG. **5** (and also FIG. **1**), controller **104** in accordance with various embodiments further comprises the peristaltic pump **118**. The peristaltic pump **118** may reside at least partially within the enclosure **122**. The peristaltic pump comprises the rotor **124** mechanically coupled to a shaft of the electric motor **534**. In some cases, and as illustrated, the rotor of the electric motor may couple directly to the rotor **124**, but in other cases various gears, pulleys, and/or belts may reside between the electric motor **534** and the rotor **124**. The electric motor **534** may take any suitable form, such as an AC motor, a DC motor, and/or a stepper-motor. To control speed of the shaft of the electric motor **534**, and thus to control speed of the rotor **124** (and the volume flow rate at the wand), the electric motor **534** may be coupled to a motor speed control circuit **536**. In the illustrative case of an AC motor, the motor speed control circuit **536** may control the voltage and frequency applied to the electric motor **534**. In the case of a DC motor, the motor speed control circuit **536** may control the DC voltage applied to the electric motor **534**. In the case of a stepper-motor, the motor speed control circuit **536** may control the current flowing to the poles of the motor, but the stepper-motor may have a sufficient number of poles, or is controlled in such a way, that the rotor **124** moves smoothly. Stated otherwise, the rotor **124** moves smoothly due to the high number of steps per turn.

The processor **500** couples to the motor speed control circuit **536**, such as by way of the digital-to-analog converter **506** (as shown by bubble C). The processor **500** may be coupled in other ways as well, such as packet-based communication over the communication port **512**. Thus, the processor **500**, running a program, may read electrical current supplied on the active terminal **518**, may read voltage supplied on the active terminal **518**, and responsive thereto may make speed control changes (and thus volume flow rate changes) by sending speed commands to the motor speed control circuit **536**. The motor speed control circuit **536**, in turn, implements the speed control changes. Speed control changes may comprise changes in speed of the rotor **124** when desired, stopping the rotor **124** when desired, and in some modes of ablation temporarily reversing the rotor **124**.

The specification now turns to a more detailed description of the various modes of ablation that may be implemented by the electrosurgical system. Each mode of ablation is illustratively named based on the aggressiveness of the ablation. However, all the illustratively identified tissue types may be ablated in each and every mode, and thus providing an indication of the type of tissue expected to be ablated in each mode shall not be read as a limitation of the applicability of any particular mode. Ablating tissue in a mode not specifically designed for the tissue may result in unwanted effects, such as discoloration or removal of too much of the target tissue or removal at a rate deemed too rapid. The available modes of ablation of the system thereby provide enhanced performance where the management of output energy in conjunction with control of aspiration flow rates creates surgical results in each mode that are tuned to the targeted tissue, the rate of aggressiveness, or type of surgical procedure.

In accordance with the various embodiments, the electrosurgical controller **100** implements at least two, and in some embodiments four, modes of ablation to modulate the flow rate dynamically in the vicinity of an active electrode in order to regulate the RF output energy: a "low mode" which may be used for treatment, ablation, and removal of portions of cartilage; a "medium mode" which may be used for treatment, ablation, and removal of meniscus; a "high mode" which may be used for aggressive treatment, ablation, and removal of tissue; and a "vacuum mode" for removal of loose, free floating and/or trapped tissue. Each illustrative mode of ablation may be characterized by a range of energies that may be applied to the active electrode (hereafter just "energy range") and a corresponding range of aspiration flows. During operation within a particular mode of ablation, the output energy provided by the voltage generator **516** and volume flow rate provided by the peristaltic pump **118** (FIG. **1**) may change based on operational conditions at the distal end **108** of the wand, but such changes shall not obviate the status of being within a particular mode of ablation. The following table characterizes at a high level the four illustrative modes of ablation.

TABLE 1

Low Mode	Medium Mode	High Mode	Vacuum Mode
Low output energy to active electrode. Low aspiration flow.	Medium output energy to active electrode. Medium aspiration flow.	High output energy to active electrode. High aspiration flow.	Low to High output energy to active electrode. Very high or pulsed aspiration flow.

Each mode will be discussed in turn.

The low mode is designed specifically for the treatment and selective ablation of articular cartilage or other very

sensitive tissue. This low mode is particularly appropriate for chondroplasty and meniscus finishing or sculpting. However, cartilage does not re-grow, and thus the amount of cartilage ablated by a surgeon during a chondroplasty procedure is in most procedures very small. The primary concern of the surgeon may be to carefully remove diseased cartilage while at the same time reducing the damage to the underlying chondral tissue that remains. For these reasons, the illustrative low mode is characterized by low output energy provided to the active electrode, as well as low volume flow rate for the aspiration. In particular, in this mode of ablation output energy delivery during treatment is desired to increase cell viability and to create reduced instantaneous output energy dissipation and heat production in the vicinity of the treatment site. The reduced suction flow and low volume flow rate associated with this mode of operation may result in a plasma and electrode circuit having a higher overall impedance.

In the low mode of ablation, the processor **500**, executing a program, controls the voltage generator **516** and peristaltic pump **118** to implement relatively high target impedance for the electrode circuit, and to avoid plasma collapse. In some embodiments, the controller **104** may provide predetermined output energy, and for impedance values falling within a predetermined range, the controller **104** may control impedance based solely on changes in speed of the peristaltic pump **118**. For variations in impedance that fall outside with a predetermined range, the control strategy may also rely on changes in output energy supplied by the voltage generator **516**. For example, control action in response to decreasing impedance (as calculated based on the current and/or voltage applied to the active electrode) may involve slowing, stopping, or temporarily reversing the peristaltic pump **118** (FIG. **1**), and in some systems increasing the output energy supplied by the voltage generator **516**. In some embodiments, changes in the electrical output energy produced by the voltage generator **516** may be implemented more quickly than changes in peristaltic pump **118** speed, and thus in some embodiments an initial reaction to measured decreasing electrode circuit impedance may be momentarily increasing the level of supplied output energy, followed by decreasing pump speed and lowering again the supplied output energy.

The medium mode of operation is designed specifically for ablation of fibro-cartilaginous tissue like meniscal tissue, but other types of tissue may also be ablated in the medium mode. This medium mode may also be appropriate for the electrosurgical treatment of labrum tissue. When ablating meniscus, the surgeon may be interested in ablating more tissue volume than with respect to cartilage, but browning of the remaining meniscus is disfavored. For at least this reason, the illustrative medium mode is characterized by medium output energy provided to the active electrode, as well as medium volume flow rate of the aspiration in order to preserve tissue consistency. In particular, in this mode of ablation output energy delivery during treatment is desired to increase tissue matrix preservation and to reduce tissue matrix alteration with reduced or no tissue discoloration, or cross-linking of the collagen fibers that could result in mechanical alterations. The medium volume flow rate may result in the electrode circuit having a lower impedance than the low mode.

In the medium mode of ablation, the processor **500**, executing a program, controls the voltage generator **516** and peristaltic pump **118** (FIG. **1**) to implement a medium target impedance for the electrode circuit. In some embodiments, the controller **104** may provide predetermined output energy, and for impedance values falling within a predetermined range, the controller **104** may control impedance based by changing speed of the peristaltic pump **118**. For variations in impedance that fall outside of a predetermined range, the control strategy may also rely on changes in output energy supplied by the voltage generator **516**. For example, control action in response to decreasing impedance (as calculated based on the current and/or voltage applied to the active electrode) may involve slowing and/or stopping the peristaltic pump **118**, and in some systems increasing the output energy supplied by the voltage generator **516**. In some embodiments, changes in the electrical output energy produced by the voltage generator **516** may be implemented more quickly than changes in peristaltic pump **118** speed, and thus in some embodiments an initial reaction to measured decreasing electrode circuit impedance may be momentarily increasing the level of supplied output energy, followed by decreasing pump speed and lowering again the supplied output energy.

The illustrative high mode of ablation is designed specifically for quickly removing tissue. By way of example, the high mode may be used for sub-acromial decompression treatments or ACL stump debridement. For this reason, the illustrative high mode is characterized by high output energy provided to the active electrode, as well as high volume flow rate for aspiration. In particular, in this mode of ablation output energy delivery during treatment is adjusted for increased tissue removal with continuous aspiration flow volume to pull tissue closer to the wand for more efficient ablation rates. The high volume flow rate will result in having lower electrode circuit impedance, and regular (but uncontrolled) plasma collapse. Thus, plasma collapse is expected in the high mode based on the aggressive aspiration flow, but the high mode may implement a minimum volume flow rate, and thus a minimum peristaltic pump speed, even if such minimum speed results in plasma collapse. The plasma should be reinstated as tissue contact ensues.

In the high mode of operation, the processor **500**, executing a program, controls the voltage generator **516** and peristaltic pump **118** to implement low target impedance for the electrode circuit. In some embodiments, the controller **104** may provide predetermined output energy, and for impedance values falling within a predetermined range, the controller **104** may control impedance based on changes in speed of the peristaltic pump **118**. For variations in impedance that fall outside with a predetermined range, the control strategy may also rely on changes in output energy supplied by the voltage generator **516**. For example, control action in response to decreasing impedance (as calculated based on the current and/or voltage applied to the active electrode) may involve slowing the peristaltic pump **118**, but only to predetermined minimum volume flow rate.

The illustrative vacuum mode of ablation is designed specifically for quickly removing loose tissue and tissue fragments within the surgical field. For this reason, the illustrative vacuum mode is characterized by variable output energy provided to the active electrode, as well as the highest volume flow rate as between the various modes (when the aspiration is active). In particular, in this mode of ablation output energy delivery during treatment is desired to be optimized for fast digestion of debris within the surgical field in conjunction with a high volume flow rate in order to attract debris to the wand tip. The high volume flow rate will result in lower electrode circuit impedance. When tissue debris is in contact with the electrode, the flow is

lessened to better digest the tissue. When the electrode has no tissue in its proximity, the voltage is dropped to lessen electrode wear.

FIG. **6** shows a graph that relates possible energy ranges (output RF energy) to aspiration flow rate (shown as pump speed settings) for four example modes of ablation—low mode, medium mode, high mode, and vacuum mode. In particular, for each mode of ablation the electrosurgical controller **104** is programmed to operate within an energy range of output RF energy and a range of aspiration flow rates. For example, in the "low mode" of ablation described above controller **104** may be pre-programmed to operate within an energy range from 25-50 Watts, and aspiration flow range from an example "−1" (i.e., reverse motor direction) to "5", which in some cases may result in an aspiration flow in a range from 0-45 ml/min. For the example "medium mode" of ablation, described above, controller **104** may be pre-programmed to operate within an energy range from 50-150 Watts, and aspiration flow range from an example "0" (i.e., peristaltic motor stopped) to "5". For the example "high mode" of ablation described above, controller **104** may be pre-programmed to operate within an energy range from 150-400 Watts, and aspiration flow range from an example "1" to "5". For the example "vacuum mode" of ablation described above, controller **104** may be pre-programmed to operate within an energy range from 350-400 Watts, and aspiration flow range from an example "2" to "5". These example output energy and flow rates and energy ranges are merely examples, and could vary in actual values.

Moreover, FIG. **6** illustrates that, within at least some of the modes of ablation, differing energy setpoints are contemplated. That is, in some example systems, within the pre-programmed energy ranges, the processor **500** (executing a program) implements at least three, and in some cases five, energy setpoint levels within a mode of ablation to enable changes of both the output RF energy (and correspondingly the flow rate in the vicinity of an active electrode). For example, FIG. **6** illustrates that each of the low mode, medium mode, and high mode may have an initial or default energy setpoint and a corresponding default aspiration volume flow setpoint (labeled in each mode with a "D" and triangular symbol). In FIG. **6**, the default energy setpoints are shown to reside in the middle of the energy range, but in other cases the default energy setpoints may be at the lower or upper ends of the respective energy ranges.

Considering the low mode as representative of modes of ablation having multiple energy setpoints within the energy range, two energy setpoints with energies above the default energy setpoint may be implemented, and these higher energy setpoints are designated in FIG. **6** as the (+) and (++) energy setpoints. By way of manually activating a control input (e.g., foot pedal, button on the controller, graphical user interface such as a touch screen, or a button on the wand), the surgeon may increase the setpoint energy level to the plus (+) or (++) level performance. Likewise, two energy setpoints with energies below the default energy setpoint may be implemented, and these lower energy setpoints are designed in FIG. **6** as the (−) and (−−) energy setpoints. By way of manually activating a control input (e.g., foot pedal, button on the controller, or a button on the wand), the surgeon may decrease the setpoint energy level to the minus (−) or (−−) level performance. Any number of energy setpoints within a mode of ablation may be implemented. While the low mode and medium mode in FIG. **6** each have five energy setpoints, the high mode is illustrative shown to have only three energy setpoints within the energy range—a default energy setpoint, a plus (+) level and a minus (−) level. It is likewise possible for the vacuum mode to have varying energy setpoints, but no such energy setpoints are illustrated in FIG. **6** to exemplify that in some systems not all modes have multiple energy setpoints within their respective energy ranges.

By way of example, in the previously described "high mode" the default (D) energy setpoint may be about 250 Watts, and an aspiration flow setpoint of level 3 (which, for example, may result in an aspiration flow rate of 200 ml/min). By advancing the controller **104** operational parameter to the plus (+) setpoint due to either a desired increase in output energy or aspiration flow rate, the controller **104** then increases each performance characteristic in a complementary fashion, such as by adjusting the output energy to about 325 Watts and the aspiration flow setpoint to level 4 (which, for example, may result in an aspiration flow rate of 300 ml/min). Alternatively, a user may desire a decrease in both output energy and flow rate setpoint, and may accordingly choose to set back the energy setpoint to the minus (−) level performance and flow rate setpoint. Thus, each mode of operation may have a plurality of performance levels delineated by energy setpoints and flow setpoints, yet operation of any of the plurality of performance levels shall still be considered to be within a particular mode of ablation.

The specification now turns to implementation of the control loops within controller **104**. In accordance with example systems, the control loops are implemented as software by the processor **500**, but in other embodiments portions or all the control loops may be implemented in discrete logic. FIG. **7** shows, in block diagram form, the logical interaction of the control loops, as well as interaction between software executed by the processor and various components of the controller **104**. In particular, FIG. **7** shows software as the various components within the software block **700**, and likewise shows the voltage generator **516**, the motor speed control **536**, the active terminal **518**, and current sense transformer **532**. Other components of the controller **104** are omitted so as not to unduly complicate the figure. Moreover, FIG. **7** also illustrates a plasma **702** in operational relationship to aspiration flow through an aperture (shown by arrow **704** in relation to tube **706**).

In accordance with example systems, the software **700** generates or selects an energy value (shown as E in the figure) as well as a flow setpoint (shown as Fsp in the figure). The energy value E and flow setpoint Fsp are generated or selected based the mode of ablation chosen by the surgeon (and the energy setpoints within the mode of ablation). The example energy value E may be applied to the voltage generator **516** in any suitable manner, such as those discussed above. In example systems, the energy value E is a single value representing the desired output energy, but in other cases the energy value E may be a value indicative of voltage to be created by the voltage generator **516**, or a combination of values representing a desired voltage or electrical current to be created by the voltage generator **516**. Based on the energy setpoint Esp, the voltage generator **516** may produce the desired voltage on the active terminal **518**, ultimately creating plasma **702**. During periods of time when voltage is being supplied by the voltage generator **516**, the electrical current may be measured by the current transformer **532**, and an indication of the instantaneous electrical current may be supplied to the software **700** as indicated in the FIG. **7**.

In accordance with example systems, during the low mode, medium mode, high mode, and certain periods of time

in the vacuum mode, the software **700** implements closed-loop control. More particularly, the example system may apply the flow setpoint Fsp to a proportional-integral-differential (PID) control loop **708**. In example systems, the flow setpoint Fsp is a single value representing the desired volume flow of fluid, but in other cases (and for ease in coding the control loops) the flow setpoint Fsp may be a value indicative of electrical current since electrical current provided by the voltage generator and volume flow of fluid are directly proportional during periods of time when plasma is present. In the example logical control-loop flow, the flow setpoint Fsp may be applied to summation block **710**. The summation block **710** may create an error signal **712** by subtracting the feedback parameter (in this illustrative case, the electrical current measured by the current transformer **532**, FIG. **5**) from the flow setpoint Fsp. As illustrated, the feedback parameter may be subjected to various filtering operations in filter block **714**, and such filtering is discussed in greater detail below. The error signal **712** may be applied to a proportional block **716**, an integral block **718**, and a differential block **720**. Each block may be associated with gain value: G_P for the proportional block **716**; G_I for the integral block **718**; and G_D for the differential block **720**. Each example block **716**, **718**, and **720** produces a response signal, and the respective response signals are summed at summation block **722**. The summed signal is then converted to a proper format for the motor speed controller **536** and applied to the motor speed controller **536** to control peristaltic pump **118** speed. Not all the PID blocks **716**, **718**, and **720** need be implemented simultaneously. In some cases only proportional-integral (PI) control may suffice, and thus the differential block **720** may be omitted or disabled (e.g., by setting the gain G_D to zero).

The specification now turns to an explanation of PID control loop **708** control in the low mode, medium mode, high mode, and certain periods of time during the vacuum mode. First, consider that the controller **107**, plasma **702**, and volume flow of fluid **704** have reached a steady state point that matches the various setpoints, and that the RF voltage generator **516** is cable of providing a substantially constant voltage regardless of impedance. Then considerer that, perhaps based on movement of the active electrode of the wand against tissue, the electrode circuit impedance increases. Increasing impedance results in decreasing electrical current flow. Responsive to the decreasing electrical current flow the summation block **710** creates an increasing magnitude error signal **712** that is applied to various blocks **716**, **718**, and **720**. The end result of this example situation is an increasing flow of fluid drawn into the aperture (by increasing the peristaltic pump speed) responsive to the electrosurgical controller detecting the active electrode is in operational relationship with tissue.

Now consider again that the controller **107**, plasma **702**, and volume flow of fluid **704** have reached a steady state point that matches the various setpoints, and that the RF voltage generator **516** is capable of providing a substantially constant voltage regardless of impedance. Then considerer that, perhaps based on of movement of the active electrode of the wand away from tissue, the electrode circuit impedance decreases. Decreasing impedance results in increasing electrical current flow. Responsive to the increasing electrical current flow the summation block **710** creates a decreasing magnitude error signal **712** that is applied to various blocks **716**, **718**, and **720**. The end result of this example situation is a decreasing flow of fluid drawn into the aperture (by decreasing the peristaltic pump speed) responsive to the electrosurgical controller detecting the active electrode has moved away from tissue. The specification now turns to distinguishing the various modes of ablation.

The various modes of ablation are distinguishable based not only on the output energy and flow ranges discussed above (and specific setpoints within the respective ranges), but also based on the gain setpoints implemented. For example, the low mode of ablation may implement a first set of gain values G_{PL}, G_{IL}, and G_{SL}, and the high mode of ablation may implement a second set of gain values G_{PH}, G_{IH}, and G_{DH} that are distinct from the low mode of ablation. Moreover, in systems that implement different output energy and flow setpoints within a mode of ablation, each energy setpoint may have a set of gain values. For example, the low mode of ablation may implement a first set of gain values at the default energy setpoint G_{PLD}, G_{ILD}, and G_{DLD}, and the low mode of ablation may implement a second set of gain values at the (+) energy setpoint G_{PL+}, G_{IL+}, and G_{DL+}, and so forth.

Moreover, other parameters may be associated with the PID control loop **708** that are not specifically delineated in FIG. **7**. For example, the integral block **718** may have additional parameters in the form of reset time for the integration, or maximum allowed values of the integral block **718** response. Such additional parameters may reduce or prevent "wind up" of the response of the integral block **718** in certain situations (such as extended periods of plasma collapse or significant voltage generator pulsing). Further still, the range of motor speed control is different between the example modes of ablation, with some modes (e.g., the low mode) having the ability to stop and even reverse direction of the peristaltic pump, and with other modes implementing minimum non-zero speeds for the peristaltic pump (e.g., the high mode), and thus the summation block **722** may have additional parameter which limit the range of values that can be applied to the motor speed controller **536** regardless of the actual summation of the various inputs.

In some example systems, gain scheduling may be implemented by the PID control loop **708** (FIG. **7**). That is, in some systems within a particular mode of ablation different gains may be used as a function of the magnitude of the error signal **712**. Consider as an example of gain scheduling the proportional block **716**. In systems where gain scheduling based on the magnitude of the error signal **712** is used, when the magnitude of the error signal **712** exceeds a first predetermined threshold, a first gain value G_{P1} may be used by the proportional block **716**, and when the magnitude of the error signal **712** exceeds a second higher predetermined threshold, a second gain value G_{P2} may be used by the proportional block **716** where the second gain value is different than the first gain value. Each example block **716**, **718**, and **720** may use gain scheduling within a particular mode of ablation, and different gain schedules may be used based on the setpoints within each mode of ablation (i.e., a first gain schedule for the default mode, and different gain schedule for each of the (+), (++), (−), and (−−) setpoints. Moreover, gain scheduling may be used within some or all of the modes of ablation. For example, the gain value for the proportional block **716** for the low mode of ablation G_m may be a set of values, such that $G_{PL}=\{G_{PL1}, G_{PL2}, G_{PL3}\}$. As another example, the gain value for the proportional block **716** for the high mode of ablation G_{PH} may be a set of values, such that $G_{PH}=\{G_{PH1}, G_{PH2}, G_{PH3}\}$. Further still, as the electrode wears due to use (discussed more below), the gains setpoints, and gain schedules, may be changed.

In some example systems, the controller **104** is pre-programmed with all the various parameters used to identify and implement the modes of ablation. For example, the

ROM **504** of the controller **104** may be pre-programmed with the some or all of the various parameters used to identify and implement the modes of ablation, and the software **700** (also stored on the ROM **504**) may, when executed, read the parameters and implement the modes of ablation based on the parameters. In other systems, however, the various parameters used to identify and implement the modes of ablation may be dependent on the wand **102** (e.g., the exposed surface area of the electrode **202**). Thus, the values associated with each mode of ablation may be wand **102** dependent, and again the controller **104** may be pre-programed with some or all the various parameters for each wand **102** which may be used with the controller **104**. In such systems, the wand **102** may be identified by the controller by any suitable means (e.g., identified by the surgeon selecting the wand from a list of supported wands using the display **130** and buttons **132**, or the wand may be identified electrically by the controller based on information readable by the pins in the connector **114**). In yet still further cases, different sets of parameters may be used with the same wand to implement different characteristics of the modes of ablation.

Still referring to FIG. **7**, the discussion now turns to example filtering performed in the filtering block **714**. In particular, while a value indicative of the electrical current read by the current transformer **532** may be logically applied directly to the summation block **710**, in some example systems the overall control of the plasma **702** may be better controlled by implementing filtering within the filtering block **714**. In order to logically tie the example filtering scenarios to the plasma control, a brief description of operational phenomenon associated with the voltage generator **516** and plasma **702** is in order. The first operational phenomenon is plasma **702** "collapse" (i.e., the plasma is extinguished). Plasma collapse is more likely in some operational situations, such as in the modes of ablation implementing higher volume flow of fluid. During periods of time when the plasma has collapsed, electrical current may flow through fluids and/or tissue abutting the electrode **202** of the wand in a thermal mode, and in the impedance to electrical current flow in the thermal mode is lower than the impedance of plasma. In most cases, the plasma is quickly re-established. Thus, plasma collapse may result in a high frequency electrical current "spike". The second operational phenomenon is voltage generator **516** "pulsing". Pulsing of the voltage generator **516** is a temporary cessation of voltage and current flow to the electrode **202** based on the output energy delivery meeting or exceeding a predetermined output energy threshold. For example, in some systems the voltage generator **516** may temporarily cease providing a voltage (and therefore cease providing a current) when the output energy delivery meets or exceeds 400 Joules per second. When output energy delivery is stopped, the plasma is extinguished, electrical current drops (e.g., to zero). When output energy is again provided the system progresses through a thermal mode (in which a current spike is seen) and then to a plasma mode.

Volume flow of fluid provided during periods of plasma collapse and generator pulsing has little effect on re-establishing the plasma, and thus in some example systems no (or very little) control action in regard to the volume flow of fluid may be taken responsive to the plasma collapse and generator pulsing events. Thus, in accordance with example systems the filtering block **714** implements control strategies to deal with plasma collapse and generator pulsing. FIG. **8** shows, in block diagram form, one example control strategy logically implemented with the filtering block **714**. In particular, the feedback parameter in the form of an indication of electrical current being supplied by the generator is applied to an averaging block **800**. As the name implies, the averaging block **800** creates a running average value of the indication of electrical current during periods of time when plasma is present (e.g., over the last 500 milli-seconds, or the last second). The running average value, as well as the indication of electrical current being supplied, is applied to a multiplexer **802**. During periods of time of generator pulsing, the multiplexer **802** passes the running average value to downstream logical components. That is, PID control loop **708** is provided the running average value created by the averaging block **800**, rather than the instantaneous indication of electrical current being supplied, during periods of generator pulsing. In this way, the PID control loop **708** may take little or no action responsive to the generator pulsing. When the generator pulsing event is completed, and plasma is re-established, the multiplexer **802** again provides the instantaneous indication of electrical current being supplied to the downstream logical components. Thus, the averaging block **800** and multiplexer **802** may be considered to address pulsing issues; however, other logical mechanism may be equivalently used.

The indication of electrical current flow propagating from the multiplexer **802** may then be applied to a low-pass filter block **804**. As the name implies, the low-pass-filter block **804** filters the signal to remove high frequency components, such as current spikes associated with plasma collapse. Thus, PID control loop **708** is provided a low-pass filtered version of the indication of electrical current created by the low-pass filter block **804**. In this way, the PID control loop **708** may take little or no action responsive to plasma collapse. Thus, the low-pass filter block **804** may be considered to address the plasma collapse issue; however, other logical mechanism may be equivalently used.

The specification now turns to control in the vacuum mode of ablation in accordance with example systems. In the vacuum mode of ablation, during periods of time when the active electrode **202** is not in operational relationship with tissue (as determined based on low overall impedance), a relatively high volume flow of fluid is drawn into the aperture. However, when the active electrode encounters tissue (as determined based on increasing impedance), rather than increase the volume flow of fluid, in the vacuum mode the opposite control strategy is implemented. That is, when the active electrode encounters tissue (and the impedance increases), the volume flow of fluid drawn into the aperture decreases. The theoretical basis for the control strategy is that the vacuum mode is designed for quickly removing free floating and/or loosely held tissue, but where the volume density of the tissue is low. Thus, there may be large volumes of bodily fluids or saline containing no tissue drawn into the aperture. The volume flow of fluid is high during periods of time when no tissue is present near the active electrode, but the volume flow of fluid slows during periods of time when tissue is in operational relationship with the active electrode to enable increased digestion rate of tissue and more thorough molecular dissociation and reduction of the tissue to decrease clogging. In some cases, during periods of time when tissue is in operational relationship with the active electrode, the volume flow of fluid may be controlled in a fashion similar to the other modes of ablation. In yet still other cases, the lack of tissue may be sensed by pulsing of the generator.

Returning briefly to FIG. **7**, in some example systems the volume flow of fluid during the vacuum mode is based on the PID control loop **708** standing alone, in combination

with a change in flow setpoint Fsp. That is, during periods of time when no tissue is in operational relationship with the active electrode, the flow setpoint Fsp in the vacuum mode may be set very high; however, when tissue is in operational relationship with the active electrode, the flow setpoint Fsp is reduced to implement the decrease in the volume flow of fluid. Moreover, the various gains associated with the blocks **716**, **718**, and **720** may be changed simultaneously with changing the flow setpoint Fsp responsive to the controller detecting the active electrode is in operational relationship with the tissue. However, other control strategies are possible, such as discussed with respect to FIG. **9**.

FIG. **9** shows, in block diagram form, a logical interaction of the control strategies in the vacuum mode, as well as interaction between software executed by the processor and various components of the controller **104**. In particular, FIG. **9** shows software as the various components within the software block **700**, and likewise shows the voltage generator **516**, the motor speed control **536**, the active terminal **518**, and current sense transformer **532**. Other components of the controller **104** are omitted so as not to unduly complicate the figure. During periods of time when plasma is being maintained by an active electrode of a wand in the vacuum mode, but where no tissue is in operational relationship to the active electrode, the flow setpoint Fspv may be directly applied to the motor speed controller **536** though logical multiplexer **900**. As shown, the speed is set, in many cases predetermined, and no changes are made the based on any feedback parameter. Thus, during the period of time when no tissue is in operational relationship with the active electrode, the example system implements open-loop flow control. However, when the system determines that there is tissue in operational relationship to the active electrode. The multiplexer **900** may be operated to couple the control signal derived from the PID control loop **708** to the motor speed controller **536**. Given that the flow setpoint Fspv is higher than the flow setpoint Fsp in this situation, the flow of fluid into the aperture decreases, and then closed-loop flow control is exercised responsive to the electrosurgical controller detecting the active electrode is in operational relationship with tissue.

Simultaneously with implementing the various control strategies for the modes of ablation, the controller **104** may also perform clog detection. That is, in some situations a large piece of tissue may enter the aperture **404** behind the active electrode **400** causing a clog either at the location of the aperture, or at another location within the wand and/or tubing. A clog reduces or stops the volume flow of fluids into the aperture. In accordance with the various embodiments, the presence of a clog may be detected by the processor **500** (executing a program) indirectly based on other parameters. For example, when a clog is present the impedance of the electrode circuit changes and thus electrical current flow changes and becomes stable (in relation to the non-clog condition). Moreover, when a clog is present the fluids within the flexible tubular member **116** may pool and/or become stationary and thus cause localized temperature increases. Further still, peristaltic pump **118** speed is related to impedance changes (assuming corresponding flow of fluid), but in the presence of a clog changes in peristaltic pump speed have little or no effect on impedance. The stator movement can be sensed, for example, by Hall Effect Sensors. These sensors show that the stator up and down movement is a predictable cycle in normal operation. When there is a clog, the cycle of movement is dampened and the clog may be detected.

Thus, in accordance with the example embodiment the controller **104** (more particularly the processor **500** executing a program) determines the presence of a clog based on two or more of the above-noted parameters. For example, the processor **500** may make an initial determination of a clog based on an impedance change and then stabilization, and the clog determination may be verified by implementing control changes in volume flow of fluid that have no effect on impedance. As yet another example, the processor **500** may make an initial determination of a clog based on an impedance change and then stabilization, and the clog determination may be verified by reading increasing temperature of the fluid flow in the tubular member **116** (such are read by temperature measurement device **304** of FIG. **3**). Other variations are possible. For example, the initial determination may be based on reading increasing temperature, and the verification based on either impedance changes and/or lack of control effect. Additionally, pressure variations or oscillations of the fluid within tubular member **116** may be sensed in the form of tubing wall pulsing, causing the flexible tubular member **116** to variably expand and contract. Inasmuch as impedance and electrical current are related (for a constant or known applied voltage), changes in impedance and changes in electrical current may be interchangeable in the determinations and/or verifications. Any suitable measure of change of impedance (or electrical current) may be used, such as variations, changes in standard deviation. The specification now turns to electrode wear considerations.

The active electrode of the example wand **102** is the location about which plasma is formed. The plasma not only ablates various tissues, but the plasma also etches the active electrode, thus removing metallic material over time. Etching of the active electrode reduces the size and/or exposed surface area of the active electrode, and also reduces the "sharpness" of asperities (if present) defined by the active electrode. After continued use, the active electrode may be reduced in size to the point that the therapeutic benefit is reduced or eliminated—that is, used beyond useful life. If used beyond the useful life, the active electrode may fail, such as by cracking, splitting, or even becoming detached from the distal tip **108**, thus lodging itself inside the body at the treatment site. Failure of the active electrode may result in serious complications, and thus should be avoided.

The amount of plasma time to which an active electrode may be exposed before failure varies based on the mode of ablation and the specifics of the wand **102**. Modes of ablation using higher energies result in more aggressive etching of the active electrode, while modes of ablation using lower energies result in less aggressive etching. For example, the inventors of the current specification estimate that the example wand **102** discussed with respect to FIGS. **2-4** may have a useful life of 8 minutes if used exclusively in the high mode of ablation and have a useful life as long as 30 minutes is used exclusively in the low mode of ablation. It is contemplated that a surgeon will vary the modes during any particular electrosurgical procedures, and thus the useful life will be dependent upon the amount of time spent in each mode of ablation. In the example, the useful life may fall somewhere between 8 and 30 minutes.

In order to gauge the state of the active electrode, in accordance with example embodiments the electrosurgical controller **104** is designed and constructed to measure an indication of active electrode wear. In one example embodiment, the measurement is made just prior to each plasma activation. In particular, in one embodiment the controller **104** (and more particularly, software executed by the pro-

cessor **500**), receiving a command to create the plasma but prior to commanding providing output energy sufficient to create a plasma, commands the voltage generator to apply a test voltage to the wand circuit (e.g., terminal **518**, conductors in the multiconductor cable **112**, the active electrode **400**, the return electrode, conductive fluids and other fluids/tissue between the active electrode and the return electrode, etc.). The test voltage is low enough that plasma is not created, but high enough to induce an electrical current flow through the wand circuit. The controller **104** measures the electrical current flow (e.g., by way of current transformer **532**), and based on the voltage and current calculates an impedance of the wand circuit. The impedance of the fixed components, such as terminals, wiring, and even the conductive fluids, is known or calculable in advance. However, a portion of the overall impedance associated with the active electrode is dependent upon the remaining size of the active electrode and/or the remaining exposed surface area. Thus, the impedance of the active electrode can be measured. Once the active electrode impedance has been measured (and assuming the impedance value is above a predetermined threshold), the controller **104** may command the voltage generator **516** to increase the voltage to create the plasma. On the other hand, if the active electrode impedance indicates the active electrode is beyond its useful life, the controller **104** may refrain from providing sufficient voltage to create the plasma, and provide an alarm or alert (e.g., posting a message on display device **130**).

In one example system, during periods of time when the impedance of the electrode circuit is being measured, the controller may apply a voltage in the range of 5-20 Volts. In some cases, the voltage is an alternating current (AC) voltage, and thus the 5-20 Volts may be a peak or RMS value. In other cases, the voltage applied may be a direct current (DC) voltage, in which case the indication of active electrode wear includes only a purely resistive component. In one example situation, a wand **102** having an active electrode that has not previously been exposed to plasma may have a real component of the measured impedance in the range of 40-100 Ohms. After the active electrode has been used to the point of being beyond useful life, the same active electrode may have a real part of the impedance of 200 Ohms or above.

In accordance with yet still further embodiments, the controller **104** may also calculate or estimate the remaining useful life of the active electrode. In particular, during of time when the voltage generator is providing output energy sufficient to establish plasma proximate to the active electrode, the controller **104** may calculate or estimate the remaining useful life of the active electrode based on the current mode of ablation (e.g., based on the current energy level being provided). The controller may provide an indication of the remaining useful life to the surgeon, such as by displaying the estimated remaining useful life on the display device **130** of the controller **104**. If the surgeon switches to a different mode of ablation, or a different energy setpoint within a mode of ablation, the calculated or estimated remaining useful life value will likewise change. That is, the value indicative of remaining useful life may be estimated or calculated assuming that the controller **104** remains operating in the current mode of ablation (and energy setpoint level) for the remaining useful life, but as the surgeon changes modes of ablation and/or energy setpoint level within the mode of ablation, the value indicative of remaining useful life will likewise change.

In yet still further embodiments, the value indicative of useful life may be checked, verified, or adjusted based on measured impedance. That is, the controller **104** may calculate or estimate remaining useful life during periods of time when plasma is present. When the impedance of the electrode circuit is measured (e.g., response to a command to create plasma, or perhaps automatically after cessation of plasma), the remaining useful life may be updated to reflect electrode wear. That, is, the calculate or estimated value indicative of remaining useful life may be increased if the measured impedance of the electrode circuit (when no plasma is present) indicates less wear than expected. Likewise, the calculate or estimated value indicative of remaining useful life may be decreased if the measured impedance of the electrode circuit (when no plasma is present) indicates more wear than expected. Moreover, the controller **104** may update the rates at which the value indicative of useful life is decremented during times when plasma is present based on actual rates calculated using two or more impedance measurements.

FIG. **10** shows a method in accordance with some embodiments, portions or all of which may be implemented by a program executed on a processor. In particular, the method starts (block **1000**) and proceeds to maintaining plasma proximate to an active electrode of an electrosurgical wand, the plasma created based on the delivery of output energy to the active electrode by an electrosurgical controller, the output energy within a predetermined first energy range (block **1002**). During periods of time when output energy is being delivered within the first energy range, the method may comprise: providing output energy at a first default energy setpoint by the electrosurgical controller, the first default energy setpoint within the first energy range (block **1004**); and providing output energy at a second energy setpoint by the electrosurgical controller, the second energy setpoint different than the first default energy setpoint, the second energy setpoint within the first energy range, and implementing the second energy setpoint responsive to the electrosurgical controller receiving a command (block **1006**). Thereafter, the method ends (block **1008**), possibly to be immediately restarted with a second energy range.

FIG. **11** shows a method in accordance with some embodiments, portions or all of which may be implemented by a program executed on a processor. In particular, the method starts (block **1100**) and proceeds to maintaining plasma proximate to an active electrode of an electrosurgical wand, the plasma created based on the delivery of output energy to the active electrode by an electrosurgical controller, the output energy within a predetermined first energy range (block **1102**). During periods of time when output energy is being delivered within the first energy range, the method may comprise: controlling flow of fluid drawn into an aperture of the electrosurgical wand at a first flow rate (block **1104**); and increasing flow of fluid drawn into the aperture responsive to the electrosurgical controller detecting the active electrode is in operational relationship with tissue (block **1106**). Moreover, the method may comprise maintaining plasma proximate to the active electrode, the plasma created based on the delivery of output energy to the active electrode within a predetermined second energy range, the second energy range distinct from the first energy range (block **1108**). During periods of time output energy is being delivered within the second energy range the method may comprise: controlling flow of fluid drawn into the aperture at a second flow rate (block **1110**); and decreasing flow of fluid drawn into the aperture responsive to the electrosurgical controller detecting the active electrode is in

operational relationship with tissue (block **1112**). Thereafter, the method ends (block **1114**), possibly to be immediately restarted.

The above discussion is meant to be illustrative of the principles and various embodiments of the present invention. Numerous variations and modifications are possible. It is intended that the following claims be interpreted to embrace all such variations and modifications.

While preferred embodiments of this disclosure have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teaching herein. The embodiments described herein are exemplary only and are not limiting. Because many varying and different embodiments may be made within the scope of the present inventive concept, including equivalent structures, materials, or methods hereafter thought of, and because many modifications may be made in the embodiments herein detailed in accordance with the descriptive requirements of the law, it is to be understood that the details herein are to be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An electrosurgical method comprising:

maintaining plasma proximate to an active electrode of an electrosurgical wand, the plasma created based on delivery of output energy to the active electrode by an electrosurgical controller, the output energy within a predetermined first energy range, and during periods of time when output energy is being delivered within the first energy range;

controlling an aspirating flow of fluid drawn into an aperture of the electrosurgical wand at a first flow rate; and increasing the aspirating flow of fluid drawn into the aperture responsive to the electrosurgical controller detecting the active electrode is in operational relationship with tissue; and

maintaining plasma proximate to the active electrode, the plasma created based on delivery of output energy to the active electrode within a predetermined second energy range, the second energy range distinct from the first energy range, and during periods of time output energy is being delivered within the second energy range;

controlling the aspirating flow of fluid drawn into the aperture at a second flow rate; and

decreasing the aspirating flow of fluid drawn into the aperture responsive to the electrosurgical controller detecting the active electrode is in operational relationship with tissue.

2. The electrosurgical method of claim **1** wherein decreasing flow of fluid drawn into the aperture further comprises decreasing a flow setpoint responsive to the electrosurgical controller detecting the active electrode is in operational relationship with tissue.

3. The electrosurgical method of claim **1**:

wherein controlling flow of fluid drawn into the aperture at the second flow rate further comprises implementing open-loop flow control; and

wherein decreasing flow of fluid drawn into the aperture further comprises implementing closed-loop flow control responsive to the electrosurgical controller detecting the active electrode is in operational relationship with tissue.

4. The electrosurgical method of claim **1** wherein maintaining plasma associated with the first energy range further comprises:

providing output energy at a default energy setpoint by the electrosurgical controller, the default energy setpoint within the first energy range; and then

providing output energy at a second energy setpoint by the electrosurgical controller, the second energy setpoint different than the default energy setpoint, the second energy setpoint within the first energy range, and implementing the second energy setpoint responsive to the electrosurgical controller receiving a command.

5. The electrosurgical method of claim **4** wherein the second energy setpoint is at least one selected from the group consisting of: a higher output energy than the default energy setpoint;

and a lower output energy than the default energy setpoint.

6. The electrosurgical method of claim **4** wherein the controller receives the command by way of at least one selected from the group consisting of: actuation of a foot pedal; actuation of a button on the electrosurgical wand; actuation of a button on the electrosurgical controller; and manipulation of a graphical user interface on the electrosurgical controller.

7. The electrosurgical method of claim **4** further comprising, after providing output energy at the default energy setpoint and providing output energy at the second energy setpoint, providing output energy at a third energy setpoint by the electrosurgical controller, the third energy setpoint different than the default energy setpoint and the second energy setpoint, the third energy setpoint within the first energy range, and implementing the third energy setpoint responsive to the electrosurgical controller receiving a command.

8. The electrosurgical method of claim **1** wherein maintaining plasma associated with the first energy range further comprises:

providing output energy at a default energy setpoint by the electrosurgical controller and controlling aspiration of fluid at a first flow setpoint; and then

providing output energy at a second energy setpoint and controlling aspiration at a second flow setpoint, the second energy setpoint being within first energy range and being different than the default energy setpoint, the second flow setpoint different than the first flow setpoint, and implementing the second energy setpoint responsive to the electrosurgical controller receiving a command.

9. The electrosurgical method of claim **1** further comprising delaying the delivery of output energy to the active electrode until at least the first flow rate of flow of fluid drawn into an aperture of the electrosurgical wand is established.

10. The electrosurgical method of claim **1** further comprising, prior to at least one step of maintaining plasma, measuring impedance of an electrode circuit that comprises the active electrode.

11. The method of claim **1**, wherein during periods of time when output energy is being delivered, adjusting the output energy so as to maintain plasma proximate the active electrode.

12. The electrosurgical method of claim **1** further comprising detecting a clog condition that alters the flow of fluid through the aperture based on an increase of temperature of tubing associated with the aperture.

13. The electrosurgical method of claim **12**, wherein the temperature is sensed by a temperature measurement device abutting an outer surface of the tubing.

14. An electrosurgical method comprising:

maintaining plasma proximate to an active electrode of an electrosurgical wand, the plasma created based on delivery of output energy to the active electrode by an electrosurgical controller, the output energy within a predetermined first energy range, and during periods of time when output energy is being delivered within the first energy range;

measuring at least one electrical parameter presented by of an electrode circuit impedance comprising the plasma and active electrode;

controlling an aspirating flow of fluid drawn into an aperture of the electrosurgical wand at a first flow rate; and increasing the aspirating flow of fluid drawn into the aperture in response to an increase in the electrode circuit impedance; and

maintaining plasma proximate to the active electrode, the plasma created based on delivery of output energy to the active electrode within a predetermined second energy range, the second energy range distinct from the first energy range, and during periods of time output energy is being delivered within the second energy range;

measuring the at least one electrical parameter indicative of an electrode circuit impedance comprising the plasma and active electrode;

controlling the aspirating flow of fluid drawn into the aperture at a second flow rate; and

decreasing the aspirating flow of fluid drawn into the aperture responsive to an increase in electrode circuit impedance.

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