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(54) **CLOSED LOOP FEEDBACK CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT BASED ON MEASURED TIME OVER A SPECIFIED NUMBER OF SHAFT ROTATIONS**

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(Continued)

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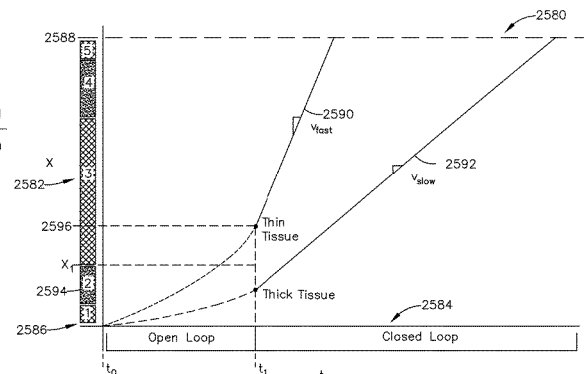
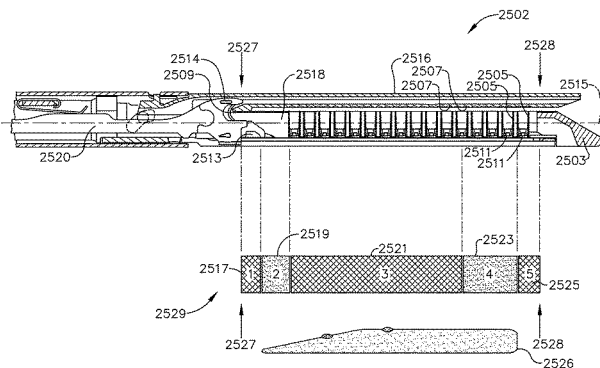
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(57) **ABSTRACT**

A motorized surgical instrument is disclosed. The surgical instrument includes a displacement member configured to translate over a plurality of predefined zones. A motor comprising a shaft is coupled to the displacement member. A control circuit is coupled to the motor. A position sensor is coupled to the control circuit to monitor the rotation of the shaft. A timer circuit is coupled to the control circuit. The control circuit is configured to receive rotations of the shaft in a current zone defined by a set rotation interval, measure time at a set position of the rotation interval, wherein the measured time is defined as the time taken by the displacement member to traverse the rotation interval based on a predetermined number of shaft rotations, and set a command velocity of the displacement member for a subsequent zone based on the measured time in the current predefined zone.

22 Claims, 22 Drawing Sheets



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WO	WO-9639088	A1	12/1996				
WO	WO-9724073	A1	7/1997				
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WO	WO-9827870	A1	7/1998				
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WO	WO-0154594	A1	8/2001				
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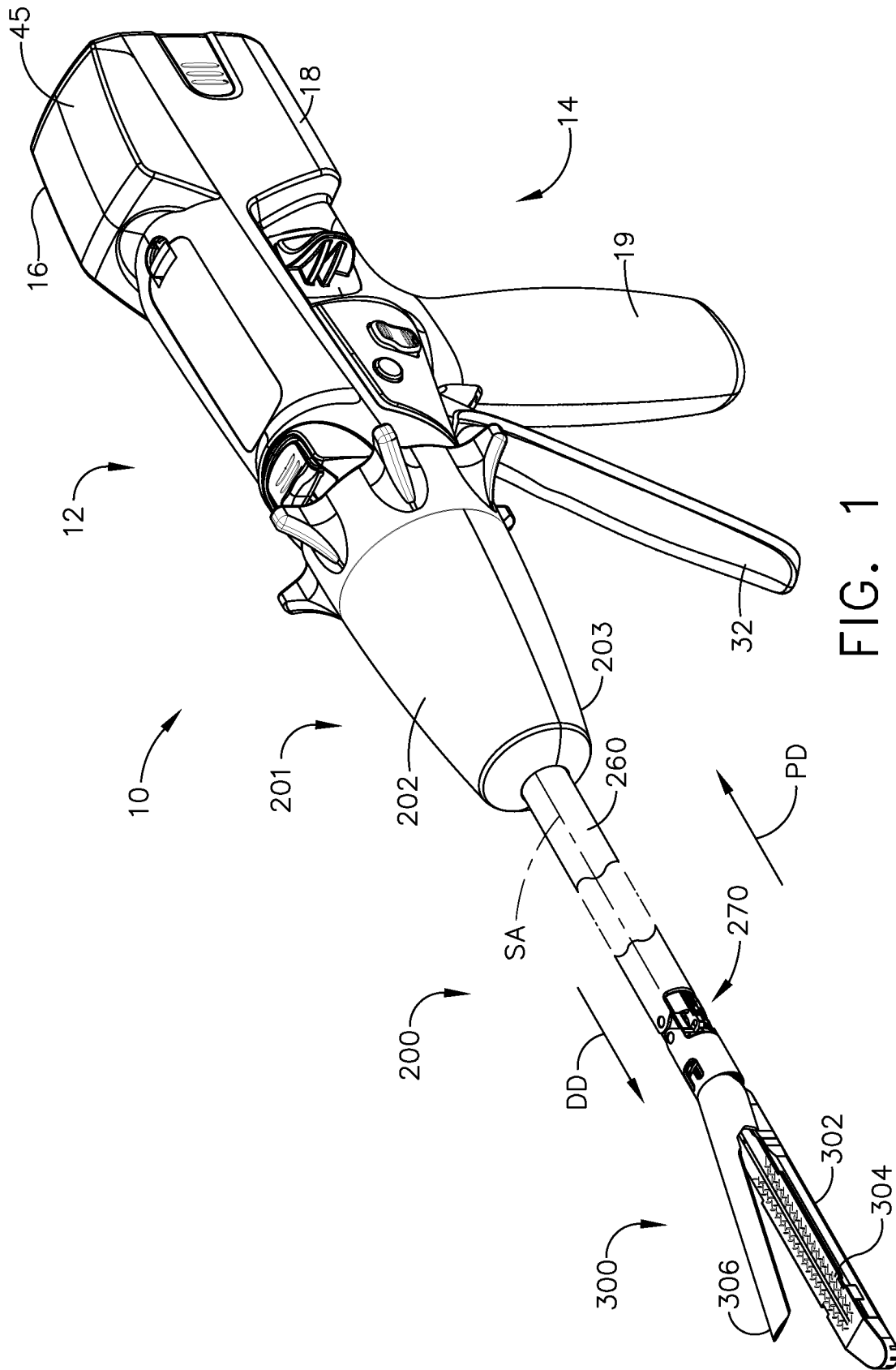


FIG. 1

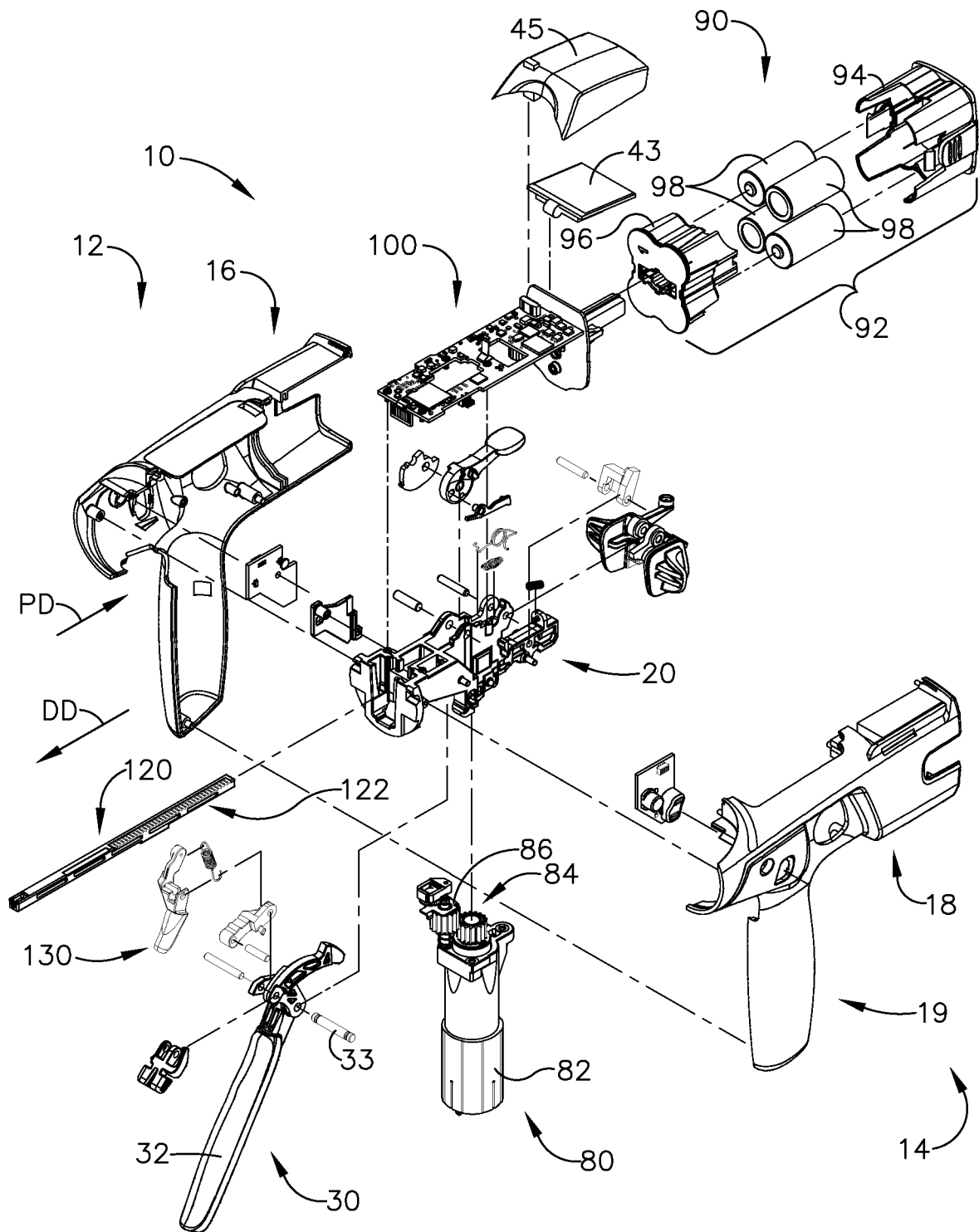


FIG. 2

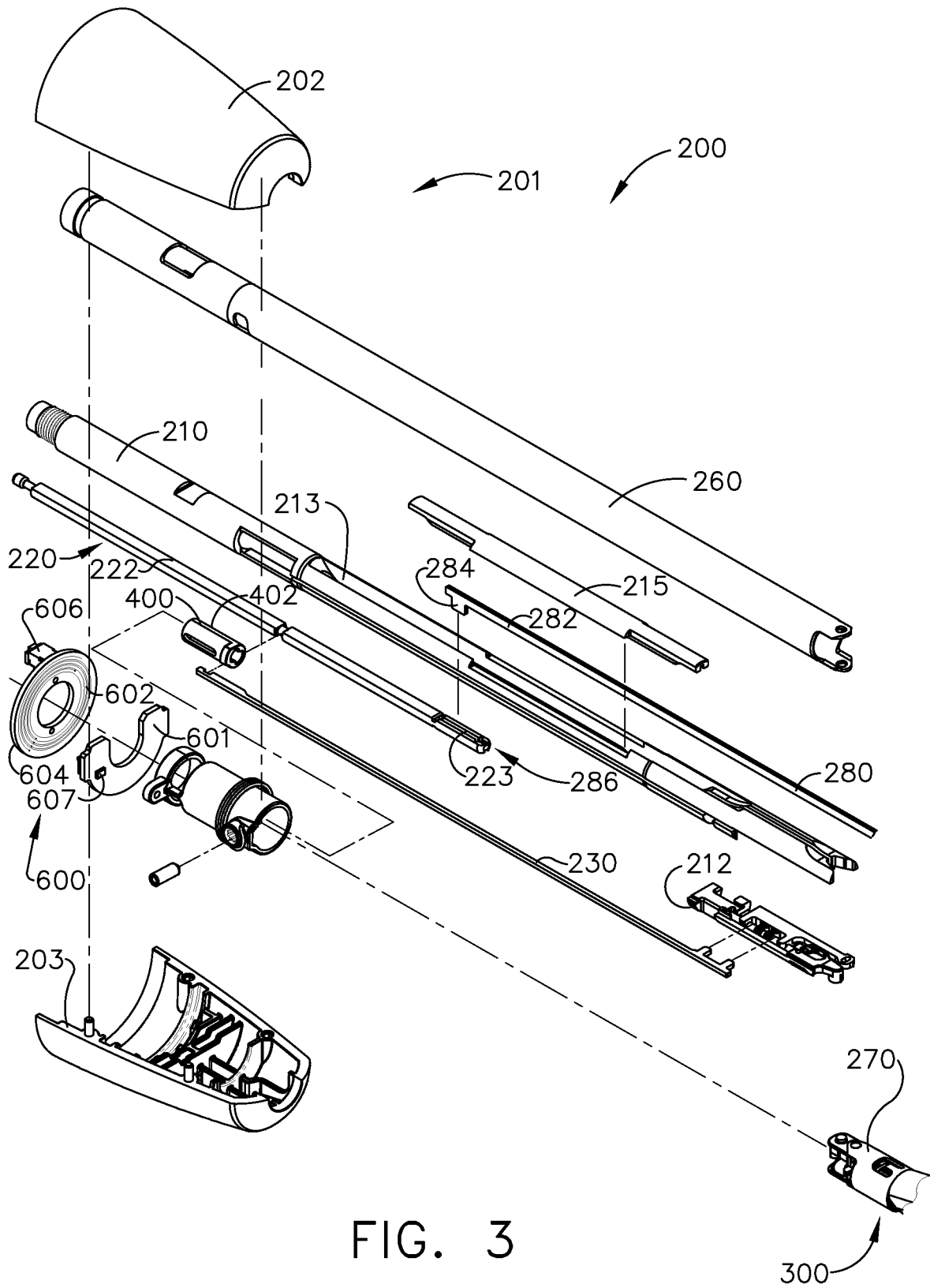


FIG. 3

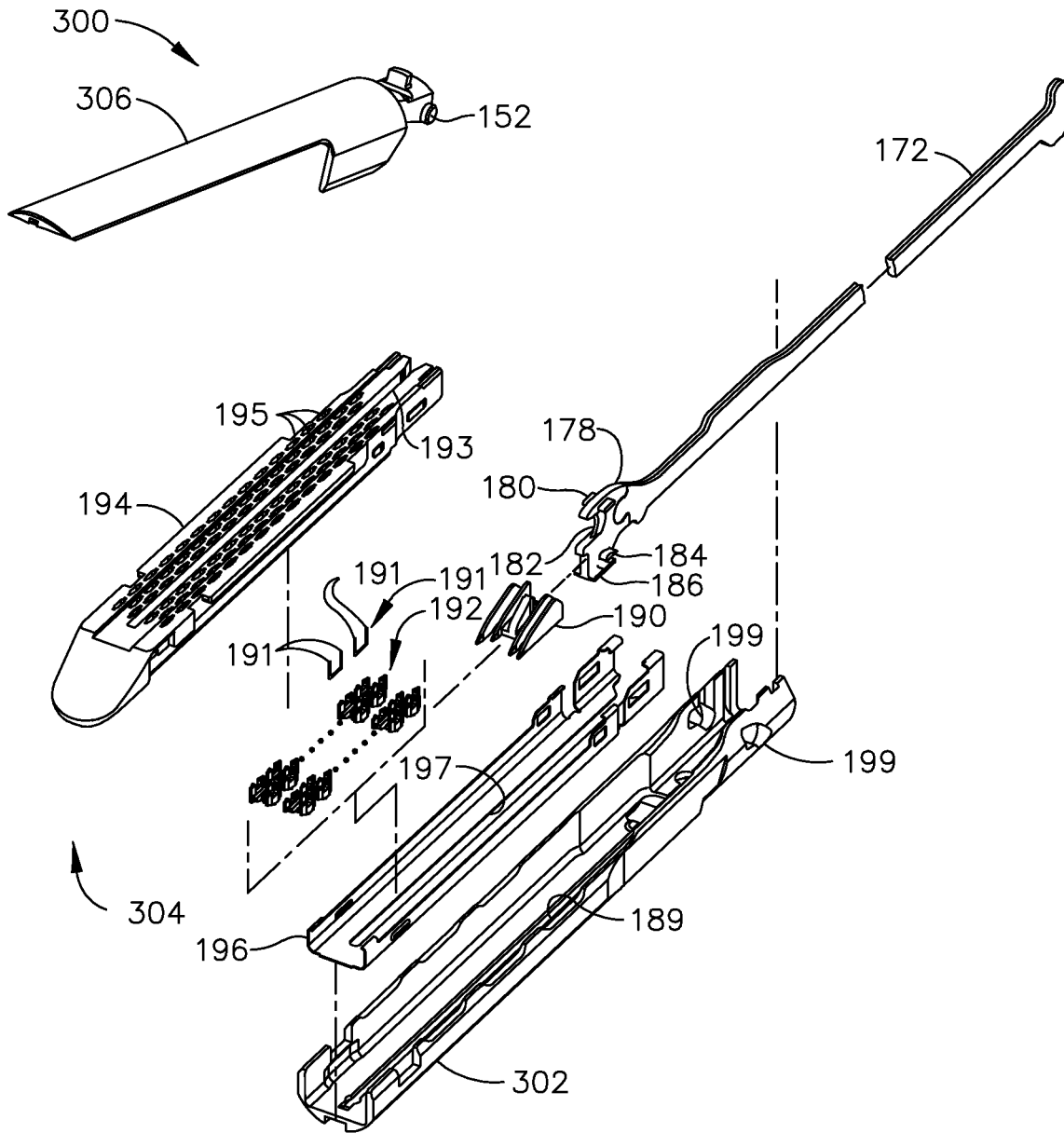


FIG. 4

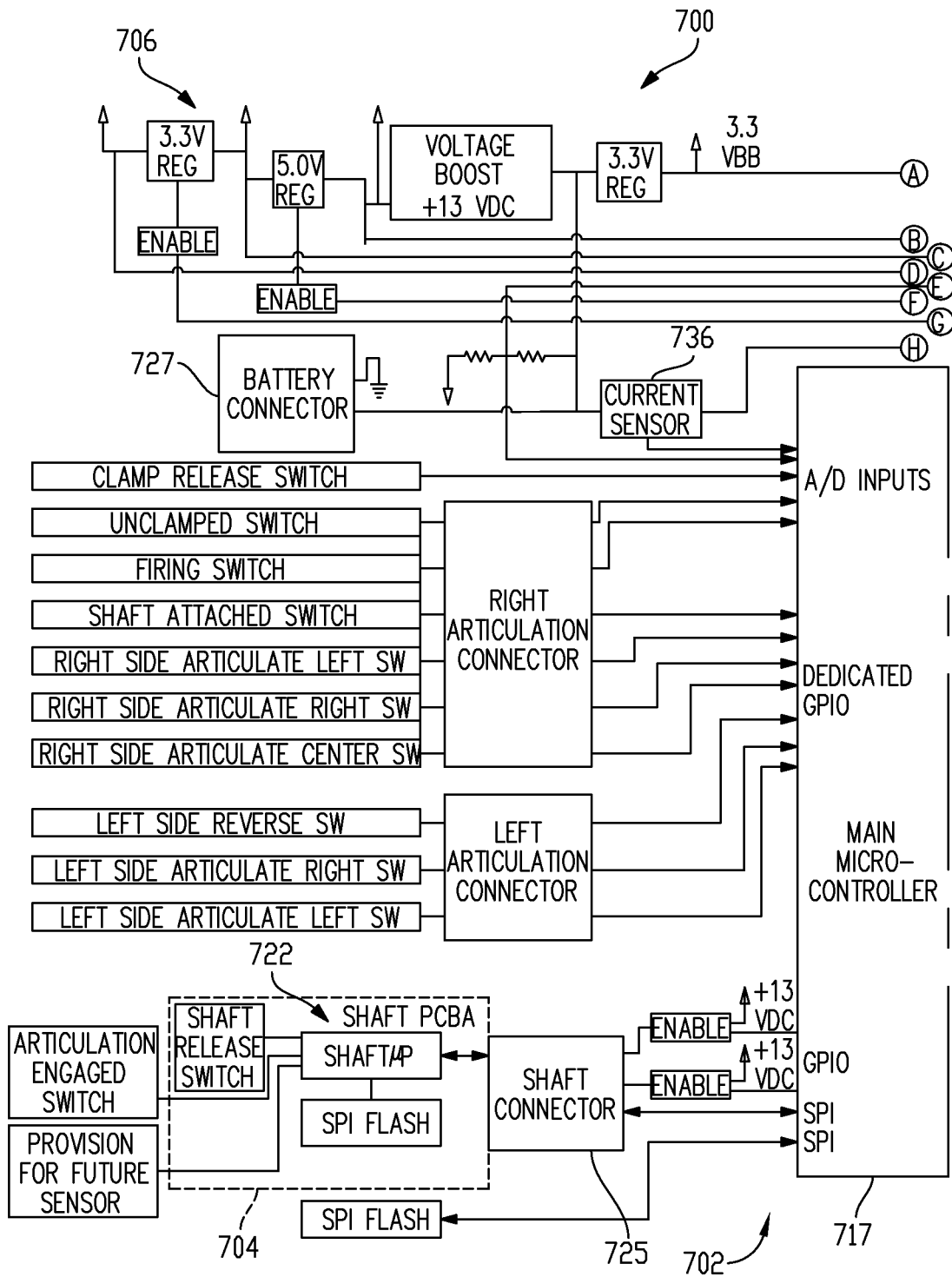


FIG. 5A

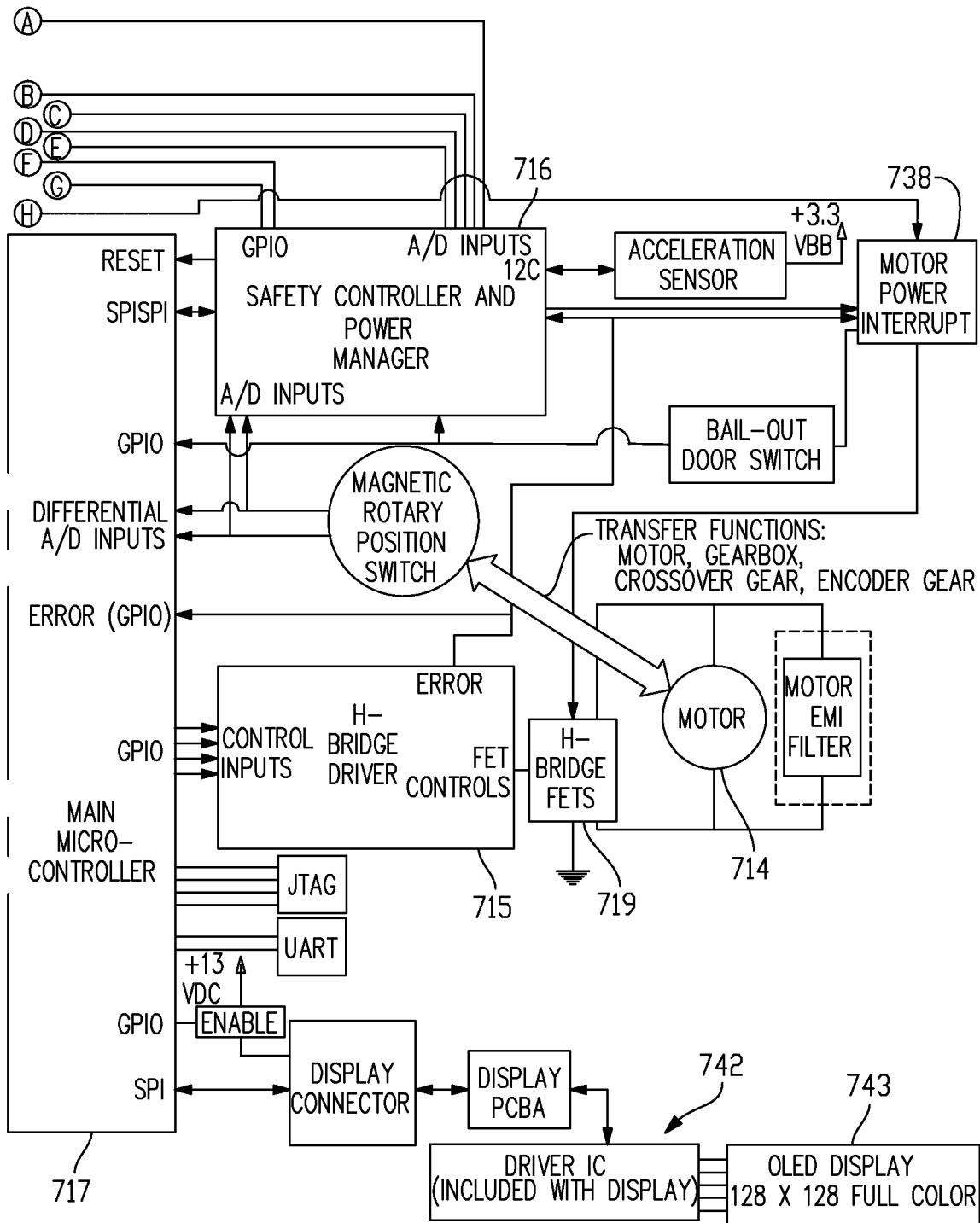


FIG. 5B

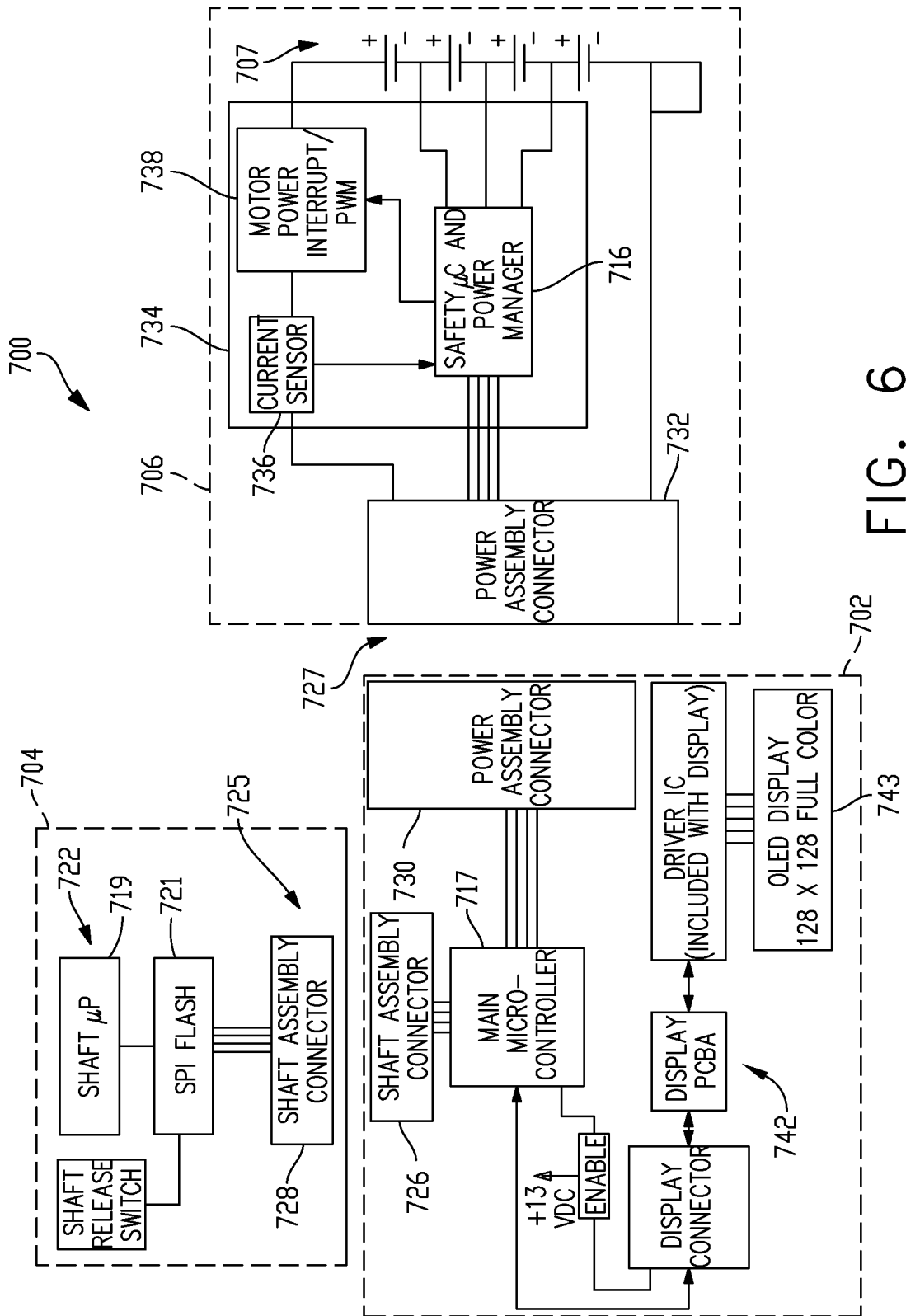


FIG. 6

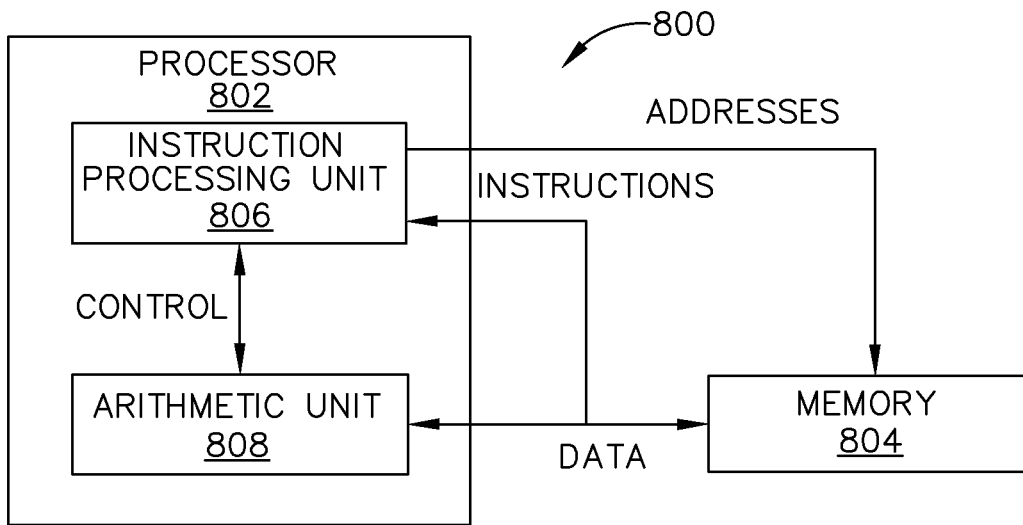


FIG. 7

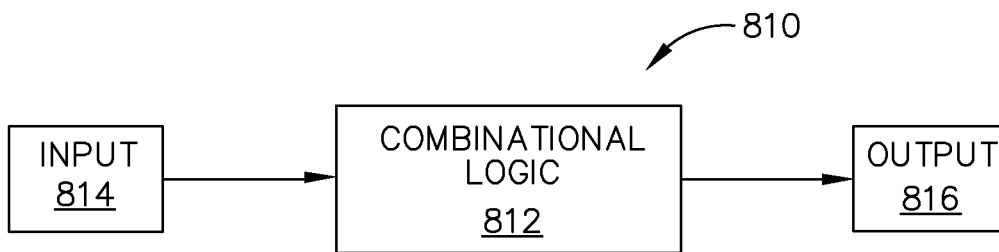


FIG. 8

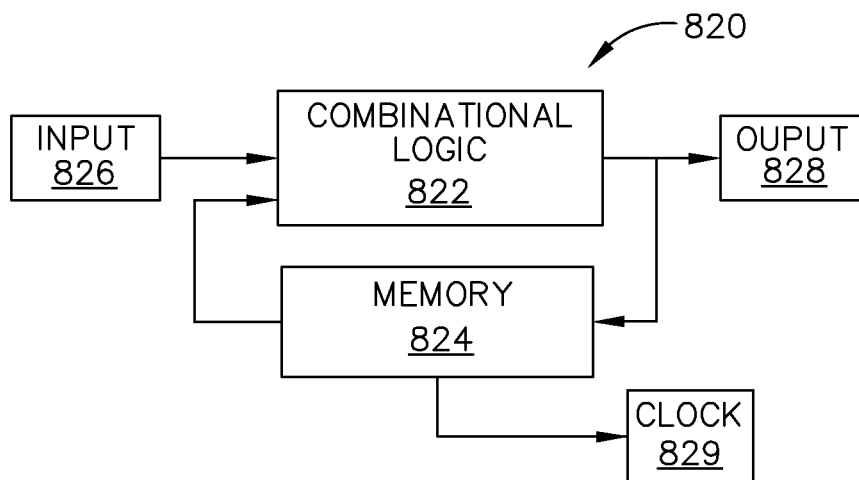


FIG. 9

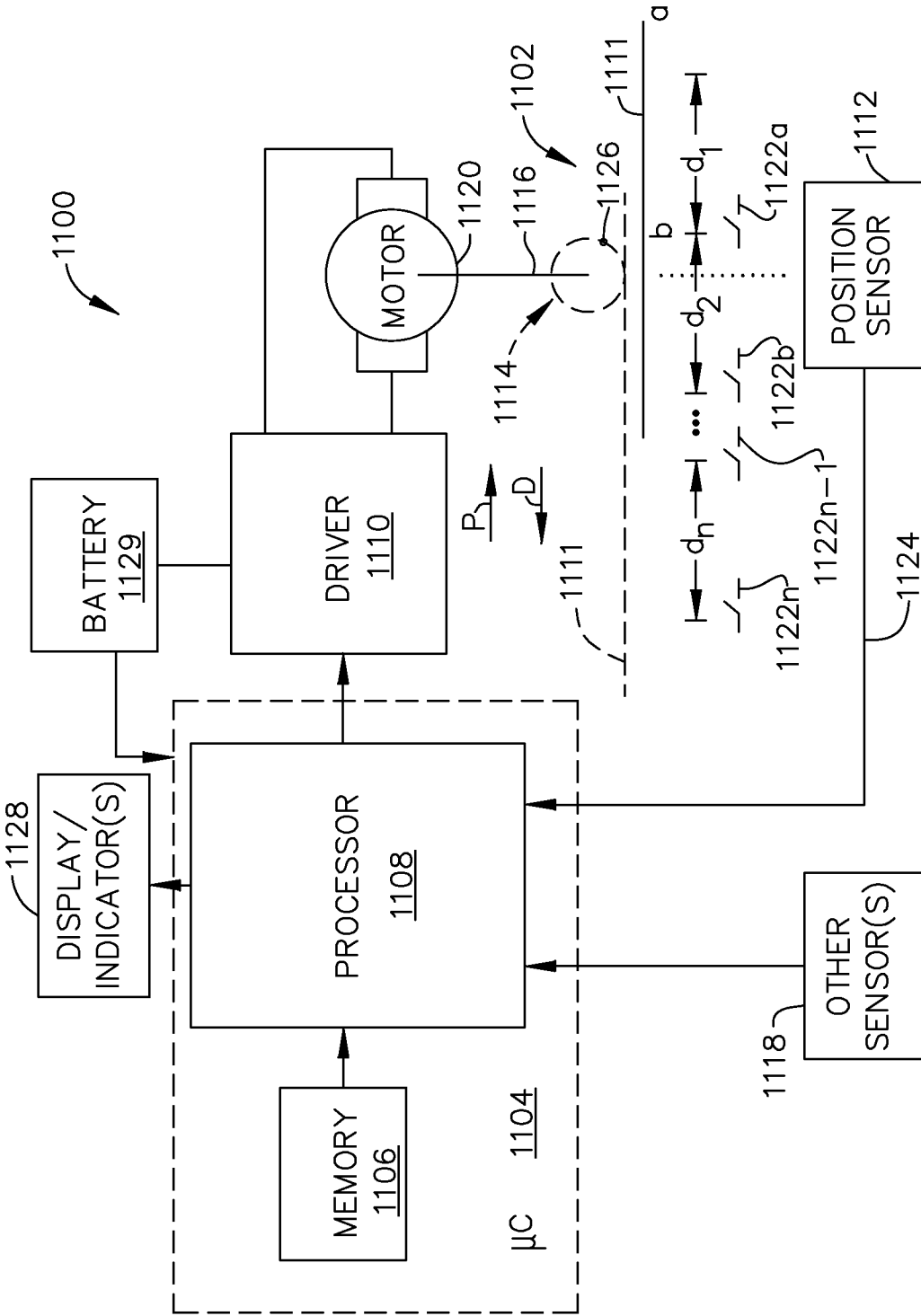


FIG. 10

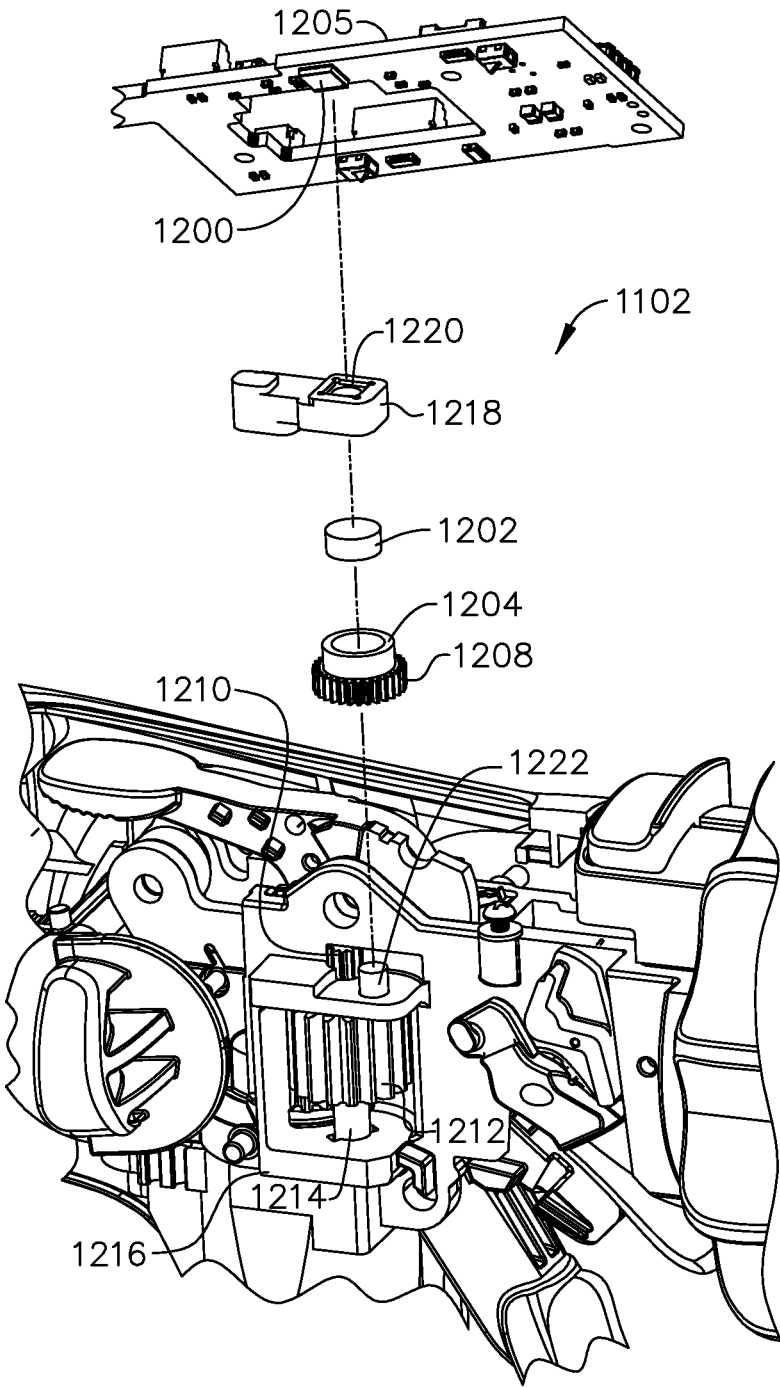


FIG. 11

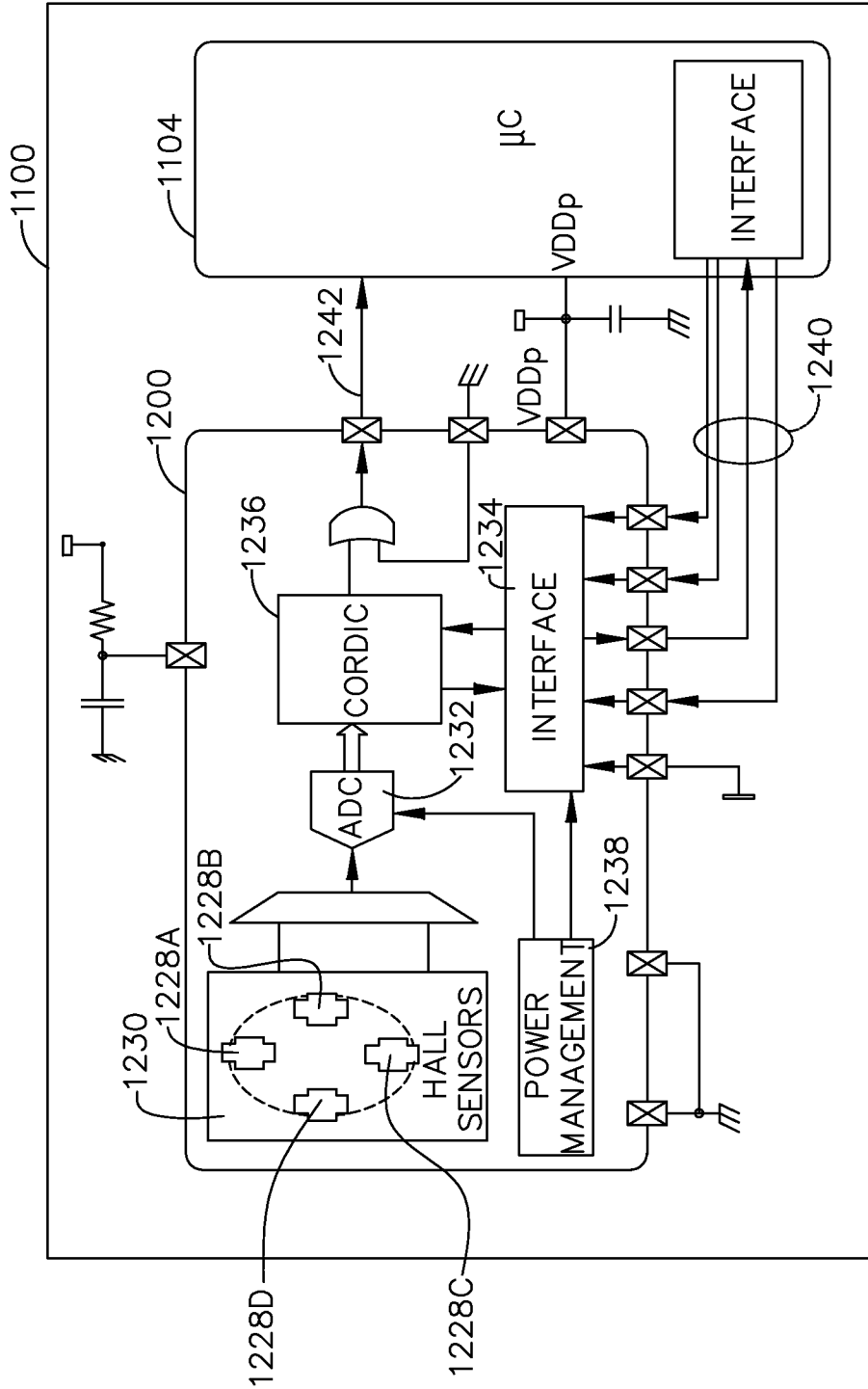


FIG. 12

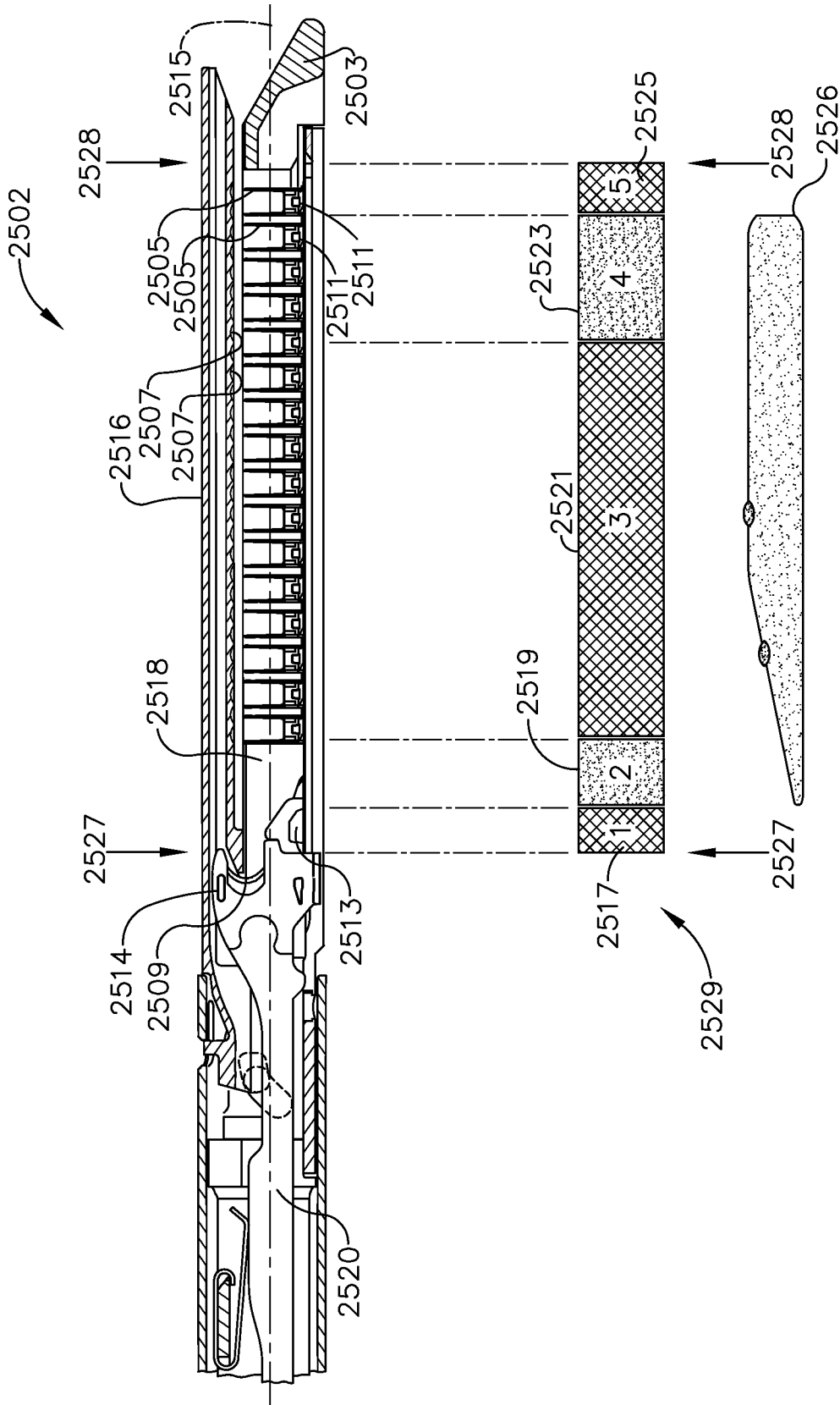


FIG. 13

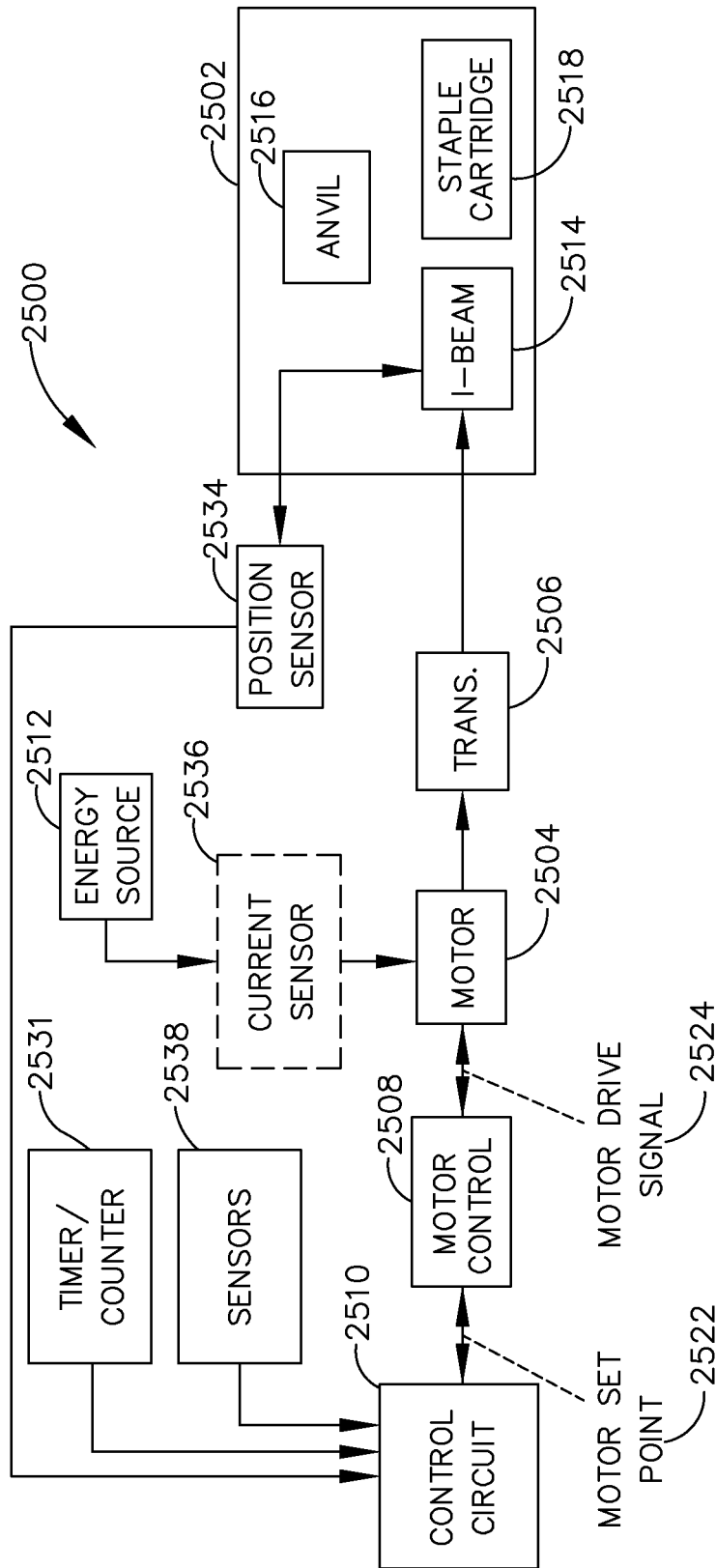


FIG. 14

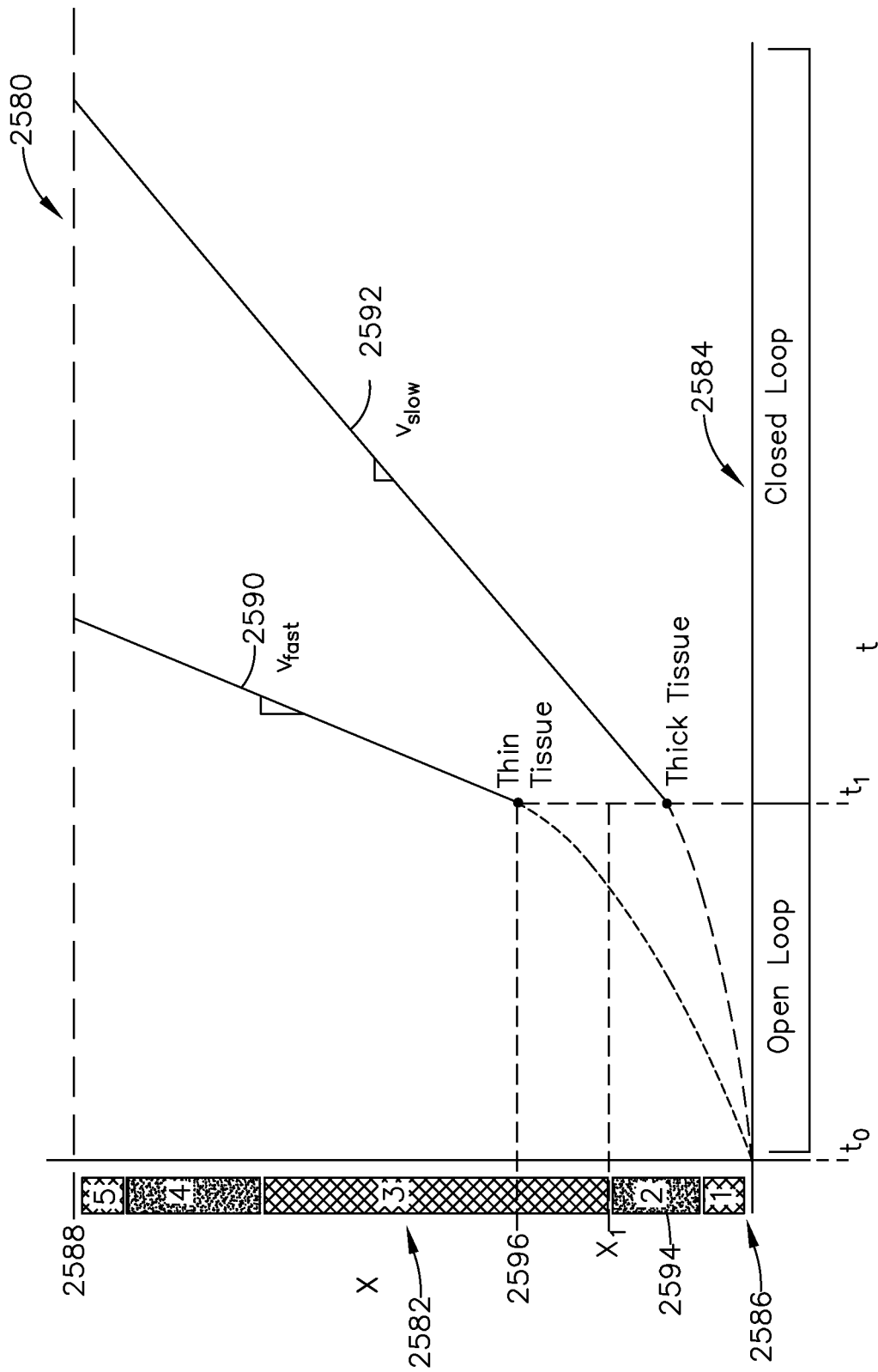


FIG. 15

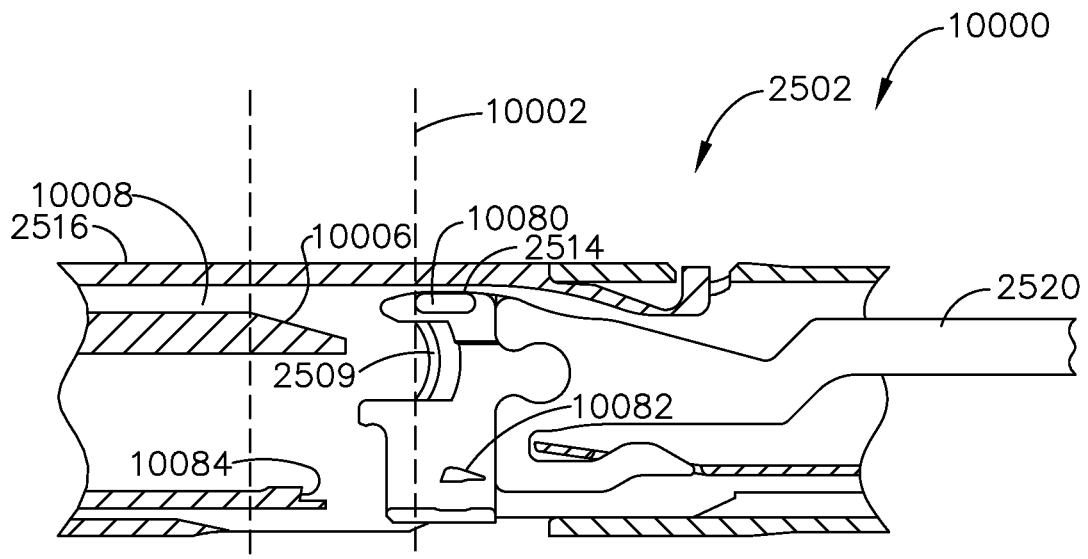


FIG. 16A

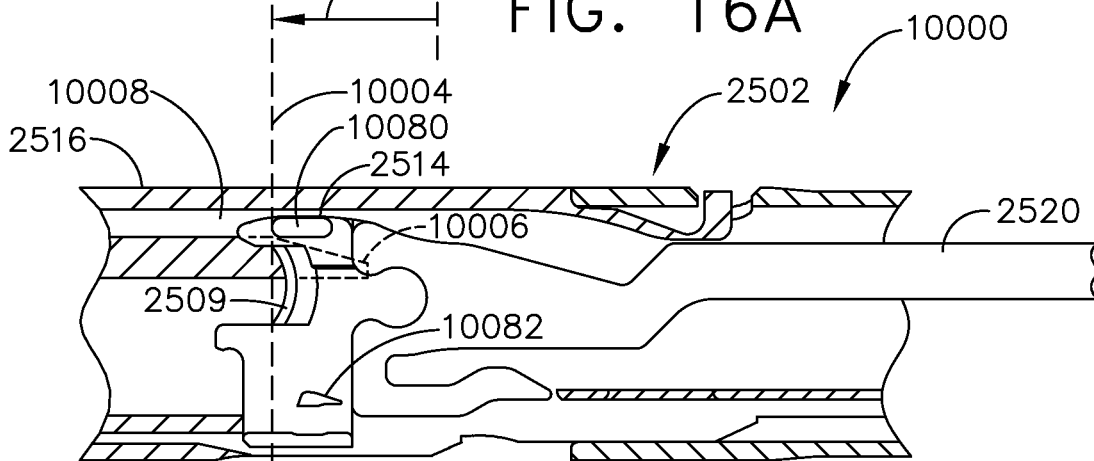


FIG. 16B

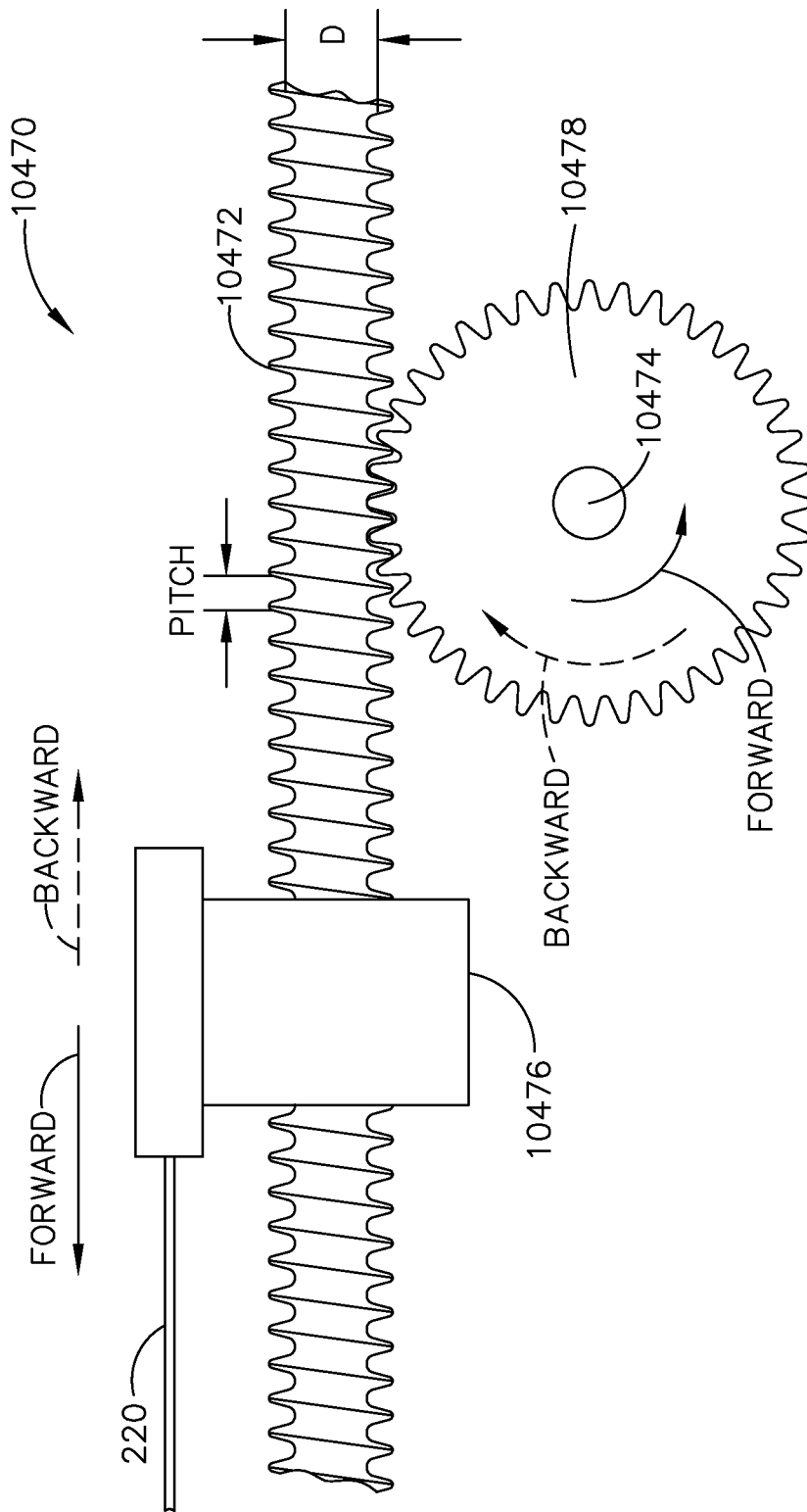


FIG. 17

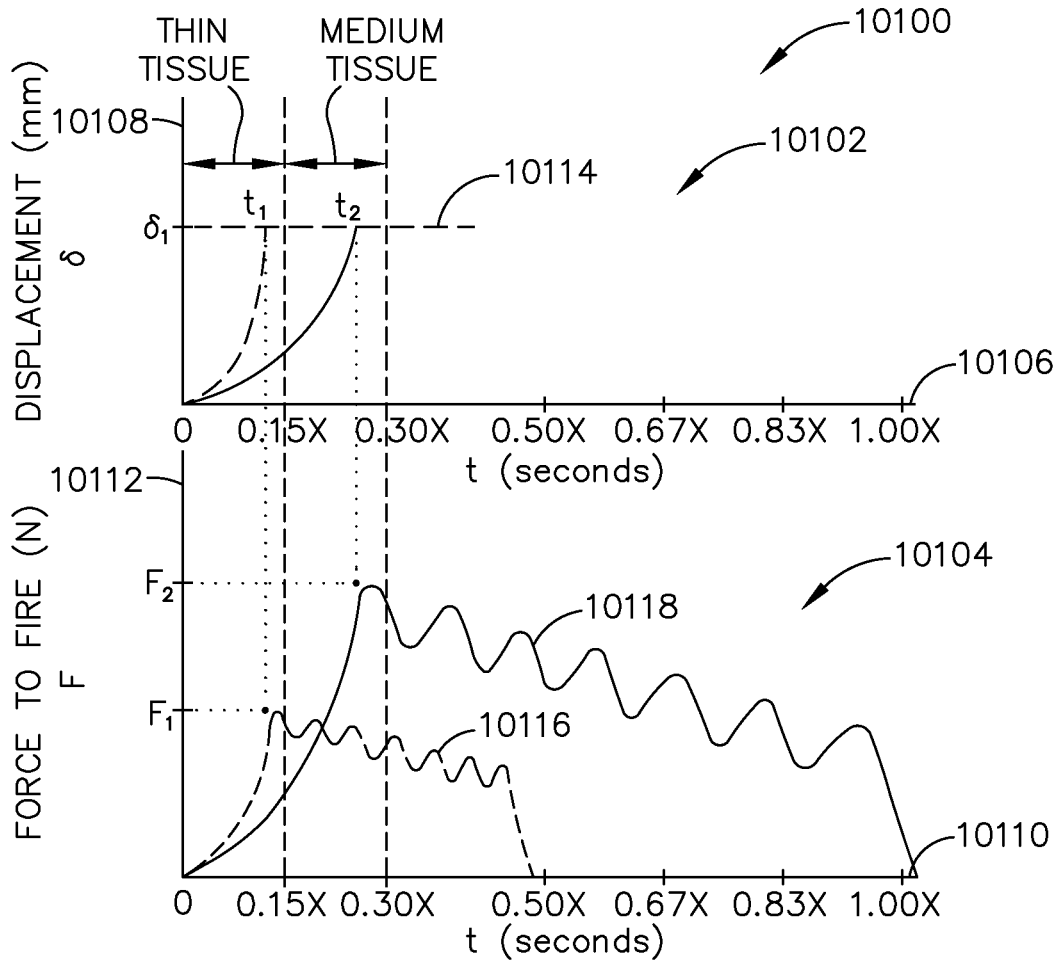


FIG. 19

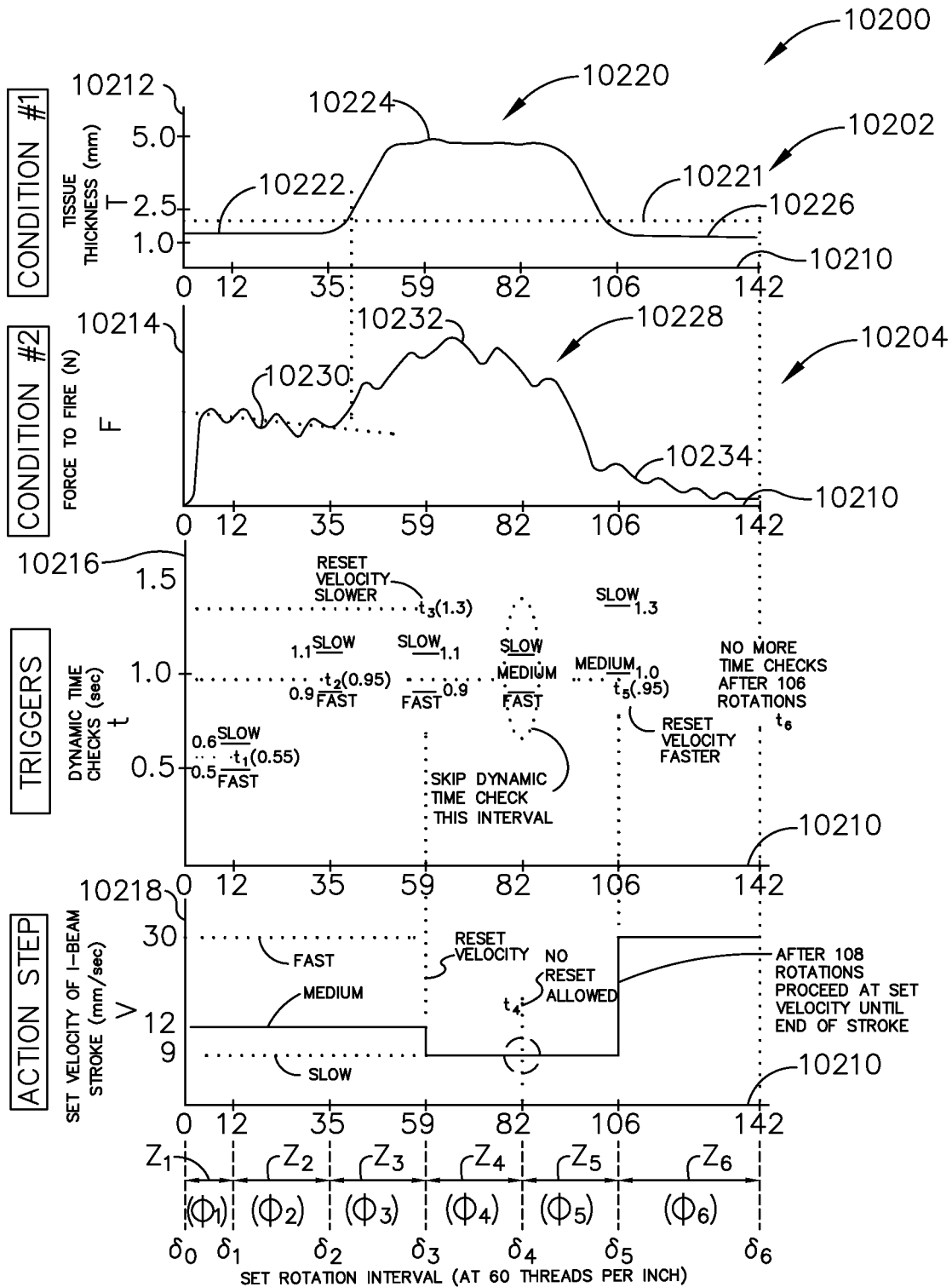


FIG. 20

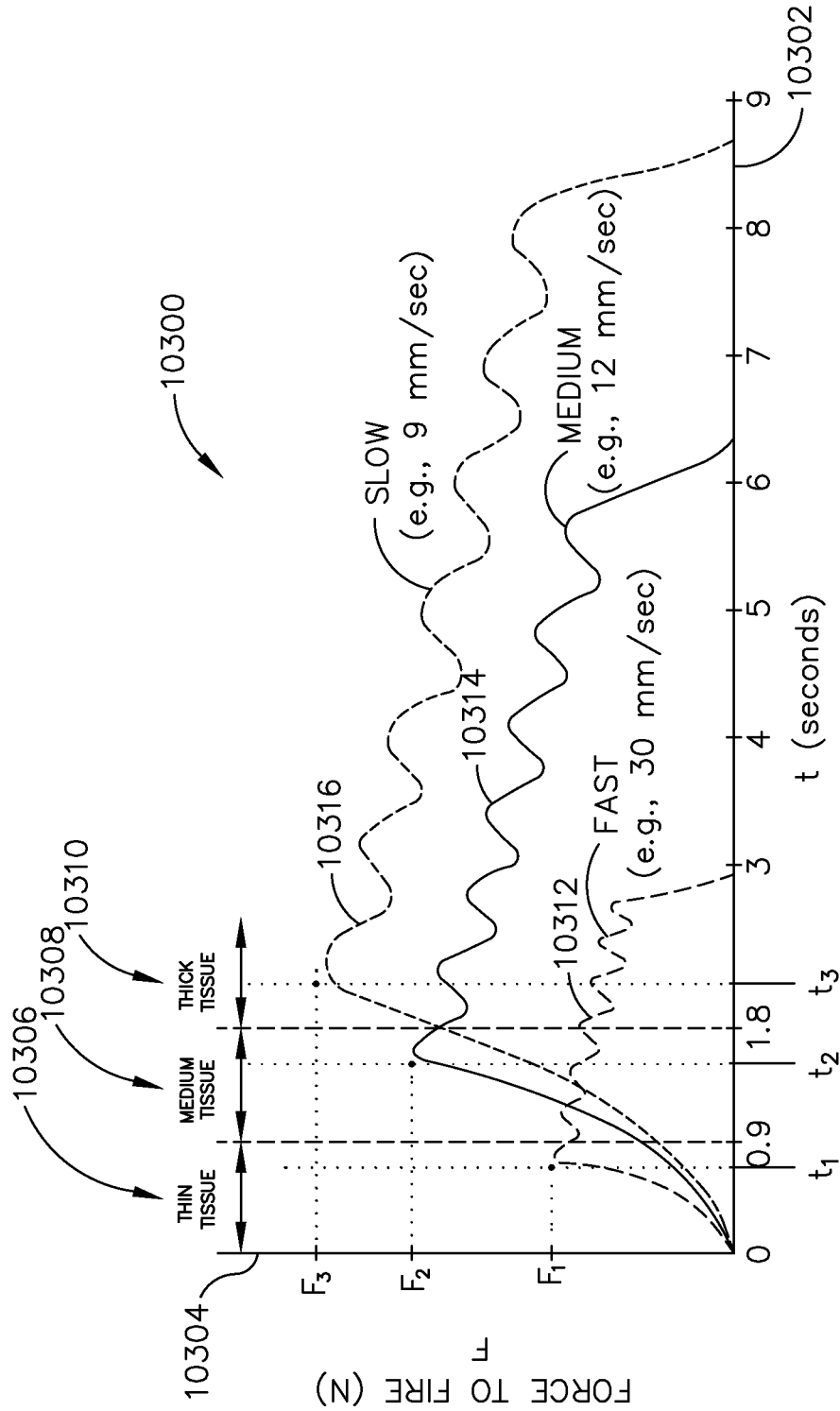


FIG. 21

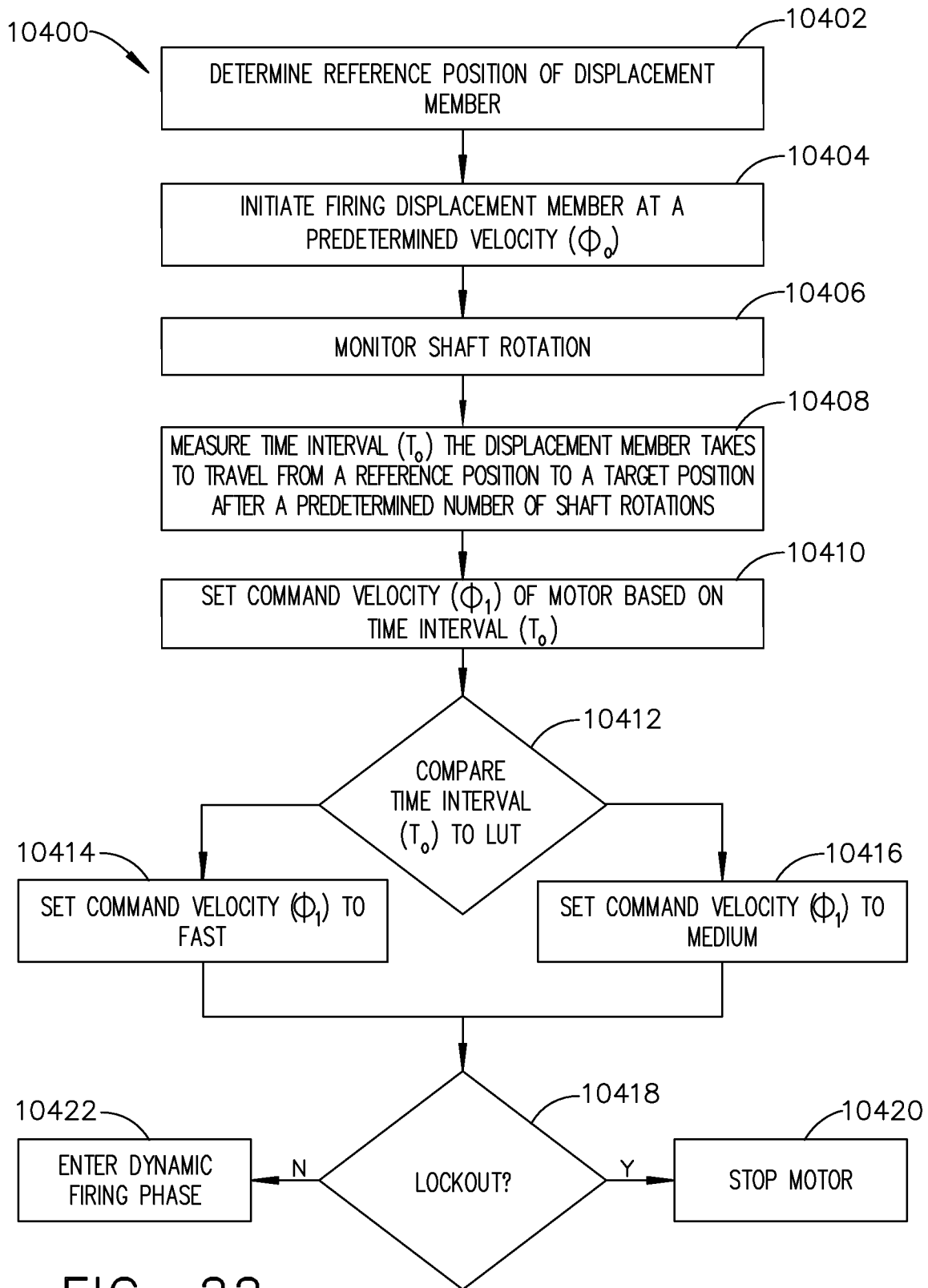


FIG. 22

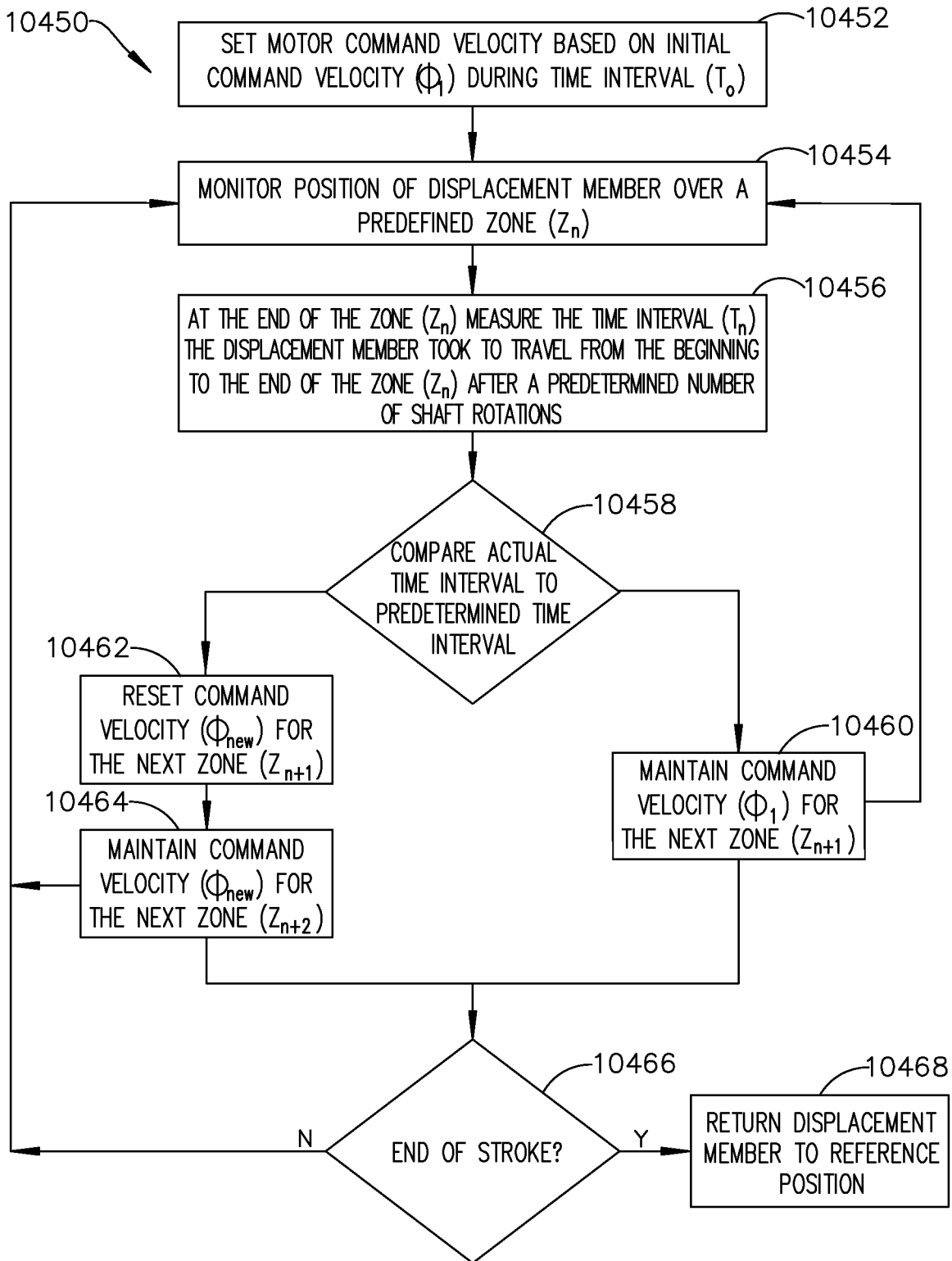


FIG. 23

1

**CLOSED LOOP FEEDBACK CONTROL OF
MOTOR VELOCITY OF A SURGICAL
STAPLING AND CUTTING INSTRUMENT
BASED ON MEASURED TIME OVER A
SPECIFIED NUMBER OF SHAFT
ROTATIONS**

TECHNICAL FIELD

The present disclosure relates to surgical instruments and, in various circumstances, to surgical stapling and cutting instruments and staple cartridges therefor that are designed to staple and cut tissue.

BACKGROUND

In a motorized surgical stapling and cutting instrument it may be useful to control the velocity of a cutting member or to control the articulation velocity of an end effector. Velocity of a displacement member may be determined by measuring elapsed time at predetermined position intervals of the displacement member or measuring the position of the displacement member at predetermined time intervals. The control may be open loop or closed loop. Such measurements may be useful to evaluate tissue conditions such as tissue thickness and adjust the velocity of the cutting member during a firing stroke to account for the tissue conditions. Tissue thickness may be determined by comparing expected velocity of the cutting member to the actual velocity of the cutting member. In some situations, it may be useful to articulate the end effector at a constant articulation velocity. In other situations, it may be useful to drive the end effector at a different articulation velocity than a default articulation velocity at one or more regions within a sweep range of the end effector.

During use of a motorized surgical stapling and cutting instrument it is possible that the velocity of the cutting member or the firing member may need to be measured and adjusted to compensate for tissue conditions. In thick tissue the velocity may be decreased to lower the force to fire experienced by the cutting member or firing member if the force to fire experienced by the cutting member or firing member is greater than a threshold force. In thin tissue the velocity may be increased if the force to fire experienced by the cutting member or firing member is less than a threshold. Therefore, it may be desirable to provide a closed loop feedback system that measures and adjusts the velocity of the cutting member or firing member based on a measurement of time over a specified number of shaft rotations. It may be desirable to measure the number of shaft rotations at a fixed time.

SUMMARY

In one aspect, the present disclosure provides a surgical instrument. The surgical instrument, comprising a displacement member configured to translate within the surgical instrument over a plurality of predefined zones; a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member; a control circuit coupled to the motor; a position sensor coupled to the control circuit, the position sensor configured to monitor the rotation of the shaft; a timer circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time; wherein the control circuit is configured to: receive, from the position sensor, rotations of the shaft in a current zone defined by a set rotation interval; measure time

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at a set position of the rotation interval, wherein the measured time is defined as the time taken by the displacement member to traverse the rotation interval based on a predetermined number of shaft rotations; and set a command velocity of the displacement member for a subsequent zone based on the measured time in the current predefined zone.

In another aspect, the surgical instrument comprises a displacement member configured to translate within the surgical instrument over a plurality of predefined zones; a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member; a control circuit coupled to the motor; a position sensor coupled to the control circuit, the position sensor configured to monitor the rotation of the shaft; a timer circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time; wherein the control circuit is configured to: receive, from the position sensor, rotations of the shaft in a current zone defined by a predetermined rotation interval; measure time as the displacement member moves from a parked position to a target position based on a predetermined number of shaft rotations; and set a command velocity of the displacement member for a first dynamic zone based on the measured time.

In another aspect, the present disclosure provides a method of controlling motor velocity in a surgical instrument, the surgical instrument comprising a displacement member configured to translate within the surgical instrument over a plurality of predefined zones, a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member, a control circuit coupled to the motor, a position sensor coupled to the control circuit, the position sensor configured to monitor the rotation of the shaft, a timer circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time, the method comprising: receiving, from a position sensor, rotations of the shaft in a current zone defined by a set rotation interval; measuring, by a timer circuit, a time at a set position of the of the rotation interval, wherein the measured time is defined by the time taken by the displacement member to traverse the rotation interval based on a predetermined number of shaft rotations; and setting, by the control circuit, a command velocity of the displacement member for a subsequent zone based on the measured time in the current zone.

FIGURES

The novel features of the aspects described herein are set forth with particularity in the appended claims. These aspects, however, both as to organization and methods of operation may be better understood by reference to the following description, taken in conjunction with the accompanying drawings.

FIG. 1 is a perspective view of a surgical instrument that has an interchangeable shaft assembly operably coupled thereto according to one aspect of this disclosure.

FIG. 2 is an exploded assembly view of a portion of the surgical instrument of FIG. 1 according to one aspect of this disclosure.

FIG. 3 is an exploded assembly view of portions of the interchangeable shaft assembly according to one aspect of this disclosure.

FIG. 4 is an exploded view of an end effector of the surgical instrument of FIG. 1 according to one aspect of this disclosure.

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FIGS. 5A-5B is a block diagram of a control circuit of the surgical instrument of FIG. 1 spanning two drawing sheets according to one aspect of this disclosure.

FIG. 6 is a block diagram of the control circuit of the surgical instrument of FIG. 1 illustrating interfaces between the handle assembly, the power assembly, and the handle assembly and the interchangeable shaft assembly according to one aspect of this disclosure.

FIG. 7 illustrates a control circuit configured to control aspects of the surgical instrument of FIG. 1 according to one aspect of this disclosure.

FIG. 8 illustrates a combinational logic circuit configured to control aspects of the surgical instrument of FIG. 1 according to one aspect of this disclosure.

FIG. 9 illustrates a sequential logic circuit configured to control aspects of the surgical instrument of FIG. 1 according to one aspect of this disclosure.

FIG. 10 is a diagram of an absolute positioning system of the surgical instrument of FIG. 1 where the absolute positioning system comprises a controlled motor drive circuit arrangement comprising a sensor arrangement according to one aspect of this disclosure.

FIG. 11 is an exploded perspective view of the sensor arrangement for an absolute positioning system showing a control circuit board assembly and the relative alignment of the elements of the sensor arrangement according to one aspect of this disclosure.

FIG. 12 is a diagram of a position sensor comprising a magnetic rotary absolute positioning system according to one aspect of this disclosure.

FIG. 13 is a section view of an end effector of the surgical instrument of FIG. 1 showing a firing member stroke relative to tissue grasped within the end effector according to one aspect of this disclosure.

FIG. 14 illustrates a block diagram of a surgical instrument programmed to control distal translation of a displacement member according to one aspect of this disclosure.

FIG. 15 illustrates a diagram plotting two example displacement member strokes executed according to one aspect of this disclosure.

FIG. 16A illustrates an end effector comprising a firing member coupled to an I-beam comprising a cutting edge according to one aspect of this disclosure.

FIG. 16B illustrates an end effector where the I-beam is located in a target position at the top of a ramp with the top pin engaged in the T-slot according to one aspect of this disclosure.

FIG. 17 illustrates a screw drive system 10470 that may be employed with the surgical instrument 10 (FIG. 1) according to one aspect of this disclosure.

FIG. 18 illustrates the I-beam firing stroke is illustrated by a chart aligned with the end effector according to one aspect of this disclosure.

FIG. 19 is a graphical depiction comparing I-beam stroke displacement as a function of time (top graph) and expected force-to-fire as a function of time (bottom graph) according to one aspect of this disclosure.

FIG. 20 is a graphical depiction comparing tissue thickness as a function of set rotation interval of I-beam stroke (top graph), force to fire as a function of set rotation interval of I-beam stroke (second graph from the top), dynamic time checks as a function of set rotation interval of I-beam stroke (third graph from the top), and set velocity of I-beam as a function of set rotation interval of I-beam stroke (bottom graph) according to one aspect of this disclosure.

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FIG. 21 is a graphical depiction of force to fire as a function of time comparing slow, medium and fast I-beam displacement velocities according to one aspect of this disclosure.

FIG. 22 is a logic flow diagram of a process depicting a control program or logic configuration for controlling command velocity in an initial firing stage according to one aspect of this disclosure.

FIG. 23 is a logic flow diagram of a process depicting a control program or logic configuration for controlling command velocity in a dynamic firing stage according to one aspect of this disclosure.

DESCRIPTION

Applicant of the present application owns the following patent applications filed on Jun. 20, 2017 and which are each herein incorporated by reference in their respective entireties:

U.S. patent application Ser. No. 15/627,998, titled CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT BASED ON ANGLE OF ARTICULATION, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Pat. No. 10,390,841.

U.S. patent application Ser. No. 15/628,019, titled SURGICAL INSTRUMENT WITH VARIABLE DURATION TRIGGER ARRANGEMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360443.

U.S. patent application Ser. No. 15/628,036, titled SYSTEMS AND METHODS FOR CONTROLLING DISPLACEMENT MEMBER MOTION OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360445.

U.S. patent application Ser. No. 15/628,050, titled SYSTEMS AND METHODS FOR CONTROLLING MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT ACCORDING TO ARTICULATION ANGLE OF END EFFECTOR, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017 now U.S. Patent Application Publication No. 2018/0360446.

U.S. patent application Ser. No. 15/628,075, titled SYSTEMS AND METHODS FOR CONTROLLING MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360447.

U.S. patent application Ser. No. 15/628,154, titled SURGICAL INSTRUMENT HAVING CONTROLLABLE ARTICULATION VELOCITY, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360456.

U.S. patent application Ser. No. 15/628,158, titled SYSTEMS AND METHODS FOR CONTROLLING VELOCITY OF A DISPLACEMENT MEMBER OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360449.

U.S. patent application Ser. No. 15/628,162, titled SYSTEMS AND METHODS FOR CONTROLLING DISPLACEMENT MEMBER VELOCITY FOR A SURGICAL INSTRUMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360450.

U.S. patent application Ser. No. 15/628,168, titled CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT BASED ON ANGLE OF ARTICULATION, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Pat. No. 10,327,767.

U.S. patent application Ser. No. 15/628,175, titled TECHNIQUES FOR ADAPTIVE CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360452.

U.S. patent application Ser. No. 15/628,045, titled TECHNIQUES FOR CLOSED LOOP CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, by inventors Raymond E. Parfett et al., filed Jun. 20, 2017, now U.S. Pat. No. 10,307,170.

U.S. patent application Ser. No. 15/628,053, titled CLOSED LOOP FEEDBACK CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT BASED ON MAGNITUDE OF VELOCITY ERROR MEASUREMENTS, by inventors Raymond E. Parfett et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360471.

U.S. patent application Ser. No. 15/628,060, titled CLOSED LOOP FEEDBACK CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT BASED ON MEASURED TIME OVER A SPECIFIED DISPLACEMENT DISTANCE, by inventors Jason L. Harris et al., filed Jun. 20, 2017, now U.S. Patent Application Publication Serial No. 2018/0360472.

U.S. Patent application Ser. No. 15/628,067, titled CLOSED LOOP FEEDBACK CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT BASED ON MEASURED DISPLACEMENT DISTANCE TRAVELED OVER A SPECIFIED TIME INTERVAL, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360473.

U.S. Patent application Ser. No. 15/628,029, titled SYSTEMS AND METHODS FOR CONTROLLING DISPLAYING MOTOR VELOCITY FOR A SURGICAL INSTRUMENT, by inventors Jason L. Harris et al., filed Jun. 20, 2017, now U.S. Pat. No. 10,368,864.

U.S. patent application Ser. No. 15/628,077, titled SYSTEMS AND METHODS FOR CONTROLLING MOTOR SPEED ACCORDING TO USER INPUT FOR A SURGICAL INSTRUMENT, by inventors Jason L. Harris et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360448.

U.S. patent application Ser. No. 15/628,115, titled CLOSED LOOP FEEDBACK CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT BASED ON SYSTEM CONDITIONS, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017, now U.S. Patent Application Publication No. 2018/0360455.

Applicant of the present application owns the following U.S. Design Patent Applications filed on Jun. 20, 2017 and which are each herein incorporated by reference in their respective entireties:

U.S. Design patent application Serial No. 29/608,238, titled GRAPHICAL USER INTERFACE FOR A DISPLAY OR PORTION THEREOF, by inventors Jason L. Harris et al., filed Jun. 20, 2017.

U.S. Design patent application Serial No. 29/608,231, titled GRAPHICAL USER INTERFACE FOR A DISPLAY OR PORTION THEREOF, by inventors Jason L. Harris et al., filed Jun. 20, 2017.

U.S. Design patent application Serial No. 29/608,246, titled GRAPHICAL USER INTERFACE FOR A DISPLAY OR PORTION THEREOF, by inventors Frederick E. Shelton, IV et al., filed Jun. 20, 2017.

Certain aspects are shown and described to provide an understanding of the structure, function, manufacture, and use of the disclosed devices and methods. Features shown or described in one example may be combined with features of other examples and modifications and variations are within the scope of this disclosure.

The terms “proximal” and “distal” are relative to a clinician manipulating the handle of the surgical instrument where “proximal” refers to the portion closer to the clinician and “distal” refers to the portion located further from the clinician. For expediency, spatial terms “vertical,” “horizontal,” “up,” and “down” used with respect to the drawings are not intended to be limiting and/or absolute, because surgical instruments can be used in many orientations and positions.

Example devices and methods are provided for performing laparoscopic and minimally invasive surgical procedures. Such devices and methods, however, can be used in other surgical procedures and applications including open surgical procedures, for example. The surgical instruments can be inserted into a through a natural orifice or through an incision or puncture hole formed in tissue. The working portions or end effector portions of the instruments can be inserted directly into the body or through an access device that has a working channel through which the end effector and elongated shaft of the surgical instrument can be advanced.

FIGS. 1-4 depict a motor-driven surgical instrument **10** for cutting and fastening that may or may not be reused. In the illustrated examples, the surgical instrument **10** includes a housing **12** that comprises a handle assembly **14** that is configured to be grasped, manipulated, and actuated by the clinician. The housing **12** is configured for operable attachment to an interchangeable shaft assembly **200** that has an end effector **300** operably coupled thereto that is configured to perform one or more surgical tasks or procedures. In accordance with the present disclosure, various forms of interchangeable shaft assemblies may be effectively employed in connection with robotically controlled surgical systems. The term “housing” may encompass a housing or similar portion of a robotic system that houses or otherwise operably supports at least one drive system configured to generate and apply at least one control motion that could be used to actuate interchangeable shaft assemblies. The term “frame” may refer to a portion of a handheld surgical instrument. The term “frame” also may represent a portion of a robotically controlled surgical instrument and/or a portion of the robotic system that may be used to operably control a surgical instrument. Interchangeable shaft assemblies may be employed with various robotic systems, instruments, components, and methods disclosed in U.S. Pat. No. 9,072,535, entitled SURGICAL STAPLING INSTRUMENTS WITH ROTATABLE STAPLE DEPLOYMENT ARRANGEMENTS, which is herein incorporated by reference in its entirety.

FIG. 1 is a perspective view of a surgical instrument **10** that has an interchangeable shaft assembly **200** operably coupled thereto according to one aspect of this disclosure. The housing **12** includes an end effector **300** that comprises a surgical cutting and fastening device configured to oper-

ably support a surgical staple cartridge **304** therein. The housing **12** may be configured for use in connection with interchangeable shaft assemblies that include end effectors that are adapted to support different sizes and types of staple cartridges, have different shaft lengths, sizes, and types. The housing **12** may be employed with a variety of interchangeable shaft assemblies, including assemblies configured to apply other motions and forms of energy such as, radio frequency (RF) energy, ultrasonic energy, and/or motion to end effector arrangements adapted for use in connection with various surgical applications and procedures. The end effectors, shaft assemblies, handles, surgical instruments, and/or surgical instrument systems can utilize any suitable fastener, or fasteners, to fasten tissue. For instance, a fastener cartridge comprising a plurality of fasteners removably stored therein can be removably inserted into and/or attached to the end effector of a shaft assembly.

The handle assembly **14** may comprise a pair of interconnectable handle housing segments **16**, **18** interconnected by screws, snap features, adhesive, etc. The handle housing segments **16**, **18** cooperate to form a pistol grip portion **19** that can be gripped and manipulated by the clinician. The handle assembly **14** operably supports a plurality of drive systems configured to generate and apply control motions to corresponding portions of the interchangeable shaft assembly that is operably attached thereto. A display may be provided below a cover **45**.

FIG. 2 is an exploded assembly view of a portion of the surgical instrument **10** of FIG. 1 according to one aspect of this disclosure. The handle assembly **14** may include a frame **20** that operably supports a plurality of drive systems. The frame **20** can operably support a “first” or closure drive system **30**, which can apply closing and opening motions to the interchangeable shaft assembly **200**. The closure drive system **30** may include an actuator such as a closure trigger **32** pivotally supported by the frame **20**. The closure trigger **32** is pivotally coupled to the handle assembly **14** by a pivot pin **33** to enable the closure trigger **32** to be manipulated by a clinician. When the clinician grips the pistol grip portion **19** of the handle assembly **14**, the closure trigger **32** can pivot from a starting or “unactuated” position to an “actuated” position and more particularly to a fully compressed or fully actuated position.

The handle assembly **14** and the frame **20** may operably support a firing drive system **80** configured to apply firing motions to corresponding portions of the interchangeable shaft assembly attached thereto. The firing drive system **80** may employ an electric motor **82** located in the pistol grip portion **19** of the handle assembly **14**. The electric motor **82** may be a DC brushed motor having a maximum rotational speed of approximately 25,000 RPM, for example. In other arrangements, the motor may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The electric motor **82** may be powered by a power source **90** that may comprise a removable power pack **92**. The removable power pack **92** may comprise a proximal housing portion **94** configured to attach to a distal housing portion **96**. The proximal housing portion **94** and the distal housing portion **96** are configured to operably support a plurality of batteries **98** therein. Batteries **98** may each comprise, for example, a Lithium Ion (LI) or other suitable battery. The distal housing portion **96** is configured for removable operable attachment to a control circuit board **100**, which is operably coupled to the electric motor **82**. Several batteries **98** connected in series may power the surgical instrument **10**. The power source **90** may be replaceable and/or rechargeable. A display **43**, which is

located below the cover **45**, is electrically coupled to the control circuit board **100**. The cover **45** may be removed to expose the display **43**.

The electric motor **82** can include a rotatable shaft (not shown) that operably interfaces with a gear reducer assembly **84** mounted in meshing engagement with a set, or rack, of drive teeth **122** on a longitudinally movable drive member **120**. The longitudinally movable drive member **120** has a rack of drive teeth **122** formed thereon for meshing engagement with a corresponding drive gear **86** of the gear reducer assembly **84**.

In use, a voltage polarity provided by the power source **90** can operate the electric motor **82** in a clockwise direction wherein the voltage polarity applied to the electric motor by the battery can be reversed in order to operate the electric motor **82** in a counter-clockwise direction. When the electric motor **82** is rotated in one direction, the longitudinally movable drive member **120** will be axially driven in the distal direction “DD.” When the electric motor **82** is driven in the opposite rotary direction, the longitudinally movable drive member **120** will be axially driven in a proximal direction “PD.” The handle assembly **14** can include a switch that can be configured to reverse the polarity applied to the electric motor **82** by the power source **90**. The handle assembly **14** may include a sensor configured to detect the position of the longitudinally movable drive member **120** and/or the direction in which the longitudinally movable drive member **120** is being moved.

Actuation of the electric motor **82** can be controlled by a firing trigger **130** that is pivotally supported on the handle assembly **14**. The firing trigger **130** may be pivoted between an unactuated position and an actuated position.

Turning back to FIG. 1, the interchangeable shaft assembly **200** includes an end effector **300** comprising an elongated channel **302** configured to operably support a surgical staple cartridge **304** therein. The end effector **300** may include an anvil **306** that is pivotally supported relative to the elongated channel **302**. The interchangeable shaft assembly **200** may include an articulation joint **270**. Construction and operation of the end effector **300** and the articulation joint **270** are set forth in U.S. Patent Application Publication No. 2014/0263541, entitled ARTICULATABLE SURGICAL INSTRUMENT COMPRISING AN ARTICULATION LOCK, which is herein incorporated by reference in its entirety. The interchangeable shaft assembly **200** may include a proximal housing or nozzle **201** comprised of nozzle portions **202**, **203**. The interchangeable shaft assembly **200** may include a closure tube **260** extending along a shaft axis SA that can be utilized to close and/or open the anvil **306** of the end effector **300**.

Turning back to FIG. 1, the closure tube **260** is translated distally (direction “DD”) to close the anvil **306**, for example, in response to the actuation of the closure trigger **32** in the manner described in the aforementioned reference U.S. Patent Application Publication No. 2014/0263541. The anvil **306** is opened by proximally translating the closure tube **260**. In the anvil-open position, the closure tube **260** is moved to its proximal position.

FIG. 3 is another exploded assembly view of portions of the interchangeable shaft assembly **200** according to one aspect of this disclosure. The interchangeable shaft assembly **200** may include a firing member **220** supported for axial travel within the spine **210**. The firing member **220** includes an intermediate firing shaft **222** configured to attach to a distal cutting portion or knife bar **280**. The firing member **220** may be referred to as a “second shaft” or a “second shaft assembly”. The intermediate firing shaft **222** may include a

longitudinal slot 223 in a distal end configured to receive a tab 284 on the proximal end 282 of the knife bar 280. The longitudinal slot 223 and the proximal end 282 may be configured to permit relative movement there between and can comprise a slip joint 286. The slip joint 286 can permit the intermediate firing shaft 222 of the firing member 220 to articulate the end effector 300 about the articulation joint 270 without moving, or at least substantially moving, the knife bar 280. Once the end effector 300 has been suitably oriented, the intermediate firing shaft 222 can be advanced distally until a proximal sidewall of the longitudinal slot 223 contacts the tab 284 to advance the knife bar 280 and fire the staple cartridge positioned within the channel 302. The spine 210 has an elongated opening or window 213 therein to facilitate assembly and insertion of the intermediate firing shaft 222 into the spine 210. Once the intermediate firing shaft 222 has been inserted therein, a top frame segment 215 may be engaged with the shaft frame 212 to enclose the intermediate firing shaft 222 and knife bar 280 therein. Operation of the firing member 220 may be found in U.S. Patent Application Publication No. 2014/0263541. A spine 210 can be configured to slidably support a firing member 220 and the closure tube 260 that extends around the spine 210. The spine 210 may slidably support an articulation driver 230.

The interchangeable shaft assembly 200 can include a clutch assembly 400 configured to selectively and releasably couple the articulation driver 230 to the firing member 220. The clutch assembly 400 includes a lock collar, or lock sleeve 402, positioned around the firing member 220 wherein the lock sleeve 402 can be rotated between an engaged position in which the lock sleeve 402 couples the articulation driver 230 to the firing member 220 and a disengaged position in which the articulation driver 230 is not operably coupled to the firing member 220. When the lock sleeve 402 is in the engaged position, distal movement of the firing member 220 can move the articulation driver 230 distally and, correspondingly, proximal movement of the firing member 220 can move the articulation driver 230 proximally. When the lock sleeve 402 is in the disengaged position, movement of the firing member 220 is not transmitted to the articulation driver 230 and, as a result, the firing member 220 can move independently of the articulation driver 230. The nozzle 201 may be employed to operably engage and disengage the articulation drive system with the firing drive system in the various manners described in U.S. Patent Application Publication No. 2014/0263541.

The interchangeable shaft assembly 200 can comprise a slip ring assembly 600 which can be configured to conduct electrical power to and/or from the end effector 300 and/or communicate signals to and/or from the end effector 300, for example. The slip ring assembly 600 can comprise a proximal connector flange 604 and a distal connector flange 601 positioned within a slot defined in the nozzle portions 202, 203. The proximal connector flange 604 can comprise a first face and the distal connector flange 601 can comprise a second face positioned adjacent to and movable relative to the first face. The distal connector flange 601 can rotate relative to the proximal connector flange 604 about the shaft axis SA-SA (FIG. 1). The proximal connector flange 604 can comprise a plurality of concentric, or at least substantially concentric, conductors 602 defined in the first face thereof. A connector 607 can be mounted on the proximal side of the distal connector flange 601 and may have a plurality of contacts wherein each contact corresponds to and is in electrical contact with one of the conductors 602. Such an arrangement permits relative rotation between the proximal

connector flange 604 and the distal connector flange 601 while maintaining electrical contact there between. The proximal connector flange 604 can include an electrical connector 606 that can place the conductors 602 in signal communication with a shaft circuit board, for example. In at least one instance, a wiring harness comprising a plurality of conductors can extend between the electrical connector 606 and the shaft circuit board. The electrical connector 606 may extend proximally through a connector opening defined in the chassis mounting flange. U.S. Patent Application Publication No. 2014/0263551, entitled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, is incorporated herein by reference in its entirety. U.S. Patent Application Publication No. 2014/0263552, entitled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, is incorporated by reference in its entirety. Further details regarding slip ring assembly 600 may be found in U.S. Patent Application Publication No. 2014/0263541.

The interchangeable shaft assembly 200 can include a proximal portion fixably mounted to the handle assembly 14 and a distal portion that is rotatable about a longitudinal axis. The rotatable distal shaft portion can be rotated relative to the proximal portion about the slip ring assembly 600. The distal connector flange 601 of the slip ring assembly 600 can be positioned within the rotatable distal shaft portion.

FIG. 4 is an exploded view of one aspect of an end effector 300 of the surgical instrument 10 of FIG. 1 according to one aspect of this disclosure. The end effector 300 may include the anvil 306 and the surgical staple cartridge 304. The anvil 306 may be coupled to an elongated channel 302. Apertures 199 can be defined in the elongated channel 302 to receive pins 152 extending from the anvil 306 to allow the anvil 306 to pivot from an open position to a closed position relative to the elongated channel 302 and surgical staple cartridge 304. A firing bar 172 is configured to longitudinally translate into the end effector 300. The firing bar 172 may be constructed from one solid section, or may include a laminate material comprising a stack of steel plates. The firing bar 172 comprises an I-beam 178 and a cutting edge 182 at a distal end thereof. A distally projecting end of the firing bar 172 can be attached to the I-beam 178 to assist in spacing the anvil 306 from a surgical staple cartridge 304 positioned in the elongated channel 302 when the anvil 306 is in a closed position. The I-beam 178 may include a sharpened cutting edge 182 to sever tissue as the I-beam 178 is advanced distally by the firing bar 172. In operation, the I-beam 178 may, or fire, the surgical staple cartridge 304. The surgical staple cartridge 304 can include a molded cartridge body 194 that holds a plurality of staples 191 resting upon staple drivers 192 within respective upwardly open staple cavities 195. A wedge sled 190 is driven distally by the I-beam 178, sliding upon a cartridge tray 196 of the surgical staple cartridge 304. The wedge sled 190 upwardly cams the staple drivers 192 to force out the staples 191 into deforming contact with the anvil 306 while the cutting edge 182 of the I-beam 178 severs clamped tissue.

The I-beam 178 can include upper pins 180 that engage the anvil 306 during firing. The I-beam 178 may include middle pins 184 and a bottom foot 186 to engage portions of the cartridge body 194, cartridge tray 196, and elongated channel 302. When a surgical staple cartridge 304 is positioned within the elongated channel 302, a slot 193 defined in the cartridge body 194 can be aligned with a longitudinal slot 197 defined in the cartridge tray 196 and a slot 189 defined in the elongated channel 302. In use, the I-beam 178 can slide through the aligned longitudinal slots 193, 197, and

189 wherein, as indicated in FIG. 4, the bottom foot 186 of the I-beam 178 can engage a groove running along the bottom surface of elongated channel 302 along the length of slot 189, the middle pins 184 can engage the top surfaces of cartridge tray 196 along the length of longitudinal slot 197, and the upper pins 180 can engage the anvil 306. The I-beam 178 can space, or limit the relative movement between, the anvil 306 and the surgical staple cartridge 304 as the firing bar 172 is advanced distally to fire the staples from the surgical staple cartridge 304 and/or incise the tissue captured between the anvil 306 and the surgical staple cartridge 304. The firing bar 172 and the I-beam 178 can be retracted proximally allowing the anvil 306 to be opened to release the two stapled and severed tissue portions.

FIGS. 5A-5B is a block diagram of a control circuit 700 of the surgical instrument 10 of FIG. 1 spanning two drawing sheets according to one aspect of this disclosure. Referring primarily to FIGS. 5A-5B, a handle assembly 702 may include a motor 714 which can be controlled by a motor driver 715 and can be employed by the firing system of the surgical instrument 10. In various forms, the motor 714 may be a DC brushed driving motor having a maximum rotational speed of approximately 25,000 RPM. In other arrangements, the motor 714 may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The motor driver 715 may comprise an H-Bridge driver comprising field-effect transistors (FETs) 719, for example. The motor 714 can be powered by the power assembly 706 releasably mounted to the handle assembly 200 for supplying control power to the surgical instrument 10. The power assembly 706 may comprise a battery which may include a number of battery cells connected in series that can be used as the power source to power the surgical instrument 10. In certain circumstances, the battery cells of the power assembly 706 may be replaceable and/or rechargeable. In at least one example, the battery cells can be Lithium-Ion batteries which can be separably coupleable to the power assembly 706.

The shaft assembly 704 may include a shaft assembly controller 722 which can communicate with a safety controller and power management controller 716 through an interface while the shaft assembly 704 and the power assembly 706 are coupled to the handle assembly 702. For example, the interface may comprise a first interface portion 725 which may include one or more electric connectors for coupling engagement with corresponding shaft assembly electric connectors and a second interface portion 727 which may include one or more electric connectors for coupling engagement with corresponding power assembly electric connectors to permit electrical communication between the shaft assembly controller 722 and the power management controller 716 while the shaft assembly 704 and the power assembly 706 are coupled to the handle assembly 702. One or more communication signals can be transmitted through the interface to communicate one or more of the power requirements of the attached interchangeable shaft assembly 704 to the power management controller 716. In response, the power management controller may modulate the power output of the battery of the power assembly 706, as described below in greater detail, in accordance with the power requirements of the attached shaft assembly 704. The connectors may comprise switches which can be activated after mechanical coupling engagement of the handle assembly 702 to the shaft assembly 704 and/or to the power assembly 706 to allow electrical communication between the shaft assembly controller 722 and the power management controller 716.

The interface can facilitate transmission of the one or more communication signals between the power management controller 716 and the shaft assembly controller 722 by routing such communication signals through a main controller 717 residing in the handle assembly 702, for example. In other circumstances, the interface can facilitate a direct line of communication between the power management controller 716 and the shaft assembly controller 722 through the handle assembly 702 while the shaft assembly 704 and the power assembly 706 are coupled to the handle assembly 702.

The main controller 717 may be any single core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the main controller 717 may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), internal read-only memory (ROM) loaded with StellarisWare® software, 2 KB electrically erasable programmable read-only memory (EEPROM), one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analog, one or more 12-bit Analog-to-Digital Converters (ADC) with 12 analog input channels, details of which are available for the product datasheet.

The safety controller may be a safety controller platform comprising two controller-based families such as TMS570 and RM4x known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

The power assembly 706 may include a power management circuit which may comprise the power management controller 716, a power modulator 738, and a current sense circuit 736. The power management circuit can be configured to modulate power output of the battery based on the power requirements of the shaft assembly 704 while the shaft assembly 704 and the power assembly 706 are coupled to the handle assembly 702. The power management controller 716 can be programmed to control the power modulator 738 of the power output of the power assembly 706 and the current sense circuit 736 can be employed to monitor power output of the power assembly 706 to provide feedback to the power management controller 716 about the power output of the battery so that the power management controller 716 may adjust the power output of the power assembly 706 to maintain a desired output. The power management controller 716 and/or the shaft assembly controller 722 each may comprise one or more processors and/or memory units which may store a number of software modules.

The surgical instrument 10 (FIGS. 1-4) may comprise an output device 742 which may include devices for providing a sensory feedback to a user. Such devices may comprise, for example, visual feedback devices (e.g., an LCD display screen, LED indicators), audio feedback devices (e.g., a speaker, a buzzer) or tactile feedback devices (e.g., haptic actuators). In certain circumstances, the output device 742 may comprise a display 743 which may be included in the handle assembly 702. The shaft assembly controller 722 and/or the power management controller 716 can provide feedback to a user of the surgical instrument 10 through the

output device **742**. The interface can be configured to connect the shaft assembly controller **722** and/or the power management controller **716** to the output device **742**. The output device **742** can instead be integrated with the power assembly **706**. In such circumstances, communication between the output device **742** and the shaft assembly controller **722** may be accomplished through the interface while the shaft assembly **704** is coupled to the handle assembly **702**.

The control circuit **700** comprises circuit segments configured to control operations of the powered surgical instrument **10**. A safety controller segment (Segment 1) comprises a safety controller and the main controller **717** segment (Segment 2). The safety controller and/or the main controller **717** are configured to interact with one or more additional circuit segments such as an acceleration segment, a display segment, a shaft segment, an encoder segment, a motor segment, and a power segment. Each of the circuit segments may be coupled to the safety controller and/or the main controller **717**. The main controller **717** is also coupled to a flash memory. The main controller **717** also comprises a serial communication interface. The main controller **717** comprises a plurality of inputs coupled to, for example, one or more circuit segments, a battery, and/or a plurality of switches. The segmented circuit may be implemented by any suitable circuit, such as, for example, a printed circuit board assembly (PCBA) within the powered surgical instrument **10**. It should be understood that the term processor as used herein includes any microprocessor, processors, controller, controllers, or other basic computing device that incorporates the functions of a computer's central processing unit (CPU) on an integrated circuit or at most a few integrated circuits. The main controller **717** is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. The control circuit **700** can be configured to implement one or more of the processes described herein.

The acceleration segment (Segment 3) comprises an accelerometer. The accelerometer is configured to detect movement or acceleration of the powered surgical instrument **10**. Input from the accelerometer may be used to transition to and from a sleep mode, identify an orientation of the powered surgical instrument, and/or identify when the surgical instrument has been dropped. In some examples, the acceleration segment is coupled to the safety controller and/or the main controller **717**.

The display segment (Segment 4) comprises a display connector coupled to the main controller **717**. The display connector couples the main controller **717** to a display through one or more integrated circuit drivers of the display. The integrated circuit drivers of the display may be integrated with the display and/or may be located separately from the display. The display may comprise any suitable display, such as, for example, an organic light-emitting diode (OLED) display, a liquid-crystal display (LCD), and/or any other suitable display. In some examples, the display segment is coupled to the safety controller.

The shaft segment (Segment 5) comprises controls for an interchangeable shaft assembly **200** (FIGS. 1 and 3) coupled to the surgical instrument **10** (FIGS. 1-4) and/or one or more controls for an end effector **300** coupled to the interchangeable shaft assembly **200**. The shaft segment comprises a shaft connector configured to couple the main controller **717** to a shaft PCBA. The shaft PCBA comprises a low-power microcontroller with a ferroelectric random access memory

(FRAM), an articulation switch, a shaft release Hall effect switch, and a shaft PCBA EEPROM. The shaft PCBA EEPROM comprises one or more parameters, routines, and/or programs specific to the interchangeable shaft assembly **200** and/or the shaft PCBA. The shaft PCBA may be coupled to the interchangeable shaft assembly **200** and/or integral with the surgical instrument **10**. In some examples, the shaft segment comprises a second shaft EEPROM. The second shaft EEPROM comprises a plurality of algorithms, routines, parameters, and/or other data corresponding to one or more shaft assemblies **200** and/or end effectors **300** that may be interfaced with the powered surgical instrument **10**.

The position encoder segment (Segment 6) comprises one or more magnetic angle rotary position encoders. The one or more magnetic angle rotary position encoders are configured to identify the rotational position of the motor **714**, an interchangeable shaft assembly **200** (FIGS. 1 and 3), and/or an end effector **300** of the surgical instrument **10** (FIGS. 1-4). In some examples, the magnetic angle rotary position encoders may be coupled to the safety controller and/or the main controller **717**.

The motor circuit segment (Segment 7) comprises a motor **714** configured to control movements of the powered surgical instrument **10** (FIGS. 1-4). The motor **714** is coupled to the main microcontroller processor **717** by an H-bridge driver comprising one or more H-bridge field-effect transistors (FETs) and a motor controller. The H-bridge driver is also coupled to the safety controller. A motor current sensor is coupled in series with the motor to measure the current draw of the motor. The motor current sensor is in signal communication with the main controller **717** and/or the safety controller. In some examples, the motor **714** is coupled to a motor electromagnetic interference (EMI) filter.

The motor controller controls a first motor flag and a second motor flag to indicate the status and position of the motor **714** to the main controller **717**. The main controller **717** provides a pulse-width modulation (PWM) high signal, a PWM low signal, a direction signal, a synchronize signal, and a motor reset signal to the motor controller through a buffer. The power segment is configured to provide a segment voltage to each of the circuit segments.

The power segment (Segment 8) comprises a battery coupled to the safety controller, the main controller **717**, and additional circuit segments. The battery is coupled to the segmented circuit by a battery connector and a current sensor. The current sensor is configured to measure the total current draw of the segmented circuit. In some examples, one or more voltage converters are configured to provide predetermined voltage values to one or more circuit segments. For example, in some examples, the segmented circuit may comprise 3.3V voltage converters and/or 5V voltage converters. A boost converter is configured to provide a boost voltage up to a predetermined amount, such as, for example, up to 13V. The boost converter is configured to provide additional voltage and/or current during power intensive operations and prevent brownout or low-power conditions.

A plurality of switches are coupled to the safety controller and/or the main controller **717**. The switches may be configured to control operations of the surgical instrument **10** (FIGS. 1-4), of the segmented circuit, and/or indicate a status of the surgical instrument **10**. A bail-out door switch and Hall effect switch for bailout are configured to indicate the status of a bail-out door. A plurality of articulation switches, such as, for example, a left side articulation left switch, a left side articulation right switch, a left side articulation center switch, a right side articulation left

switch, a right side articulation right switch, and a right side articulation center switch are configured to control articulation of an interchangeable shaft assembly **200** (FIGS. **1** and **3**) and/or the end effector **300** (FIGS. **1** and **4**). A left side reverse switch and a right side reverse switch are coupled to the main controller **717**. The left side switches comprising the left side articulation left switch, the left side articulation right switch, the left side articulation center switch, and the left side reverse switch are coupled to the main controller **717** by a left flex connector. The right side switches comprising the right side articulation left switch, the right side articulation right switch, the right side articulation center switch, and the right side reverse switch are coupled to the main controller **717** by a right flex connector. A firing switch, a clamp release switch, and a shaft engaged switch are coupled to the main controller **717**.

Any suitable mechanical, electromechanical, or solid state switches may be employed to implement the plurality of switches, in any combination. For example, the switches may be limit switches operated by the motion of components associated with the surgical instrument **10** (FIGS. **1-4**) or the presence of an object. Such switches may be employed to control various functions associated with the surgical instrument **10**. A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection. Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. In other implementations, the switches may be solid state switches that operate under the influence of a magnetic field such as Hall-effect devices, magneto-resistive (MR) devices, giant magneto-resistive (GMR) devices, magnetometers, among others. In other implementations, the switches may be solid state switches that operate under the influence of light, such as optical sensors, infrared sensors, ultraviolet sensors, among others. Still, the switches may be solid state devices such as transistors (e.g., FET, Junction-FET, metal-oxide semiconductor-FET (MOSFET), bipolar, and the like). Other switches may include wireless switches, ultrasonic switches, accelerometers, inertial sensors, among others.

FIG. **6** is another block diagram of the control circuit **700** of the surgical instrument of FIG. **1** illustrating interfaces between the handle assembly **702** and the power assembly **706** and between the handle assembly **702** and the interchangeable shaft assembly **704** according to one aspect of this disclosure. The handle assembly **702** may comprise a main controller **717**, a shaft assembly connector **726** and a power assembly connector **730**. The power assembly **706** may include a power assembly connector **732**, a power management circuit **734** that may comprise the power management controller **716**, a power modulator **738**, and a current sense circuit **736**. The shaft assembly connectors **730**, **732** form an interface **727**. The power management circuit **734** can be configured to modulate power output of the battery **707** based on the power requirements of the interchangeable shaft assembly **704** while the interchangeable shaft assembly **704** and the power assembly **706** are coupled to the handle assembly **702**. The power management controller **716** can be programmed to control the power modulator **738** of the power output of the power assembly **706** and the current sense circuit **736** can be employed to monitor power output of the power assembly **706** to provide feedback to the power management controller **716** about the

power output of the battery **707** so that the power management controller **716** may adjust the power output of the power assembly **706** to maintain a desired output. The shaft assembly **704** comprises a shaft processor **719** coupled to a non-volatile memory **721** and shaft assembly connector **728** to electrically couple the shaft assembly **704** to the handle assembly **702**. The shaft assembly connectors **726**, **728** form interface **725**. The main controller **717**, the shaft processor **719**, and/or the power management controller **716** can be configured to implement one or more of the processes described herein.

The surgical instrument **10** (FIGS. **1-4**) may comprise an output device **742** to a sensory feedback to a user. Such devices may comprise visual feedback devices (e.g., an LCD display screen, LED indicators), audio feedback devices (e.g., a speaker, a buzzer), or tactile feedback devices (e.g., haptic actuators). In certain circumstances, the output device **742** may comprise a display **743** that may be included in the handle assembly **702**. The shaft assembly controller **722** and/or the power management controller **716** can provide feedback to a user of the surgical instrument **10** through the output device **742**. The interface **727** can be configured to connect the shaft assembly controller **722** and/or the power management controller **716** to the output device **742**. The output device **742** can be integrated with the power assembly **706**. Communication between the output device **742** and the shaft assembly controller **722** may be accomplished through the interface **725** while the interchangeable shaft assembly **704** is coupled to the handle assembly **702**. Having described a control circuit **700** (FIGS. **5A-5B** and **6**) for controlling the operation of the surgical instrument **10** (FIGS. **1-4**), the disclosure now turns to various configurations of the surgical instrument **10** (FIGS. **1-4**) and control circuit **700**.

FIG. **7** illustrates a control circuit **800** configured to control aspects of the surgical instrument **10** (FIGS. **1-4**) according to one aspect of this disclosure. The control circuit **800** can be configured to implement various processes described herein. The control circuit **800** may comprise a controller comprising one or more processors **802** (e.g., microprocessor, microcontroller) coupled to at least one memory circuit **804**. The memory circuit **804** stores machine executable instructions that when executed by the processor **802**, cause the processor **802** to execute machine instructions to implement various processes described herein. The processor **802** may be any one of a number of single or multi-core processors known in the art. The memory circuit **804** may comprise volatile and non-volatile storage media. The processor **802** may include an instruction processing unit **806** and an arithmetic unit **808**. The instruction processing unit may be configured to receive instructions from the memory circuit **804**.

FIG. **8** illustrates a combinational logic circuit **810** configured to control aspects of the surgical instrument **10** (FIGS. **1-4**) according to one aspect of this disclosure. The combinational logic circuit **810** can be configured to implement various processes described herein. The circuit **810** may comprise a finite state machine comprising a combinational logic circuit **812** configured to receive data associated with the surgical instrument **10** at an input **814**, process the data by the combinational logic **812**, and provide an output **816**.

FIG. **9** illustrates a sequential logic circuit **820** configured to control aspects of the surgical instrument **10** (FIGS. **1-4**) according to one aspect of this disclosure. The sequential logic circuit **820** or the combinational logic circuit **822** can be configured to implement various processes described

herein. The circuit **820** may comprise a finite state machine. The sequential logic circuit **820** may comprise a combinational logic circuit **822**, at least one memory circuit **824**, and a clock **829**, for example. The at least one memory circuit **820** can store a current state of the finite state machine. In certain instances, the sequential logic circuit **820** may be synchronous or asynchronous. The combinational logic circuit **822** is configured to receive data associated with the surgical instrument **10** an input **826**, process the data by the combinational logic circuit **822**, and provide an output **828**. In other aspects, the circuit may comprise a combination of the processor **802** and the finite state machine to implement various processes herein. In other aspects, the finite state machine may comprise a combination of the combinational logic circuit **810** and the sequential logic circuit **820**.

Aspects may be implemented as an article of manufacture. The article of manufacture may include a computer readable storage medium arranged to store logic, instructions, and/or data for performing various operations of one or more aspects. For example, the article of manufacture may comprise a magnetic disk, optical disk, flash memory, or firmware containing computer program instructions suitable for execution by a general purpose processor or application specific processor.

FIG. **10** is a diagram of an absolute positioning system **1100** of the surgical instrument **10** (FIGS. **1-4**) where the absolute positioning system **1100** comprises a controlled motor drive circuit arrangement comprising a sensor arrangement **1102** according to one aspect of this disclosure. The sensor arrangement **1102** for an absolute positioning system **1100** provides a unique position signal corresponding to the location of a displacement member **1111**. Turning briefly to FIGS. **2-4**, in one aspect the displacement member **1111** represents the longitudinally movable drive member **120** (FIG. **2**) comprising a rack of drive teeth **122** for meshing engagement with a corresponding drive gear **86** of the gear reducer assembly **84**. In other aspects, the displacement member **1111** represents the firing member **220** (FIG. **3**), which could be adapted and configured to include a rack of drive teeth. In yet another aspect, the displacement member **1111** represents the firing bar **172** (FIG. **4**) or the I-beam **178** (FIG. **4**), each of which can be adapted and configured to include a rack of drive teeth. Accordingly, as used herein, the term displacement member is used generically to refer to any movable member of the surgical instrument **10** such as the drive member **120**, the firing member **220**, the firing bar **172**, the I-beam **178**, or any element that can be displaced. In one aspect, the longitudinally movable drive member **120** is coupled to the firing member **220**, the firing bar **172**, and the I-beam **178**. Accordingly, the absolute positioning system **1100** can, in effect, track the linear displacement of the I-beam **178** by tracking the linear displacement of the longitudinally movable drive member **120**. In various other aspects, the displacement member **1111** may be coupled to any sensor suitable for measuring linear displacement. Thus, the longitudinally movable drive member **120**, the firing member **220**, the firing bar **172**, or the I-beam **178**, or combinations, may be coupled to any suitable linear displacement sensor. Linear displacement sensors may include contact or non-contact displacement sensors. Linear displacement sensors may comprise linear variable differential transformers (LVDT), differential variable reluctance transducers (DVRT), a slide potentiometer, a magnetic sensing system comprising a movable magnet and a series of linearly arranged Hall effect sensors, a magnetic sensing system comprising a fixed magnet and a series of movable linearly

arranged Hall effect sensors, an optical sensing system comprising a movable light source and a series of linearly arranged photo diodes or photo detectors, or an optical sensing system comprising a fixed light source and a series of movable linearly arranged photo diodes or photo detectors, or any combination thereof.

An electric motor **1120** can include a rotatable shaft **1116** that operably interfaces with a gear assembly **1114** that is mounted in meshing engagement with a set, or rack, of drive teeth on the displacement member **1111**. A sensor element **1126** may be operably coupled to a gear assembly **1114** such that a single revolution of the sensor element **1126** corresponds to some linear longitudinal translation of the displacement member **1111**. An arrangement of gearing and sensors **1118** can be connected to the linear actuator via a rack and pinion arrangement or a rotary actuator via a spur gear or other connection. A power source **1129** supplies power to the absolute positioning system **1100** and an output indicator **1128** may display the output of the absolute positioning system **1100**. In FIG. **2**, the displacement member **1111** represents the longitudinally movable drive member **120** comprising a rack of drive teeth **122** formed thereon for meshing engagement with a corresponding drive gear **86** of the gear reducer assembly **84**. The displacement member **1111** represents the longitudinally movable firing member **220**, firing bar **172**, I-beam **178**, or combinations thereof.

A single revolution of the sensor element **1126** associated with the position sensor **1112** is equivalent to a longitudinal linear displacement d_1 of the of the displacement member **1111**, where d_1 is the longitudinal linear distance that the displacement member **1111** moves from point "a" to point "b" after a single revolution of the sensor element **1126** coupled to the displacement member **1111**. The sensor arrangement **1102** may be connected via a gear reduction that results in the position sensor **1112** completing one or more revolutions for the full stroke of the displacement member **1111**. The position sensor **1112** may complete multiple revolutions for the full stroke of the displacement member **1111**.

A series of switches **1122a-1122n**, where n is an integer greater than one, may be employed alone or in combination with gear reduction to provide a unique position signal for more than one revolution of the position sensor **1112**. The state of the switches **1122a-1122n** are fed back to a controller **1104** that applies logic to determine a unique position signal corresponding to the longitudinal linear displacement $d_1+d_2+ \dots +d_n$ of the displacement member **1111**. The output **1124** of the position sensor **1112** is provided to the controller **1104**. The position sensor **1112** of the sensor arrangement **1102** may comprise a magnetic sensor, an analog rotary sensor like a potentiometer, an array of analog Hall-effect elements, which output a unique combination of position signals or values.

The absolute positioning system **1100** provides an absolute position of the displacement member **1111** upon power up of the instrument without retracting or advancing the displacement member **1111** to a reset (zero or home) position as may be required with conventional rotary encoders that merely count the number of steps forwards or backwards that the motor **1120** has taken to infer the position of a device actuator, drive bar, knife, and the like.

The controller **1104** may be programmed to perform various functions such as precise control over the speed and position of the knife and articulation systems. In one aspect, the controller **1104** includes a processor **1108** and a memory **1106**. The electric motor **1120** may be a brushed DC motor with a gearbox and mechanical links to an articulation or

knife system. In one aspect, a motor driver **1110** may be an A3941 available from Allegro Microsystems, Inc. Other motor drivers may be readily substituted for use in the absolute positioning system **1100**. A more detailed description of the absolute positioning system **1100** is described in U.S. patent application Ser. No. 15/130,590, entitled SYSTEMS AND METHODS FOR CONTROLLING A SURGICAL STAPLING AND CUTTING INSTRUMENT, filed on Apr. 15, 2016, the entire disclosure of which is herein incorporated by reference.

The controller **1104** may be programmed to provide precise control over the speed and position of the displacement member **1111** and articulation systems. The controller **1104** may be configured to compute a response in the software of the controller **1104**. The computed response is compared to a measured response of the actual system to obtain an “observed” response, which is used for actual feedback decisions. The observed response is a favorable, tuned, value that balances the smooth, continuous nature of the simulated response with the measured response, which can detect outside influences on the system.

The absolute positioning system **1100** may comprise and/or be programmed to implement a feedback controller, such as a PID, state feedback, and adaptive controller. A power source **1129** converts the signal from the feedback controller into a physical input to the system, in this case voltage. Other examples include pulse width modulation (PWM) of the voltage, current, and force. Other sensor(s) **1118** may be provided to measure physical parameters of the physical system in addition to position measured by the position sensor **1112**. In a digital signal processing system, absolute positioning system **1100** is coupled to a digital data acquisition system where the output of the absolute positioning system **1100** will have finite resolution and sampling frequency. The absolute positioning system **1100** may comprise a compare and combine circuit to combine a computed response with a measured response using algorithms such as weighted average and theoretical control loop that drives the computed response towards the measured response. The computed response of the physical system takes into account properties like mass, inertial, viscous friction, inductance resistance, etc., to predict what the states and outputs of the physical system will be by knowing the input. The controller **1104** may be a control circuit **700** (FIGS. 5A-5B).

The motor driver **1110** may be an A3941 available from Allegro Microsystems, Inc. The A3941 driver **1110** is a full-bridge controller for use with external N-channel power metal oxide semiconductor field effect transistors (MOSFETs) specifically designed for inductive loads, such as brush DC motors. The driver **1110** comprises a unique charge pump regulator provides full (>10 V) gate drive for battery voltages down to 7 V and allows the A3941 to operate with a reduced gate drive, down to 5.5 V. A bootstrap capacitor may be employed to provide the above-battery supply voltage required for N-channel MOSFETs. An internal charge pump for the high-side drive allows DC (100% duty cycle) operation. The full bridge can be driven in fast or slow decay modes using diode or synchronous rectification. In the slow decay mode, current recirculation can be through the high-side or the lowside FETs. The power FETs are protected from shoot-through by resistor adjustable dead time. Integrated diagnostics provide indication of undervoltage, overtemperature, and power bridge faults, and can be configured to protect the power MOSFETs under most short circuit conditions. Other motor drivers may be readily substituted for use in the absolute positioning system **1100**.

Having described a general architecture for implementing aspects of an absolute positioning system **1100** for a sensor arrangement **1102**, the disclosure now turns to FIGS. **11** and **12** for a description of one aspect of a sensor arrangement **1102** for the absolute positioning system **1100**. FIG. **11** is an exploded perspective view of the sensor arrangement **1102** for the absolute positioning system **1100** showing a circuit **1205** and the relative alignment of the elements of the sensor arrangement **1102**, according to one aspect. The sensor arrangement **1102** for an absolute positioning system **1100** comprises a position sensor **1200**, a magnet **1202** sensor element, a magnet holder **1204** that turns once every full stroke of the displacement member **1111**, and a gear assembly **1206** to provide a gear reduction. With reference briefly to FIG. **2**, the displacement member **1111** may represent the longitudinally movable drive member **120** comprising a rack of drive teeth **122** for meshing engagement with a corresponding drive gear **86** of the gear reducer assembly **84**. Returning to FIG. **11**, a structural element such as bracket **1216** is provided to support the gear assembly **1206**, the magnet holder **1204**, and the magnet **1202**. The position sensor **1200** comprises magnetic sensing elements such as Hall elements and is placed in proximity to the magnet **1202**. As the magnet **1202** rotates, the magnetic sensing elements of the position sensor **1200** determine the absolute angular position of the magnet **1202** over one revolution.

The sensor arrangement **1102** may comprise any number of magnetic sensing elements, such as, for example, magnetic sensors classified according to whether they measure the total magnetic field or the vector components of the magnetic field. The techniques used to produce both types of magnetic sensors encompass many aspects of physics and electronics. The technologies used for magnetic field sensing include search coil, fluxgate, optically pumped, nuclear precession, SQUID, Hall-effect, anisotropic magnetoresistance, giant magnetoresistance, magnetic tunnel junctions, giant magnetoimpedance, magnetostrictive/piezoelectric composites, magnetodiode, magnetotransistor, fiber optic, magneto optic, and microelectromechanical systems-based magnetic sensors, among others.

A gear assembly comprises a first gear **1208** and a second gear **1210** in meshing engagement to provide a 3:1 gear ratio connection. A third gear **1212** rotates about a shaft **1214**. The third gear **1212** is in meshing engagement with the displacement member **1111** (or **120** as shown in FIG. **2**) and rotates in a first direction as the displacement member **1111** advances in a distal direction **D** and rotates in a second direction as the displacement member **1111** retracts in a proximal direction **P**. The second gear **1210** also rotates about the shaft **1214** and, therefore, rotation of the second gear **1210** about the shaft **1214** corresponds to the longitudinal translation of the displacement member **1111**. Thus, one full stroke of the displacement member **1111** in either the distal or proximal directions **D**, **P** corresponds to three rotations of the second gear **1210** and a single rotation of the first gear **1208**. Since the magnet holder **1204** is coupled to the first gear **1208**, the magnet holder **1204** makes one full rotation with each full stroke of the displacement member **1111**.

The position sensor **1200** is supported by a position sensor holder **1218** defining an aperture **1220** suitable to contain the position sensor **1200** in precise alignment with a magnet **1202** rotating below within the magnet holder **1204**. The fixture is coupled to the bracket **1216** and to the circuit **1205** and remains stationary while the magnet **1202** rotates with the magnet holder **1204**. A hub **1222** is provided to mate with

the first gear **1208** and the magnet holder **1204**. The second gear **1210** and third gear **1212** coupled to shaft **1214** also are shown.

FIG. **12** is a diagram of a position sensor **1200** for an absolute positioning system **1100** comprising a magnetic rotary absolute positioning system according to one aspect of this disclosure. The position sensor **1200** may be implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **1200** is interfaced with the controller **1104** to provide an absolute positioning system **1100**. The position sensor **1200** is a low-voltage and low-power component and includes four Hall-effect elements **1228A**, **1228B**, **1228C**, **1228D** in an area **1230** of the position sensor **1200** that is located above the magnet **1202** (FIGS. **15** and **16**). A high-resolution ADC **1232** and a smart power management controller **1238** are also provided on the chip. A CORDIC processor **1236** (for Coordinate Rotation Digital Computer), also known as the digit-by-digit method and Volder's algorithm, is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations. The angle position, alarm bits, and magnetic field information are transmitted over a standard serial communication interface such as an SPI interface **1234** to the controller **1104**. The position sensor **1200** provides 12 or 14 bits of resolution. The position sensor **1200** may be an AS5055 chip provided in a small QFN 16-pin 4x4x0.85 mm package.

The Hall-effect elements **1228A**, **1228B**, **1228C**, **1228D** are located directly above the rotating magnet **1202** (FIG. **11**). The Hall-effect is a well-known effect and for expediency will not be described in detail herein, however, generally, the Hall-effect produces a voltage difference (the Hall voltage) across an electrical conductor transverse to an electric current in the conductor and a magnetic field perpendicular to the current. A Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and properties of the charge carriers that constitute the current. In the AS5055 position sensor **1200**, the Hall-effect elements **1228A**, **1228B**, **1228C**, **1228D** are capable producing a voltage signal that is indicative of the absolute position of the magnet **1202** in terms of the angle over a single revolution of the magnet **1202**. This value of the angle, which is unique position signal, is calculated by the CORDIC processor **1236** is stored onboard the AS5055 position sensor **1200** in a register or memory. The value of the angle that is indicative of the position of the magnet **1202** over one revolution is provided to the controller **1104** in a variety of techniques, e.g., upon power up or upon request by the controller **1104**.

The AS5055 position sensor **1200** requires only a few external components to operate when connected to the controller **1104**. Six wires are needed for a simple application using a single power supply: two wires for power and four wires **1240** for the SPI interface **1234** with the controller **1104**. A seventh connection can be added in order to send an interrupt to the controller **1104** to inform that a new valid angle can be read. Upon power-up, the AS5055 position sensor **1200** performs a full power-up sequence including one angle measurement. The completion of this cycle is indicated as an INT output **1242**, and the angle value is stored in an internal register. Once this output is set, the AS5055 position sensor **1200** suspends to sleep mode. The controller **1104** can respond to the INT request at the INT

output **1242** by reading the angle value from the AS5055 position sensor **1200** over the SPI interface **1234**. Once the angle value is read by the controller **1104**, the INT output **1242** is cleared again. Sending a "read angle" command by the SPI interface **1234** by the controller **1104** to the position sensor **1200** also automatically powers up the chip and starts another angle measurement. As soon as the controller **1104** has completed reading of the angle value, the INT output **1242** is cleared and a new result is stored in the angle register. The completion of the angle measurement is again indicated by setting the INT output **1242** and a corresponding flag in the status register.

Due to the measurement principle of the AS5055 position sensor **1200**, only a single angle measurement is performed in very short time (~600 μ s) after each power-up sequence. As soon as the measurement of one angle is completed, the AS5055 position sensor **1200** suspends to power-down state. An on-chip filtering of the angle value by digital averaging is not implemented, as this would require more than one angle measurement and, consequently, a longer power-up time that is not desired in low-power applications. The angle jitter can be reduced by averaging of several angle samples in the controller **1104**. For example, an averaging of four samples reduces the jitter by 6 dB (50%).

FIG. **13** is a section view of an end effector **2502** of the surgical instrument **10** (FIGS. **1-4**) showing an I-beam **2514** firing stroke relative to tissue **2526** grasped within the end effector **2502** according to one aspect of this disclosure. The end effector **2502** is configured to operate with the surgical instrument **10** shown in FIGS. **1-4**. The end effector **2502** comprises an anvil **2516** and an elongated channel **2503** with a staple cartridge **2518** positioned in the elongated channel **2503**. A firing bar **2520** is translatable distally and proximally along a longitudinal axis **2515** of the end effector **2502**. When the end effector **2502** is not articulated, the end effector **2502** is in line with the shaft of the instrument. An I-beam **2514** comprising a cutting edge **2509** is illustrated at a distal portion of the firing bar **2520**. A wedge sled **2513** is positioned in the staple cartridge **2518**. As the I-beam **2514** translates distally, the cutting edge **2509** contacts and may cut tissue **2526** positioned between the anvil **2516** and the staple cartridge **2518**. Also, the I-beam **2514** contacts the wedge sled **2513** and pushes it distally, causing the wedge sled **2513** to contact staple drivers **2511**. The staple drivers **2511** may be driven up into staples **2505**, causing the staples **2505** to advance through tissue and into pockets **2507** defined in the anvil **2516**, which shape the staples **2505**.

An example I-beam **2514** firing stroke is illustrated by a chart **2529** aligned with the end effector **2502**. Example tissue **2526** is also shown aligned with the end effector **2502**. The firing member stroke may comprise a stroke begin position **2527** and a stroke end position **2528**. During an I-beam **2514** firing stroke, the I-beam **2514** may be advanced distally from the stroke begin position **2527** to the stroke end position **2528**. The I-beam **2514** is shown at one example location of a stroke begin position **2527**. The I-beam **2514** firing member stroke chart **2529** illustrates five firing member stroke regions **2517**, **2519**, **2521**, **2523**, **2525**. In a first firing stroke region **2517**, the I-beam **2514** may begin to advance distally. In the first firing stroke region **2517**, the I-beam **2514** may contact the wedge sled **2513** and begin to move it distally. While in the first region, however, the cutting edge **2509** may not contact tissue and the wedge sled **2513** may not contact a staple driver **2511**. After static friction is overcome, the force to drive the I-beam **2514** in the first region **2517** may be substantially constant.

In the second firing member stroke region **2519**, the cutting edge **2509** may begin to contact and cut tissue **2526**. Also, the wedge sled **2513** may begin to contact staple drivers **2511** to drive staples **2505**. Force to drive the I-beam **2514** may begin to ramp up. As shown, tissue encountered initially may be compressed and/or thinner because of the way that the anvil **2516** pivots relative to the staple cartridge **2518**. In the third firing member stroke region **2521**, the cutting edge **2509** may continuously contact and cut tissue **2526** and the wedge sled **2513** may repeatedly contact staple drivers **2511**. Force to drive the I-beam **2514** may plateau in the third region **2521**. By the fourth firing stroke region **2523**, force to drive the I-beam **2514** may begin to decline. For example, tissue in the portion of the end effector **2502** corresponding to the fourth firing region **2523** may be less compressed than tissue closer to the pivot point of the anvil **2516**, requiring less force to cut. Also, the cutting edge **2509** and wedge sled **2513** may reach the end of the tissue **2526** while in the fourth region **2523**. When the I-beam **2514** reaches the fifth region **2525**, the tissue **2526** may be completely severed. The wedge sled **2513** may contact one or more staple drivers **2511** at or near the end of the tissue. Force to advance the I-beam **2514** through the fifth region **2525** may be reduced and, in some examples, may be similar to the force to drive the I-beam **2514** in the first region **2517**. At the conclusion of the firing member stroke, the I-beam **2514** may reach the stroke end position **2528**. The positioning of firing member stroke regions **2517**, **2519**, **2521**, **2523**, **2525** in FIG. **18** is just one example. In some examples, different regions may begin at different positions along the end effector longitudinal axis **2515**, for example, based on the positioning of tissue between the anvil **2516** and the staple cartridge **2518**.

As discussed above and with reference now to FIGS. **10-13**, the electric motor **1122** positioned within the handle assembly of the surgical instrument **10** (FIGS. **1-4**) can be utilized to advance and/or retract the firing system of the shaft assembly, including the I-beam **2514**, relative to the end effector **2502** of the shaft assembly in order to staple and/or incise tissue captured within the end effector **2502**. The I-beam **2514** may be advanced or retracted at a desired speed, or within a range of desired speeds. The controller **1104** may be configured to control the speed of the I-beam **2514**. The controller **1104** may be configured to predict the speed of the I-beam **2514** based on various parameters of the power supplied to the electric motor **1122**, such as voltage and/or current, for example, and/or other operating parameters of the electric motor **1122** or external influences. The controller **1104** may be configured to predict the current speed of the I-beam **2514** based on the previous values of the current and/or voltage supplied to the electric motor **1122**, and/or previous states of the system like velocity, acceleration, and/or position. The controller **1104** may be configured to sense the speed of the I-beam **2514** utilizing the absolute positioning sensor system described herein. The controller can be configured to compare the predicted speed of the I-beam **2514** and the sensed speed of the I-beam **2514** to determine whether the power to the electric motor **1122** should be increased in order to increase the speed of the I-beam **2514** and/or decreased in order to decrease the speed of the I-beam **2514**. U.S. Pat. No. 8,210,411, entitled MOTOR-DRIVEN SURGICAL CUTTING INSTRUMENT, which is incorporated herein by reference in its entirety. U.S. Pat. No. 7,845,537, entitled SURGICAL INSTRUMENT HAVING RECORDING CAPABILITIES, which is incorporated herein by reference in its entirety.

Force acting on the I-beam **2514** may be determined using various techniques. The I-beam **2514** force may be determined by measuring the motor **2504** current, where the motor **2504** current is based on the load experienced by the I-beam **2514** as it advances distally. The I-beam **2514** force may be determined by positioning a strain gauge on the drive member **120** (FIG. **2**), the firing member **220** (FIG. **2**), I-beam **2514** (I-beam **178**, FIG. **20**), the firing bar **172** (FIG. **2**), and/or on a proximal end of the cutting edge **2509**. The I-beam **2514** force may be determined by monitoring the actual position of the I-beam **2514** moving at an expected velocity based on the current set velocity of the motor **2504** after a predetermined elapsed period T_1 and comparing the actual position of the I-beam **2514** relative to the expected position of the I-beam **2514** based on the current set velocity of the motor **2504** at the end of the period T_1 . Thus, if the actual position of the I-beam **2514** is less than the expected position of the I-beam **2514**, the force on the I-beam **2514** is greater than a nominal force. Conversely, if the actual position of the I-beam **2514** is greater than the expected position of the I-beam **2514**, the force on the I-beam **2514** is less than the nominal force. The difference between the actual and expected positions of the I-beam **2514** is proportional to the deviation of the force on the I-beam **2514** from the nominal force. Such techniques are described in U.S. patent application Ser. No. 15/628,075, which is incorporated herein by reference in its entirety.

FIG. **14** illustrates a block diagram of a surgical instrument **2500** programmed to control distal translation of a displacement member according to one aspect of this disclosure. In one aspect, the surgical instrument **2500** is programmed to control distal translation of a displacement member **1111** such as the I-beam **2514**. The surgical instrument **2500** comprises an end effector **2502** that may comprise an anvil **2516**, an I-beam **2514** (including a sharp cutting edge **2509**), and a removable staple cartridge **2518**. The end effector **2502**, anvil **2516**, I-beam **2514**, and staple cartridge **2518** may be configured as described herein, for example, with respect to FIGS. **1-13**.

The position, movement, displacement, and/or translation of a liner displacement member **1111**, such as the I-beam **2514**, can be measured by the absolute positioning system **1100**, sensor arrangement **1102**, and position sensor **1200** as shown in FIGS. **10-12** and represented as position sensor **2534** in FIG. **14**. Because the I-beam **2514** is coupled to the longitudinally movable drive member **120**, the position of the I-beam **2514** can be determined by measuring the position of the longitudinally movable drive member **120** employing the position sensor **2534**. Accordingly, in the following description, the position, displacement, and/or translation of the I-beam **2514** can be achieved by the position sensor **2534** as described herein. A control circuit **2510**, such as the control circuit **700** described in FIGS. **5A** and **5B**, may be programmed to control the translation of the displacement member **1111**, such as the I-beam **2514**, as described in connection with FIGS. **10-12**. The control circuit **2510**, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the I-beam **2514**, in the manner described. In one aspect, a timer/counter circuit **2531** provides an output signal, such as elapsed time or a digital count, to the control circuit **2510** to correlate the position of the I-beam **2514** as determined by the position sensor **2534** with the output of the timer/counter circuit **2531** such that the control circuit **2510** can determine the position of the I-beam **2514** at a specific time (t) relative

to a starting position. The timer/counter circuit **2531** may be configured to measure elapsed time, count external events, or time external events.

The control circuit **2510** may generate a motor set point signal **2522**. The motor set point signal **2522** may be provided to a motor controller **2508**. The motor controller **2508** may comprise one or more circuits configured to provide a motor drive signal **2524** to the motor **2504** to drive the motor **2504** as described herein. In some examples, the motor **2504** may be a brushed DC electric motor, such as the motor **82**, **714**, **1120** shown in FIGS. **1**, **5B**, **10**. For example, the velocity of the motor **2504** may be proportional to the motor drive signal **2524**. In some examples, the motor **2504** may be a brushless direct current (DC) electric motor and the motor drive signal **2524** may comprise a pulse-width-modulated (PWM) signal provided to one or more stator windings of the motor **2504**. Also, in some examples, the motor controller **2508** may be omitted and the control circuit **2510** may generate the motor drive signal **2524** directly.

The motor **2504** may receive power from an energy source **2512**. The energy source **2512** may be or include a battery, a super capacitor, or any other suitable energy source **2512**. The motor **2504** may be mechanically coupled to the I-beam **2514** via a transmission **2506**. The transmission **2506** may include one or more gears or other linkage components to couple the motor **2504** to the I-beam **2514**. A position sensor **2534** may sense a position of the I-beam **2514**. The position sensor **2534** may be or include any type of sensor that is capable of generating position data that indicates a position of the I-beam **2514**. In some examples, the position sensor **2534** may include an encoder configured to provide a series of pulses to the control circuit **2510** as the I-beam **2514** translates distally and proximally. The control circuit **2510** may track the pulses to determine the position of the I-beam **2514**. Other suitable position sensor may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **2514**. Also, in some examples, the position sensor **2534** may be omitted. Where the motor **2504** is a stepper motor, the control circuit **2510** may track the position of the I-beam **2514** by aggregating the number and direction of steps that the motor **2504** has been instructed to execute. The position sensor **2534** may be located in the end effector **2502** or at any other portion of the instrument.

The control circuit **2510** may be in communication with one or more sensors **2538**. The sensors **2538** may be positioned on the end effector **2502** and adapted to operate with the surgical instrument **2500** to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **2538** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **2502**. The sensors **2538** may include one or more sensors.

The one or more sensors **2538** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **2516** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **2538** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **2516** and the staple cartridge **2518**. The sensors **2538** may be configured to detect impedance of a tissue section located between the

anvil **2516** and the staple cartridge **2518** that is indicative of the thickness and/or fullness of tissue located therebetween.

The sensors **2538** may be configured to measure forces exerted on the anvil **2516** by the closure drive system **30**. For example, one or more sensors **2538** can be at an interaction point between the closure tube **260** (FIG. **3**) and the anvil **2516** to detect the closure forces applied by the closure tube **260** to the anvil **2516**. The forces exerted on the anvil **2516** can be representative of the tissue compression experienced by the tissue section captured between the anvil **2516** and the staple cartridge **2518**. The one or more sensors **2538** can be positioned at various interaction points along the closure drive system **30** (FIG. **2**) to detect the closure forces applied to the anvil **2516** by the closure drive system **30**. The one or more sensors **2538** may be sampled in real time during a clamping operation by a processor as described in FIGS. **5A-5B**. The control circuit **2510** receives real-time sample measurements to provide analyze time based information and assess, in real time, closure forces applied to the anvil **2516**.

A current sensor **2536** can be employed to measure the current drawn by the motor **2504**. The force required to advance the I-beam **2514** corresponds to the current drawn by the motor **2504**. The force is converted to a digital signal and provided to the control circuit **2510**.

Using the physical properties of the instruments disclosed herein in connection with FIGS. **1-14**, and with reference to FIG. **14**, the control circuit **2510** can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam **2514** in the end effector **2502** at or near a target velocity. The surgical instrument **2500** can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a State Feedback, LQR, and/or an Adaptive controller, for example. The surgical instrument **2500** can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, pulse width modulated (PWM) voltage, frequency modulated voltage, current, torque, and/or force, for example.

The actual drive system of the surgical instrument **2500** is configured to drive the displacement member, cutting member, or I-beam **2514**, by a brushed DC motor with gearbox and mechanical links to an articulation and/or knife system. Another example is the electric motor **2504** that operates the displacement member and the articulation driver, for example, of an interchangeable shaft assembly. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies and friction on the physical system. Such outside influence can be referred to as drag which acts in opposition to the electric motor **2504**. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

Before explaining aspects of the surgical instrument **2500** in detail, it should be noted that the example aspects are not limited in application or use to the details of construction and arrangement of parts illustrated in the accompanying drawings and description. The example aspects may be implemented or incorporated in other aspects, variations and modifications, and may be practiced or carried out in various ways. Further, unless otherwise indicated, the terms and expressions employed herein have been chosen for the purpose of describing the example aspects for the convenience of the reader and are not for the purpose of limitation thereof. Also, it will be appreciated that one or more of the following-described aspects, expressions of aspects and/or

examples, can be combined with any one or more of the other following-described aspects, expressions of aspects and/or examples.

Various example aspects are directed to a surgical instrument **2500** comprising an end effector **2502** with motor-driven surgical stapling and cutting implements. For example, a motor **2504** may drive a displacement member distally and proximally along a longitudinal axis of the end effector **2502**. The end effector **2502** may comprise a pivotable anvil **2516** and, when configured for use, a staple cartridge **2518** positioned opposite the anvil **2516**. A clinician may grasp tissue between the anvil **2516** and the staple cartridge **2518**, as described herein. When ready to use the instrument **2500**, the clinician may provide a firing signal, for example by depressing a trigger of the instrument **2500**. In response to the firing signal, the motor **2504** may drive the displacement member distally along the longitudinal axis of the end effector **2502** from a proximal stroke begin position to a stroke end position distal of the stroke begin position. As the displacement member translates distally, an I-beam **2514** with a cutting element positioned at a distal end, may cut the tissue between the staple cartridge **2518** and the anvil **2516**.

In various examples, the surgical instrument **2500** may comprise a control circuit **2510** programmed to control the distal translation of the displacement member, such as the I-beam **2514**, for example, based on one or more tissue conditions. The control circuit **2510** may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit **2510** may be programmed to select a firing control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit **2510** may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit **2510** may be programmed to translate the displacement member at a higher velocity and/or with higher power.

In some examples, the control circuit **2510** may initially operate the motor **2504** in an open-loop configuration for a first open-loop portion of a stroke of the displacement member. Based on a response of the instrument **2500** during the open-loop portion of the stroke, the control circuit **2510** may select a firing control program. The response of the instrument may include, a translation distance of the displacement member during the open-loop portion, a time elapsed during the open-loop portion, energy provided to the motor **2504** during the open-loop portion, a sum of pulse widths of a motor drive signal, etc. After the open-loop portion, the control circuit **2510** may implement the selected firing control program for a second portion of the displacement member stroke. For example, during the closed loop portion of the stroke, the control circuit **2510** may modulate the motor **2504** based on translation data describing a position of the displacement member in a closed-loop manner to translate the displacement member at a constant velocity.

FIG. **15** illustrates a diagram **2580** plotting two example displacement member strokes executed according to one aspect of this disclosure. The diagram **2580** comprises two axes. A horizontal axis **2584** indicates elapsed time. A vertical axis **2582** indicates the position of the I-beam **2514** between a stroke begin position **2586** and a stroke end position **2588**. On the horizontal axis **2584**, the control circuit **2510** may receive the firing signal and begin provid-

ing the initial motor setting at t_0 . The open-loop portion of the displacement member stroke is an initial time period that may elapse between t_0 and t_1 .

A first example **2592** shows a response of the surgical instrument **2500** when thick tissue is positioned between the anvil **2516** and the staple cartridge **2518**. During the open-loop portion of the displacement member stroke, e.g., the initial time period between t_0 and t_1 , the I-beam **2514** may traverse from the stroke begin position **2586** to position **2594**. The control circuit **2510** may determine that position **2594** corresponds to a firing control program that advances the I-beam **2514** at a selected constant velocity (V_{slow}), indicated by the slope of the example **2592** after t_1 (e.g., in the closed loop portion). The control circuit **2510** may drive I-beam **2514** to the velocity V_{slow} by monitoring the position of I-beam **2514** and modulating the motor set point **2522** and/or motor drive signal **2524** to maintain V_{slow} . A second example **2590** shows a response of the surgical instrument **2500** when thin tissue is positioned between the anvil **2516** and the staple cartridge **2518**.

During the initial time period (e.g., the open-loop period) between t_0 and t_1 , the I-beam **2514** may traverse from the stroke begin position **2586** to position **2596**. The control circuit may determine that position **2596** corresponds to a firing control program that advances the displacement member at a selected constant velocity (V_{fast}). Because the tissue in example **2590** is thinner than the tissue in example **2592**, it may provide less resistance to the motion of the I-beam **2514**. As a result, the I-beam **2514** may traverse a larger portion of the stroke during the initial time period. Also, in some examples, thinner tissue (e.g., a larger portion of the displacement member stroke traversed during the initial time period) may correspond to higher displacement member velocities after the initial time period.

The disclosure now turns to a closed loop feedback system to provide velocity control of a displacement member. The closed loop feedback system adjusts the velocity of the displacement member based on a measurement of actual time over a specified number of shaft rotations. In one aspect, the closed loop feedback system comprises two phases. A start phase defined as the start of a firing stroke followed by a dynamic firing phase while the I-beam **2514** advances distally during the firing stroke. FIGS. **16A** and **16B** show the I-beam **2514** positioned at the start phase of the firing stroke. FIG. **16A** illustrates an end effector **2502** comprising a firing member **2520** coupled to an I-beam **2514** comprising a cutting edge **2509**. The anvil **2516** is in the closed position and the I-beam **2514** is located in a proximal or parked position **10002** at the bottom of the closure ramp **10006**. The parked position **10002** is the position of the I-beam **2514** prior to traveling up the anvil **2516** closure ramp **10006** to the top of the ramp **10006** to the T-slot **10008** after a predetermined number of shaft rotations. A top pin **10080** is configured to engage a T-slot **10008** and a lockout pin **10082** is configured to engage a latch feature **10084**.

In FIG. **16B** the I-beam **2514** is located in a target position **10004** at the top of the ramp **10006** with the top pin **10080** engaged in the T-slot **10008**. As shown in FIGS. **14**, **16A**, and **16B**, in traveling from the parked position **10002** to the target position **10004**, the I-beam **2514** travels a distance indicated as x_0 in the horizontal distal direction after a predetermined number of shaft rotations. During the start phase, the velocity of the I-beam **2514** is set to a predetermined initial velocity ϕ_0 rotations per seconds. A control circuit **2510** measures the actual time t_0 that it takes the I-beam **2514** to travel up the ramp **10006** from the parked position **10002** to the target position **10004** at the initial

velocity ϕ_0 , rotations per second. In one aspect, the horizontal distance is in the range of 5 mm to 10 mm and in one example is 7.4 mm and the initial velocity $\phi_0 = 5$ rotations per second. As described in more detail below, the actual time t_0 is used to set the command velocity of the I-beam **2514** in terms of rotations per second of the shaft to slow, medium, or fast in the subsequent staple cartridge zone Z as the I-beam **2514** advances distally. The number of zones may depend on the length/size of the staple cartridge (e.g., 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, 60 mm, >60 mm). The command velocity or set velocity is the velocity of the motor **2504** that is applied to the motor **2504** by the control circuit **2510** and motor control **2508** in order effect a desired velocity of the I-beam **2514**. In one aspect, the velocity is determined based on rotations of the shaft of the motor **2504** in terms of rotations per second. The actual velocity of the I-beam **2514** is determined by the control circuit **2510** by measuring the actual time t_0 with the timer/counter **2531** circuit that it takes the I-beam **2514** to traverse a specified or fixed distance provided by the position sensor **2534** based on a set rotation interval assuming, in one example, of 60 threads per inch. In accordance with one aspect of the present disclosure, the closed loop feedback control system of the surgical instrument measures the actual time t_n it takes the I-beam **2514**, or a displacement member, to travel a predetermined fixed distance or rotation interval X_n after a predetermined set of rotation interval of the motor shaft assuming a 60 threads per inch. A predetermined fixed distance or rotation interval X_n is defined for each zone (e.g., $Z_1, Z_2, Z_3 \dots Z_n$).

FIG. 17 illustrates a screw drive system **10470** that may be employed with the surgical instrument **10** (FIG. 1) according to one aspect of this disclosure. In one aspect, the longitudinally movable drive member **120** (FIG. 2) may be replaced with the screw drive (sometime referred to as a nut drive) system **10470**. The screw drive system **10470** comprises a leadscrew **10472**, ball screw or other mechanical linear actuator, adapted and configured to couple to the shaft **10474** of the motor **82** (FIG. 2) via the drive gear **10478** to translate rotational motion to linear motion. The leadscrew **10472** is coupled to the firing member **220** via a nut **1476**. The firing member **220** is coupled to firing bar **172**, which is coupled to the I-beam **178** as shown and described with reference to FIGS. 2-4. The drive gear **10478**, which is driven by the shaft **1474** of the motor **82** is adapted to rotate the screw drive system **10470**.

The screw drive system **10470** comprises a leadscrew **10472** and a nut **10476**, also known as a power screw or translation screw, and is adapted to couple to the shaft **10474** of the motor **82** via the drive gear **10478** to translate turning motion of the shaft **10474** of the motor **82** into linear motion of the displacement member, such as the I-beam **2514**, for example, which is coupled to the nut **10476**. The leadscrew **10472** threads are in sliding contact with their counterparts within the nut **10476** such that as the leadscrew **10472** rotates the nut **10476** translates forward and backward according to the rotation of the drive gear **10478** as indicated. A ball screw also may be used for low friction application. In a ball screw, a threaded shaft provides a helical raceway for ball bearings which act as a precision screw. As well as being able to apply or withstand high thrust loads, they can do so with minimum internal friction. Close tolerances make it suitable for use in high precision applications. The ball assembly acts as the nut while the threaded shaft is the screw. The screw drive system **10470**, such as the leadscrew **10472** and nut **10476**, or ball screw drive, may include a threaded shaft having 60 threads per inch such that

a 60 mm staple cartridge can be traversed in approximately 142 rotations of the motor shaft. For example, one rotation of the threaded shaft of the leadscrew **10472** advances the nut **10476** and the displacement member 1 inch (25.4 mm). A 60 mm cartridge is 2.36 inches long and requires ~142 rotations of the leadscrew **10472** to advance the nut **10476** and the displacement member the full 60 mm stroke if the ratio is a 1:1 ratio between the rotation of the shaft **10474** and the rotation of the leadscrew **10472**. Other ratios using gear reduction assemblies may be adapted without limitation. The rotation of the shaft **10474** can be measured by a position sensor arrangement comprising one or more magnets and one or more Hall effect sensors to measure the rotation of the shaft **10474** and provide the shaft rotation signals to the control circuit.

In one aspect, with reference to FIG. 17 and also FIGS. 2-4 and 10-12, the rotations of the shaft **10474** of the motor **82** (FIG. 2) or **1116** (FIG. 10) can be measured by measuring the rotation of the shaft **1214** (FIG. 11) coupled to the drive gear **86** (FIG. 2) using the absolute positioning system **1100** (FIGS. 10 and 12) and position sensor **1200** (FIGS. 11, 12). With reference to FIG. 12, the position sensor **1200** for the absolute positioning system **1100** comprising a magnetic rotary absolute positioning system can be employed to measure magnetic rotary position of the shaft of the motor. The position sensor **1200** is interfaced with the controller **1104** to provide an absolute positioning system **1100**. Additional details of absolute positioning system **1100** and position sensor **1200** are described above in reference to FIG. 12 and for expedience will not be repeated here.

Turning now to FIG. 18, there is illustrated an I-beam **2514** firing stroke as a chart **9009** aligned with the end effector **2502** according to one aspect of this disclosure. As shown, the initial zone (Z_0), or base zone, is defined as the distance traveled by the I-beam **2514** from the parked position **10002** to the target position **10004**. The measured time T_0 is the time it takes the I-beam **2514** to travel up the closure ramp **10006** to the target position **10004** at an initial set velocity Φ_0 rotations/sec. The measured times T_1 - T_5 are reference periods of time for traversing the corresponding zones Z_1 - Z_5 , respectively. The displacement of the I-beam **2514** in zone Z_0 is Θ_0 rotations. The period T_0 , the time it takes for the I-beam **2514** to travel over a distance Θ_0 , is used to set the command velocity in the subsequent zone Z_1 .

With reference now to FIGS. 14-18, at the start phase, e.g., at the beginning of a firing stroke, the control circuit **2510** is configured to initiate firing the displacement member, such as the I-beam **2514**, at a predetermined velocity Φ_0 (e.g., 5 rotations/sec). During the start phase, the control circuit **2510** is configured to monitor the position of the I-beam **2514** and measure the time t_0 (sec) it takes for the I-beam **2514** to travel from the I-beam **2514** parked position **10002** to the I-beam **2514** target position **10004**, either to the top of the anvil **2516** closure ramp **10006**, or at the end of a low power mode of operation. Time t_0 in the initial zone **10010** is used by the control circuit **2510** to determine the firing velocity of the I-beam **2514** through the first zone Z_1 . For example, in one aspect, if time t_0 is <0.9 sec the velocity Φ_1 may be set to fast and if time $t_0 \geq 0.9$ sec the velocity Φ_1 may be set to medium. Faster or slower times may be selected based on the length of the staple cartridge **2518**. The actual time t_1 - t_5 that it takes the I-beam **2514** to traverse a corresponding zone Z_1 to Z_5 is measured at a corresponding set rotation displacement δ_1 - δ_5 and is compared to a corresponding reference time period T_1 - T_5 . In various aspects, if a lockout condition is encountered, the motor **2504** will stall before the I-beam **2514** reaches the target position **10004**.

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When this condition occurs, the surgical instrument display indicates the instrument status and may issue a stall warning. The display also may indicate a speed selection.

During the dynamic firing phase, the surgical instrument enters the dynamic firing phase, where the control circuit 2510 is configured to monitor the rotation interval δ_n of the I-beam 2514 and measure the time t_n that it takes the I-beam 2514 to travel from the beginning of a zone to the end of a zone (e.g., a total distance of 12 rotations or 23 rotations). In FIG. 17, the reference time T_1 is the time taken by the I-beam 2514 to travel from the beginning of zone Z_1 to the end of zone Z_1 at a set velocity Φ_1 . Likewise, the reference time T_2 is the time it takes the I-beam 2514 to travel from the beginning of zone Z_2 to the end of zone Z_2 at a set velocity Φ_2 , and so on. Table 1 shows zones that may be defined for staple cartridges 2518 of various sizes.

TABLE 1

Defined Zones For Staple Cartridges Of Various Sizes						
Staple Cartridge	Zones					
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6
35 mm	0-12 rotations	12-35 rotations	35-59 rotations	>59 rotations	N/A	N/A
40-45 mm	0-12 rotations	12-35 rotations	35-59 rotations	59-82 rotations	>82 rotations	N/A
55-60 mm	0-12 rotations	12-35 rotations	35-59 rotations	59-82 rotations	82-106 rotations	>106 rotations

For staple cartridges 2518 over 60 mm, the pattern continues, but the last 10-15 mm continues at a command or indicated velocity of the previous zone pending other interventions for end of stroke, among others. At the end of each zone, the actual time t_n it took the I-beam 2514 to pass through the zone is compared to the values in other tables (e.g., Tables 2-5 below) to determine how to set the command velocity for the next zone. The command velocity is updated for the next zone and the process continues. Whenever the command velocity is updated, the next zone will not be evaluated. The end of stroke is handled in accordance with a predetermined protocol/algorithm of the surgical instrument including limit switches, controlled deceleration, etc. At the end of stroke, the I-beam 2514 is returned to the initial I-beam park position 10002 at the fast speed. End of return stroke (returning to the parked position 10002) is handled in accordance with the protocol/algorithm of the surgical instrument. Other zones may be defined without limitation.

TABLE 2

Time To Travel Through Zones At Specified Command Velocity For Various Dynamic Firing Zones			
Dynamic Firing Zone (rotations)	Time (sec) to Travel Through Zone at Specified Command Velocity		
	Fast	Medium	Slow
First Zone (Θ_1 rotations)	$t < t_1$	$t_1 < t < t_2$	$t > t_2$
Intermediate Zones (Θ_2 rotations)	$t < t_3$	$t_3 < t < t_4$	$t > t_4$
Last Measured Zone (Θ_3 rotations)	$t < t_5$	$t_5 < t < t_6$	$t > t_6$

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TABLE 3

Non-limiting Examples Of Time To Travel Through Zones At Specified Command Velocity For Various Dynamic Firing Zones			
Dynamic Firing Zone (rotations)	Time (sec) to Travel Through Zone at Specified Command Velocity		
	Fast	Medium	Slow
First Zone (5 mm long)	$t < 0.5$	$0.5 < t < 0.6$	$t > 0.6$
Intermediate Zones (10 mm long)	$t < 0.9$	$0.9 < t < 1.1$	$t > 1.1$
Last Measured Zone (10 mm long)	$t < 1.0$	$1.0 < t < 1.3$	$t > 1.3$

TABLE 4

Algorithm To Set Velocity Based On Time To Travel Up Ramp		
Algorithm	t_a (sec)	t_b (sec)
If time t (sec) for I-beam to travel up ramp is . . .	$t_1 < t < t_2$	$t > t_2$ to t_3
Then initial velocity V of I-beam in T-slot is . . .	V_1 (mm/sec)	V_2 (mm/sec)
And automatic velocity is set at . . .	FAST	MEDIUM

TABLE 5

Non-limiting Example Of Algorithm To Set Velocity Based On Time To Travel Up Ramp		
Algorithm	t_a (sec)	t_b (sec)
If time t (sec) for I-beam to travel up ramp is . . .	$t < 0.9$	$t \geq 0.9$
Then initial velocity of I-beam in T-slot is . . .	30 mm/sec	12 mm/sec
And automatic velocity is set at . . .	FAST	MEDIUM

In one aspect, Tables 1-5 may be stored in memory of the surgical instrument. The Tables 1-5 may be stored in memory in the form of a look-up table (LUT) such that the control circuit 2510 can retrieve the values and control the command velocity of the I-beam 2514 in each zone based on the values stored in the LUT.

FIG. 19 is a graphical depiction 10100 comparing the I-beam 2514 stroke rotation interval δ_n as a function of time 10102 (top graph) and expected force-to-fire the I-beam 2514 as a function of time 10104 (bottom graph) according to one aspect of this disclosure. Referring to the top graph 10102, the horizontal axis 10106 represents time (t) in seconds (sec) from 0-1.00 X, where X is a scaling factor. For example, in one aspect, X=6 and the horizontal axis 10106 represents time from 0-6 sec. The vertical axis 10108 represents displacement (δ) of the I-beam 2514 in millimeters (mm). The rotation interval δ_1 represents the I-beam 2615 stroke 10114 or displacement at the top of the ramp 10006 (FIGS. 16A, 16B) for thin tissue and medium thick tissue. The time for the I-beam 2514 to reach the top of ramp stroke 10114 for thin tissue is t_1 and the time for the I-beam 2514 to reach the top of ramp stroke 10114 for medium thick tissue is t_2 . As shown, $t_1 < t_2$, such that it takes less time for the I-beam 2514 to reach the top of the ramp stroke 10114 for thin tissue as it takes for medium or thick tissue. In one example, the top of ramp stroke 10114 rotation interval δ_1 is about 4.1 mm (01.60 inches) and the time t_1 is less than 0.9 sec ($t_1 < 0.9$ sec) and the time t_2 is greater than 0.9 sec but less than 1.8 sec ($0.9 < t_2 < 1.8$ sec). Accordingly, with reference also to Table 5, the velocity to reach the top of ramp stroke 10114 is fast for thin tissue and medium for medium thick tissue.

Turning now to the bottom graph **10104**, the horizontal axis **10110** represents time (t) in seconds (sec) and has the same scale of the horizontal axis **10106** of the top graph **10102**. The vertical axis **10112**, however, represents expected force to fire (F) the I-beam **2514** in newtons (N) for thin tissue force to fire graph **10116** and medium thick tissue force to fire graph **10118**. The thin tissue force to fire graph **10116** is lower than medium thick tissue force to fire graph **10118**. The peak force F_1 for the thin tissue force to fire graph **10116** is lower than the peak force F_2 for the medium thick tissue to fire graph **10118**. Also, with reference to the top and bottom graphs **10102**, **10104**, the initial velocity of the I-beam **2514** in zone Z_0 can be determined based on estimated tissue thickness. As shown by the thin tissue force to fire graph **10116**, the I-beam **2514** reaches the peak force F_1 top of ramp stroke **10114** at a fast initial velocity (e.g., 30 mm/sec) and as shown by the medium thick tissue force to fire graph **10118**, the I-beam **2514** reaches the peak force F_2 top of ramp stroke **10114** at a medium initial velocity (e.g., 12 mm/sec). Once the initial velocity in zone Z_0 is determined, the control circuit **2510** can set the estimated velocity of the I-beam **2514** in zone Z_1 , and so on.

FIG. **20** is a graphical depiction **10200** comparing tissue thickness as a function of set rotation interval of I-beam stroke **10202** (top graph), force to fire as a function of set rotation interval of I-beam stroke **10204** (second graph from the top), dynamic time checks as a function of set rotation interval of I-beam stroke **10206** (third graph from the top), and set velocity of I-beam as a function of set rotation interval of I-beam stroke **10208** (bottom graph) according to one aspect of this disclosure. The horizontal axis **10210** for each of the graphs **10202**, **10204**, **10206**, **10208** represents set rotation interval of the shaft of the motor **2504** for a 60 mm staple cartridge, for example. The motor **2504** shaft rotations correspond to a displacement of the displacement member, such as the I-beam **2514**, for example. In one example, a 60 mm cartridge **2518** can be traversed by the I-beam **2514** in about 142 rotations of the motor **2504** shaft with a 60 threads per inch screw drive. With reference also to Table 1, the horizontal axis **10210** has been marked to identify the defined zones Z_1 - Z_6 for a 60 mm staple cartridge. As indicated in Table 1, the defined zones may be marked for staple cartridges of various sizes. The horizontal axis **10210** is marked from 0 to 142 rotations for a 60 mm cartridge and 60 threads per inch leadscrew drive. With reference also to FIG. **14**, in accordance with the present disclosure, the control circuit **2510** samples or measures the elapsed time from the timer/counter circuit **2531** for a number of motor **2504** shaft rotation intervals corresponding to the displacement of the I-beam **2514** traversing the staple cartridge **2518** during the firing stroke. At set rotation intervals δ_n , 12 rotations, 23 rotations, or other suitable number of shaft rotations for example, received from the position sensor **2534**, the control circuit **2510** samples or measures the elapsed time t_n taken by the I-beam **2514** to travel a distance corresponding to the fixed rotation intervals δ_n . For example, a leadscrew with 60 threads per inch corresponds to 0.42 mm per rotation. Thus, 12 rotations of the motor **2504** shaft correspond to a linear displacement of 5.04 mm (~5 mm) and 23 rotations of the motor **2504** shaft corresponds to a displacement of 9.66 mm (~10 mm), for example. In this manner, the control circuit **2510** can determine the actual velocity of the I-beam **2514** and compare the actual velocity to the estimated velocity and make any necessary adjustments to the motor **2504** velocity.

The tissue thickness graph **10202** shows a tissue thickness profile **10220** along the staple cartridge **2518** and an indi-

cated thickness **10221** as shown by the horizontal dashed line. The force to fire graph **10204** shows the force to fire profile **10228** along the staple cartridge **2518**. The force to fire **10230** remains relatively constant while the tissue thickness **10222** remains below the indicated thickness **10221** as the I-beam **2514** traverse zones Z_1 and Z_2 . As the I-beam **2514** enters zone Z_3 , the tissue thickness **10224** increases and the force to fire also increase while the I-beam **2514** traverses the thicker tissue in zones Z_3 , Z_4 , and Z_5 . As the I-beam **2514** exits zone Z_5 and enters zone Z_6 , the tissue thickness **10226** decrease and the force to fire **10234** also decreases.

With reference now to FIGS. **14**, **16-20** and Tables 2-3, the velocity Φ_1 in zone Z_1 is set to the command velocity Φ_0 in rotations per second determined by the control circuit **2510** in zone Z_0 , which is based on the time it takes the I-beam **2514** to travel to the top of the ramp **10006** in zone Z_0 as discussed in reference to FIGS. **16A**, **16B**, and **18**. Turning also to the graphs **10206**, **10208** in FIG. **19**, the initial set velocity Φ_0 was set to Medium and thus the set velocity Φ_1 in zone Z_1 is set to Medium such that $\Phi_1 = \Phi_0$.

At set rotation position δ_1 (e.g., 12 rotations [5.04 mm] for a 60 mm staple cartridge and 60 threads per inch leadscrew), as the I-beam **2514** exits zone Z_1 and enters zone Z_2 , the control circuit **2510** measures the actual time t_1 that it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_1 (12 rotations, 5.04 mm) and determines the actual velocity of the I-beam **2514**. With reference to graphs **10206** and **10208** in FIG. **19**, at set rotation position δ_1 , the actual time t_1 it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_1 is $t_1 = 0.55$ sec. According to Table 3, an actual travel time $t_1 = 0.55$ sec in zone Z_1 requires the command or set velocity Φ_2 in zone Z_2 to be set to Medium. Accordingly, the control circuit **2510** does not reset the command velocity for zone Z_2 and maintains it at Medium.

At set rotation position δ_2 (e.g., 35 rotations [14.7 mm] for a 60 mm staple cartridge and 60 threads per inch leadscrew), as the I-beam **2514** exits zone Z_2 and enters zone Z_3 , the control circuit **2510** measures the actual time t_2 it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_2 (23 rotations, 9.66 mm) and determines the actual velocity of the I-beam **2514**. With reference to graphs **10606** and **10608** in FIG. **19**, at set rotation position δ_2 , the actual time t_2 it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_2 is $t_2 = 0.95$ sec. According to Table 3, an actual travel time $t_2 = 0.95$ sec in zone Z_2 requires the command or set velocity Φ_3 in zone Z_3 to be set to Medium. Accordingly, the control circuit **2510** does not reset the command velocity for zone Z_3 and maintains it at Medium.

At set rotation position δ_3 (e.g., 59 rotations [24.78 mm] for a 60 mm staple cartridge and 60 threads per inch leadscrew), as the I-beam **2514** exits zone Z_3 and enters zone Z_4 , the control circuit **2510** measures the actual time t_3 it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_3 (23 rotations, 9.66 mm) and determines the actual velocity of the I-beam **2514**. With reference to graphs **10606** and **10608** in FIG. **19**, at set rotation position δ_3 , the actual time t_3 it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_3 is $t_3 = 1.30$ sec. According to Table 3, an actual travel time $t_3 = 1.30$ sec in zone Z_3 requires the command or set velocity Φ_4 in zone Z_4 to be set to Slow. This is because the actual travel time of 1.3 sec is greater than 1.10 sec and is outside the previous range. Accordingly, the control circuit **2510** determines that the actual I-beam **2514** velocity in zone Z_3 was slower than

expected due to external influences such as thicker tissue than expected as shown in tissue region **10224** in graph **10202**. Accordingly, the control circuit **2510** resets the command velocity Φ_4 in zone Z_4 from Medium to Slow.

In one aspect, the control circuit **2510** may be configured to disable velocity reset in a zone following a zone in which the velocity was reset. Stated otherwise, whenever the velocity is updated in a present zone the subsequent zone will not be evaluated. Since the velocity was updated in zone Z_4 , the time it takes the I-beam **2514** to traverse zone Z_4 will not be measured at the end of zone Z_4 at the set rotation distance δ_4 (e.g., 82 rotations [34.44 mm] for a 60 mm staple cartridge). Accordingly, the velocity in zone Z_5 will remain the same as the velocity in zone Z_4 and dynamic time measurements resume at set rotation position δ_5 (e.g., 106 rotations [44.52 mm] for a 60 mm staple cartridge and 60 threads per inch leadscrew).

At set rotation position δ_5 (e.g., 106 rotations [44.52 mm] for a 60 mm staple cartridge and 60 threads per inch leadscrew) as the I-beam **2514** exits zone Z_5 and enters zone Z_6 , the control circuit **2510** measures the actual time t_5 it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_5 (23 rotations, 9.75 mm) and determines the actual velocity of the I-beam **2514**. With reference to graphs **10606** and **10608** in FIG. **19**, at set rotation position δ_5 , the actual time t_5 it takes the I-beam **2514** to travel a set distance during the set rotation interval Θ_5 is $t_5=0.95$ sec. According to Table 3, an actual travel time of $t_5=0.95$ sec in zone Z_5 requires the command or set velocity Φ_6 in zone Z_6 to be set to High. This is because the actual travel time of 0.95 sec is less than 1.00 sec is outside the previous range. Accordingly, the control circuit **2510** determines that the actual velocity of the I-beam **2514** in zone Z_5 was faster than expected due to external influences such as thinner tissue than expected as shown in tissue region **10626** in graph **10602**. Accordingly, the control circuit **2510** resets the command velocity Φ_6 in zone Z_6 from Slow to High.

FIG. **21** is a graphical depiction **10300** of force to fire as a function of time comparing slow, medium and fast I-beam **2514** displacement velocities according to one aspect of this disclosure. The horizontal axis **10302** represents time t (sec) that it takes an I-beam to traverse a staple cartridge. The vertical axis **10304** represents force to fire F (N). The graphical depiction shows three separate force to fire curves versus time. A first force to fire curve **10312** represents an I-beam **2514** (FIG. **14**) traversing through thin tissue **10306** at a fast velocity and reaching a maximum force to fire F_1 at the top of the ramp **10006** (FIG. **16B**) at t_1 . In one example, a fast traverse velocity for the I-beam **2514** is ~ 30 mm/sec (~ 71 rotations/sec). A second force to fire curve **10314** represents an I-beam **2514** traversing through medium tissue **10308** at a medium velocity and reaching a maximum force to fire F_2 at the top of the ramp **10006** at t_2 , which is greater than t_1 . In one example, a medium traverse velocity for the I-beam **2514** is ~ 12 mm/sec (~ 29 rotations/sec). A third force to fire curve **10316** represents an I-beam **2514** traversing through thick tissue **10310** at a slow velocity and reaching a maximum force to fire F_3 at the top of the ramp **9006** at t_3 , which is greater than t_2 . In one example, a slow traverse velocity for the I-beam **2514** is ~ 9 mm/sec (~ 21 rotations/sec).

FIG. **22** is a logic flow diagram of a process **10400** depicting a control program or logic configuration for controlling command velocity in an initial firing stage according to one aspect of this disclosure. With reference also to FIGS. **14** and **16-20**, the control circuit **2510** determines **10402** the reference position of the displacement member, such as the

I-beam **2514**, based on the number of rotations of the motor **2504** shaft and the number threads per mm or inch of the leadscrew. As discussed previously, a leadscrew having 60 threads per inch advances the displacement member 0.42 mm per rotation of the shaft. The position information based on the shaft rotation information is provided by the position sensor **2534**. In the I-beam **2514** example, the reference position is the proximal or parked position **10002** at the bottom of the closure ramp **10006** as shown in FIG. **16B**. Once the reference position is determined **10402**, the control circuit **2510** and motor control **2508** set the command velocity of the motor **2504** to a predetermined command velocity Φ_0 and initiates **10404** firing the displacement member (e.g., I-beam **2514**) at the predetermined command velocity Φ_0 for the initial or base zone Z_0 . In one example, the initial predetermined command velocity Φ_0 is ~ 12 mm/sec (29 rotations/sec), however, other initial predetermined command velocity Φ_0 may be employed. The control circuit **2510** monitors **10406** the shaft rotation information received from the position sensor **2534** until the I-beam **2514** reaches a target position at the top of the ramp **10006** as shown in FIG. **16B**. The predetermined rotation interval period T_n is the expected period that the displacement member will take to travel a predetermined distance while traveling at the current set command velocity Φ_0 . The deviation between actual rotation period T_n and the predetermined rotation period T_0 is due at least in part to external influences acting on the displacement member such as tissue thickness acting on the cutting edge **2509** of the I-beam **2514**.

With timing information received from the timer/counter circuit **2531** and shaft rotation information received from the position sensor **2534**, the control circuit **2510** measures **10408** the time t_0 it takes the displacement member to travel from the reference position **10002** to the target position **10004** after a specified number of shaft rotations (e.g., 12 or 24 rotations). The control circuit **210** sets **10410** the command velocity Φ_1 for the first zone Z_1 based on the measured time t_0 . As indicated in Table 1, various defined zones may be defined for staple cartridges of various sizes. Other zones, however, may be defined. The control circuit **2510** sets **10410** the command velocity Φ_1 for the first zone Z_1 by comparing **9412** the measured time t_0 to values stored in memory, such as, for example, stored in a lookup table (LUT). In one example, as indicated in Table 4 generally and in Table 5 by way of specific example, if the time t_0 it takes the I-beam **2514** to travel up the ramp **10006** from the reference position **10002** to the target position **10004** at 5 rotations/sec is less than 0.9 sec ($t_0 < 0.9$ sec), then the command velocity for the first zone Z_1 is set **10414** to FAST (e.g., 30 mm/sec, 71 rotations/sec). Otherwise, if the time t_0 (sec) for the I-beam **2514** to travel up the ramp **10006** from the reference position **10002** to the target position **10004** at 5 rotations/sec is greater than or equal to 0.9 sec ($t_0 \geq 0.9$), then the command velocity for the first zone Z_1 is set **10416** to MEDIUM (e.g., 12 mm/sec, 29 rotations/sec). Subsequently, the control circuit **2510** checks **10418** for lockout and stops **10420** the motor **2504** if there is a lockout condition. Otherwise, the control circuit enters **10422** the dynamic firing phase as described below in reference to process **10450** in FIG. **22**.

FIG. **23** is a logic flow diagram of a process **10450** depicting a control program or logic configuration for controlling command velocity in a dynamic firing stage according to one aspect of this disclosure. With reference also to FIGS. **14** and **16-20**, the control circuit **2510** sets **10452** the initial command velocity of the motor **2504** in rotations per

second for the first zone Z_1 based on the initial time t_0 , as described in reference to the process **10400** in FIG. **21**. As the displacement member traverses the staple cartridge **2518**, the control circuit **2510** receives the shaft rotation information from the position sensor **2534** and timing information from the timer/counter **2531** circuit and monitors **10454** the number of shaft rotations that represent the position of the displacement member over the predefined zone Z_n . At the end of the zone Z_n , the control circuit **2510** measures **10456** the actual time t_n , the displacement member took to travel from the beginning of the zone Z_n to the end of the zone Z_n based on a predetermined number of shaft rotations and compares **10458** the actual time t_n to a predetermined time for a particular zone as shown generally in Table 2 and by way of specific example in Table 3. The predetermined rotation period T_n is the expected rotation period of the displacement member traveling at the current set command velocity Φ_n rotations/sec. The deviation between actual rotation period t_n and the predetermined rotation period T_n is due at least in part to external influences acting on the displacement member such as tissue thickness acting on the cutting edge **2509** of the I-beam **2514**.

For example, with reference to Table 3 the time to travel through a zone at a specified command velocity is provided for various dynamic firing zones. For example, if the dynamic firing zone is the zone Z_1 (12 rotations) and $t_n < 0.5$ sec, the command velocity for the next zone Z_2 is set to FAST; if $0.5 < t_n < 0.6$ sec, the command velocity for the next zone Z_2 is set to MEDIUM; and if $t_n > 0.6$ sec, the command velocity for the next zone Z_2 is set to SLOW.

If, however, the dynamic firing zone is an intermediate zone Z_2 - Z_5 (24 rotations), for example, located between the first zone Z_1 and the last zone Z_6 and if $t_n < 0.9$ sec, the command velocity for the next zone Z_2 is set to FAST; if $0.9 < t_n < 1.1$ sec, the command velocity for the next zone Z_3 - Z_5 is set to MEDIUM; and if $t_n > 1.1$ sec, the command velocity for the next zone Z_3 - Z_5 is set to SLOW.

Finally, if the dynamic firing zone is the last measured zone Z_5 (24 rotations) and $t_n < 1.0$ sec, the command velocity for the final zone Z_6 is set to FAST; if $1.0 < t_n < 1.3$ sec, the command velocity for the final zone Z_6 is set to MEDIUM; and if $t_n > 1.3$ sec, the command velocity for the final zone Z_6 is set to SLOW. Other parameters may be employed not only to define the dynamic firing zones but also to define the time to travel through a zone at specified command velocity for various dynamic firing zones.

Based on the results of the comparison **10458** algorithm, the control circuit **2510** will continue the process **10450**. For example, if the results of the comparison **10458** indicate that the actual velocity (FAST, MEDIUM, SLOW) in the previous zone Z_n is the same as the previous command velocity V_1 (FAST, MEDIUM, SLOW), the control circuit **2510** maintains **10460** the command velocity for the next zone Z_{n+1} the same as the as the previous command velocity. The process **10450** continues to monitor **10454** the number of shaft rotations over the next predefined zone Z_{n+1} . At the end of the next zone Z_{n+1} , the control circuit **2510** measures **10456** the time t_{n+1} the displacement member took to travel a distance from the beginning of the next zone Z_{n+1} to the end of the next zone Z_{n+1} during the predetermined number of shaft rotations and compares **10458** the actual time t_{n+1} to a predetermined time for a particular zone as shown generally in Table 2 and by way of specific example in Table 3. If there are no changes required to the command velocity, the process **10450** until the number of rotations indicates that the displacement member, e.g., the I-beam **2514**, has

reached the end of stroke **10466** and returns **10468** the displacement member to the reference position **10002**.

If the results of the comparison **10458** indicate that the actual velocity (FAST, MEDIUM, SLOW) in the previous zone Z_n is different as the previous command velocity Φ_1 (FAST, MEDIUM, SLOW), the control circuit **2510** resets **10462** or updates the command velocity for the next zone Z_{n+1} according to the algorithm summarized in Tables 2 and 3. If the command speed is reset **10462** or updated to Φ_{new} , the control circuit **2510** maintains **10464** the command velocity Φ_{new} for an additional zone Z_{n+2} . In other words, at the end of the next zone Z_{n+1} , the control circuit **2510** does not evaluate or measure the time. The process **10450** continues to monitor **10454** the number of shaft rotations representative of the position of the displacement member over the next predefined zone Z_{n+1} until the number of rotations indicates that the displacement member, e.g., the I-beam **2514**, has reached the end of stroke **10466** and returns **10468** the displacement member to the reference position **10002**.

The functions or processes **10400**, **10450** described herein may be executed by any of the processing circuits described herein, such as the control circuit **700** described in connection with FIGS. **5-6**, the circuits **800**, **810**, **820** described in FIGS. **7-9**, the microcontroller **1104** described in connection with FIGS. **10** and **12**, and/or the control circuit **2510** described in FIG. **14**.

Aspects of the motorized surgical instrument may be practiced without the specific details disclosed herein. Some aspects have been shown as block diagrams rather than detail. Parts of this disclosure may be presented in terms of instructions that operate on data stored in a computer memory. An algorithm refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities which may take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. These signals may be referred to as bits, values, elements, symbols, characters, terms, numbers. These and similar terms may be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities.

Generally, aspects described herein which can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or any combination thereof can be viewed as being composed of various types of "electrical circuitry." Consequently, "electrical circuitry" includes electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit, electrical circuitry forming a general purpose computing device configured by a computer program (e.g., a general purpose computer or processor configured by a computer program which at least partially carries out processes and/or devices described herein, electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). These aspects may be implemented in analog or digital form, or combinations thereof.

The foregoing description has set forth aspects of devices and/or processes via the use of block diagrams, flowcharts, and/or examples, which may contain one or more functions and/or operation. Each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of

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hardware, software, firmware, or virtually any combination thereof. In one aspect, several portions of the subject matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), Programmable Logic Devices (PLDs), circuits, registers and/or software components, e.g., programs, subroutines, logic and/or combinations of hardware and software components. logic gates, or other integrated formats. Some aspects disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure.

The mechanisms of the disclosed subject matter are capable of being distributed as a program product in a variety of forms, and that an illustrative aspect of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include the following: a recordable type medium such as a floppy disk, a hard disk drive, a Compact Disc (CD), a Digital Video Disk (DVD), a digital tape, a computer memory, etc.; and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link (e.g., transmitter, receiver, transmission logic, reception logic, etc.).

The foregoing description of these aspects has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. These aspects were chosen and described in order to illustrate principles and practical application to thereby enable one of ordinary skill in the art to utilize the aspects and with modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

Various aspects of the subject matter described herein are set out in the following numbered examples:

Example 1

A surgical instrument, comprising: a displacement member configured to translate within the surgical instrument over a plurality of predefined zones; a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member; a control circuit coupled to the motor; a position sensor coupled to the control circuit, the position sensor configured to monitor the rotation of the shaft; a timer circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time; wherein the control circuit is configured to: receive, from the position sensor, rotations of the shaft in a current zone defined by a set rotation interval; measure time at a set position of the rotation interval, wherein the measured time is defined as the time taken by the displacement member to traverse the rotation interval based on a predetermined number of shaft rotations; and set a command velocity of the

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displacement member for a subsequent zone based on the measured time in the current predefined zone.

Example 2

The surgical instrument of Example 1, wherein the control circuit is configured to: determine the set rotation interval in which the displacement member is located, wherein the set rotation interval is defined by a number of rotations of the shaft that result in a linear translation of the displacement member from a beginning position to an ending position; and measure the time when the displacement member reaches the ending position of the rotation interval.

Example 3

The surgical instrument of Example 1 through Example 2, wherein the control circuit is configured to: compare the measured time to a predetermined time stored in a memory coupled to the control circuit; and determine whether to adjust or maintain the command velocity based on the comparison.

Example 4

The surgical instrument of Example 3, wherein the control circuit is configured to maintain the command velocity for the subsequent zone the same as the command velocity of the current zone when the measured time is within a range of predetermined times.

Example 5

The surgical instrument of Example 3 through Example 4, wherein the control circuit is configured to set the command velocity for the subsequent zone different from the command velocity of the current zone when the measured time is outside a range of predetermined times.

Example 6

The surgical instrument of claim 5, wherein the control circuit is configured to skip a time measurement for a subsequent zone when the command velocity is adjusted.

Example 7

The surgical instrument of Example 1 through Example 6, wherein multiple zones are defined for a staple cartridge configured to operate with the surgical instrument.

Example 8

The surgical instrument of claim Example 7, wherein at least two zones have a different length.

Example 9

The surgical instrument of Example 1 through Example 8, further comprising a screw drive system coupled to the shaft of the motor, the screw drive system comprising a lead screw coupled to a nut, wherein the nut is coupled to the displacement member.

Example 10

A surgical instrument, comprising: a displacement member configured to translate within the surgical instrument

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over a plurality of predefined zones; a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member; a control circuit coupled to the motor; a position sensor coupled to the control circuit, the position sensor configured to monitor the rotation of the shaft; a timer circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time; wherein the control circuit is configured to: receive, from the position sensor, rotations of the shaft in a current zone defined by a predetermined rotation interval; measure time as the displacement member moves from a parked position to a target position based on a predetermined number of shaft rotations; and set a command velocity of the displacement member for a first dynamic zone based on the measured time.

Example 11

The surgical instrument of Example 10, wherein the control circuit is configured to compare the measured time to a predetermined time stored in a memory coupled to the control circuit.

Example 12

The surgical instrument of Example 11, wherein the control circuit is configured to set the command velocity for the initial zone to a first velocity when the measured time is within a first range of times and set the command velocity for the initial zone to a second velocity when the measured time is within a second range of times.

Example 13

The surgical instrument of Example 10 through Example 12, wherein the control circuit is configured to determine a lockout condition and stop the motor.

Example 14

The surgical instrument of Example 10 through Example 13, further comprising a screw drive system coupled to the shaft of the motor, the screw drive system comprising a lead screw coupled to a nut, wherein the nut is coupled to the displacement member.

Example 15

A method of controlling motor velocity in a surgical instrument, the surgical instrument comprising a displacement member configured to translate within the surgical instrument over a plurality of predefined zones, a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member, a control circuit coupled to the motor, a position sensor coupled to the control circuit, the position sensor configured to monitor the rotation of the shaft, a timer circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time, the method comprising: receiving, from a position sensor, rotations of the shaft in a current zone defined by a set rotation interval; measuring, by a timer circuit, a time at a set position of the of the rotation interval, wherein the measured time is defined by the time taken by the displacement member to traverse the rotation interval based on a predetermined number of shaft rotations; and setting, by the control circuit, a command velocity of the

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displacement member for a subsequent zone based on the measured time in the current zone.

Example 16

The method of Example 15, further comprising: determining, by the control circuit and the timer circuit, the set rotation interval in which the displacement member is located, wherein the set rotation interval is defined by a number of rotations of the shaft that result in a linear translation of the displacement member from a beginning position to an ending position; and measuring, by the control circuit, the time when the displacement member reaches the ending position of the rotation interval.

Example 17

The method of Example 15 through Example 16, further comprising: comparing, by the control circuit, the measured time to a predetermined time stored in a memory coupled to the control circuit; and determining, by the control circuit, whether to adjust or maintain the command velocity based on the comparison.

Example 18

The method of Example 17, further comprising maintaining, by the control circuit, the command velocity for the subsequent zone the same as the command velocity of the current zone when the measured time is within a range of predetermined times.

Example 19

The method of Example 17 through Example 18, further comprising setting, by the control circuit, the command velocity for the subsequent zone different from the command velocity of the current zone when the measured time is outside a range of predetermined times.

Example 20

The method of Example 19, further comprising skipping, by the control circuit, a time measurement for a subsequent zone when the command velocity is adjusted.

Example 21

The method of Example 15 through Example 20, further comprising defining, by the control circuit, multiple zones are defined for a staple cartridge configured to operate with the surgical instrument.

Example 22

The method of Example 21, further comprising defining, by the control circuit, at least two zones having a different length.

The invention claimed is:

1. A surgical instrument, comprising:
 - a displacement member configured to translate within the surgical instrument over a plurality of predefined zones;
 - a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member;
 - a control circuit coupled to the motor;

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a position sensor coupled to the control circuit, the position sensor configured to monitor rotation of the shaft;

a timer/counter circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time; 5

wherein the control circuit is configured to:

- receive, from the position sensor, rotations of the shaft in a current zone defined by a set rotation interval;
- measure time at a set position of the set rotation interval, wherein the measured time is defined as the time taken by the displacement member to traverse the set rotation interval based on a predetermined number of shaft rotations;
- set a command velocity of the displacement member for a subsequent zone based on the measured time in the current zone; and
- without stopping the displacement member, cause the motor to drive the displacement member at the command velocity as the displacement member enters the subsequent zone. 20

2. The surgical instrument of claim 1, wherein the control circuit is configured to:

- determine the set rotation interval in which the displacement member is located, wherein the set rotation interval is defined by a number of rotations of the shaft that result in a linear translation of the displacement member from a beginning position to an ending position; and
- measure the time when the displacement member reaches the ending position. 30

3. The surgical instrument of claim 1, wherein the control circuit is configured to:

- compare the measured time to a predetermined time stored in a memory coupled to the control circuit; and
- determine whether to adjust or maintain the command velocity based on the comparison. 35

4. The surgical instrument of claim 3, wherein the control circuit is configured to maintain the command velocity for the subsequent zone the same as the command velocity of the current zone when the measured time is within a range of predetermined times. 40

5. The surgical instrument of claim 3, wherein the control circuit is configured to adjust the command velocity for the subsequent zone different from the command velocity of the current zone when the measured time is outside a range of predetermined times. 45

6. The surgical instrument of claim 5, wherein the control circuit is configured to skip a time measurement for a second subsequent zone when the command velocity is adjusted. 50

7. The surgical instrument of claim 1, wherein multiple zones are defined for a staple cartridge configured to operate with the surgical instrument.

8. The surgical instrument of claim 7, wherein at least two zones have a different length. 55

9. The surgical instrument of claim 1, further comprising a screw drive system coupled to the shaft of the motor, the screw drive system comprising a lead screw coupled to a nut, wherein the nut is coupled to the displacement member.

10. A surgical instrument, comprising: 60

- a displacement member configured to translate within the surgical instrument over a plurality of predefined zones;
- a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member;
- a control circuit coupled to the motor; 65

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a position sensor coupled to the control circuit, the position sensor configured to monitor rotation of the shaft;

a timer/counter circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time;

wherein the control circuit is configured to:

- receive, from the position sensor, rotations of the shaft in an initial zone defined by a predetermined rotation interval;
- measure time as the displacement member moves from a parked position to a target position based on a predetermined number of shaft rotations;
- set a command velocity of the displacement member for a first dynamic zone based on the measured time; and
- without stopping the displacement member, cause the motor to drive the displacement member at the command velocity as the displacement member enters the first dynamic zone.

11. The surgical instrument of claim 10, wherein the control circuit is configured to compare the measured time to a predetermined time stored in a memory coupled to the control circuit.

12. The surgical instrument of claim 11, wherein the control circuit is configured to set the command velocity for the first dynamic zone to a first velocity when the measured time is within a first range of times and set the command velocity for the first dynamic zone to a second velocity when the measured time is within a second range of times.

13. The surgical instrument of claim 10, wherein the control circuit is configured to determine a lockout condition and stop the motor.

14. The surgical instrument of claim 10, further comprising a screw drive system coupled to the shaft of the motor, the screw drive system comprising a lead screw coupled to a nut, wherein the nut is coupled to the displacement member.

15. A method of controlling motor velocity in a surgical instrument, the surgical instrument comprising a displacement member configured to translate within the surgical instrument over a plurality of predefined zones, a motor comprising a shaft, the motor coupled to the displacement member to translate the displacement member, a control circuit coupled to the motor, a position sensor coupled to the control circuit, the position sensor configured to monitor rotation of the shaft, a timer/counter circuit coupled to the control circuit, the timer/counter circuit configured to measure elapsed time, the method comprising: 50

- receiving, from the position sensor, rotations of the shaft in a current zone defined by a set rotation interval;
- measuring, by the timer/counter circuit, a time at a set position of the set rotation interval, wherein the measured time is defined by the time taken by the displacement member to traverse the set rotation interval based on a predetermined number of shaft rotations;
- setting, by the control circuit, a command velocity of the displacement member for a subsequent zone based on the measured time in the current zone; and
- without stopping the displacement member, causing the motor to drive the displacement member at the command velocity as the displacement member enters the subsequent zone.

16. The method of claim 15, further comprising: 55

- determining, by the control circuit and the timer/counter circuit, the set rotation interval in which the displacement member is located, wherein the set rotation inter-

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val is defined by a number of rotations of the shaft that result in a linear translation of the displacement member from a beginning position to an ending position; and

measuring, by the control circuit, the time when the displacement member reaches the ending position of the set rotation interval.

17. The method of claim 15, further comprising:

comparing, by the control circuit, the measured time to a predetermined time stored in a memory coupled to the control circuit; and

determining, by the control circuit, whether to adjust or maintain the command velocity based on the comparison.

18. The method of claim 17, further comprising maintaining, by the control circuit, the command velocity for the

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subsequent zone the same as the command velocity of the current zone when the measured time is within a range of predetermined times.

19. The method of claim 17, further comprising adjusting, by the control circuit, the command velocity for the subsequent zone different from the command velocity of the current zone when the measured time is outside a range of predetermined times.

20. The method of claim 19, further comprising skipping, by the control circuit, a time measurement for a subsequent zone when the command velocity is adjusted.

21. The method of claim 15, further comprising defining, by the control circuit, multiple zones for a staple cartridge configured to operate with the surgical instrument.

22. The method of claim 21, further comprising defining, by the control circuit, at least two zones having a different length.

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