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MOTOR ASSEMBLY

Abstract

Techniques for controlling an instrument using a motor assembly include a control system having a first memory storing instructions and a processor. When the processor executes the instructions, the processor is configured to receive one or more motor parameters stored in a second memory of the motor assembly, receive one or more instrument parameters stored in a third memory of an instrument, determine an instruction for a motor of the motor assembly based on at least the one or more motor parameters and the one or more instrument parameters, and transmit the instruction to the motor assembly. The motor assembly is coupled to the control system. The instrument is coupled to the motor assembly. The instruction is for controlling motion of an end effector of the instrument using the motor.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 17/514,765, filed Oct. 29, 2021, which is a continuation of U.S. patent application Ser. No. 16/361,095, filed Mar. 21, 2019, issued as U.S. Pat. No. 11,185,378, which is a continuation of U.S. patent application Ser. No. 14/154,087, filed Jan. 13, 2014, issued as U.S. Pat. No. 10,277,097, and claims priority to U.S. Provisional Patent Application No. 61/752,409, filed Jan. 14, 2013 and entitled "Motor Assembly." The subject matter of these related applications is incorporated herein by reference in its entirety.

TECHNICAL FIELD
[0002] Embodiments of the present invention are directed to the management of torque parameters in surgical instruments such as staplers or vessel sealers to control the force at the distal tip.
DISCUSSION OF RELATED ART
[0003] Minimally invasive surgical techniques are aimed at reducing the amount of extraneous tissue that is damaged during diagnostic or surgical procedures, thereby reducing patient recovery time, discomfort, and deleterious side effects. As a consequence, the average length of a hospital stay for standard surgery may be shortened significantly using minimally invasive surgical techniques. Also, patient recovery times, patient discomfort, surgical side effects, and time away from work may also be reduced with minimally invasive surgery.
[0004] A common form of minimally invasive surgery is endoscopy, and a common form of endoscopy is laparoscopy, which is minimally invasive inspection and surgery inside the abdominal cavity. In standard laparoscopic surgery, a patient's abdomen is insufflated with gas, and cannula sleeves are passed through small (approximately one-half inch or less) incisions to provide entry ports for laparoscopic instruments.
[0005] Laparoscopic surgical instruments generally include an endoscope (e.g., laparoscope) for viewing the surgical field and tools for working at the surgical site. The working tools are typically similar to those used in conventional (open) surgery, except that the working end or end effector of each tool is separated from its handle by an extension tube (also known as, e.g., an instrument shaft or a main shaft). The end effector can include, for example, a clamp, grasper, scissor, stapler, vessel sealer, cautery tool, linear cutter, needle holder, or other instrument.
[0006] To perform surgical procedures, the surgeon passes working tools through cannula sleeves to an internal surgical site and manipulates them from outside the abdomen. The surgeon views the procedure from a monitor that displays an image of the surgical site taken from the endoscope. Similar endoscopic techniques are employed in, for example, arthroscopy, retroperitoneoscopy, pelviscopy, nephroscopy, cystoscopy, cisternoscopy, sinoscopy, hysteroscopy, urethroscopy, and the like.

[0007] Minimally invasive telesurgical robotic systems are being developed to increase a surgeon's dexterity when working on an internal surgical site, as well as to allow a surgeon to operate on a patient from a remote location (outside the sterile field). In a telesurgery system, the surgeon is often provided with an image of the surgical site at a control console. While viewing a three dimensional image of the surgical site on a suitable viewer or display, the surgeon performs the surgical procedures on the patient by manipulating master input or control devices of the control console. Each of the master input devices controls the motion of a servo-mechanically actuated/articulated surgical instrument. During the surgical procedure, the telesurgical system can provide mechanical actuation and control of a variety of surgical instruments or tools having end effectors that perform various functions for the surgeon, for example, holding or driving a needle, grasping a blood vessel, dissecting tissue, or the like, in response to manipulation of the master input devices.

[0008] Manipulation and control of these end effectors is a particularly beneficial aspect of robotic surgical systems. For this reason, it is desirable to provide surgical tools that include mechanisms that provide three degrees of rotational movement of an end effector to mimic the natural action of a surgeon's wrist. Such mechanisms should be appropriately sized for use in a minimally invasive procedure and relatively simple in design to reduce possible points of failure. In addition, such mechanisms should provide an adequate range of motion to allow the end effector to be manipulated in a wide variety of positions.

[0009] Surgical clamping and cutting instruments (e.g., non-robotic linear clamping, stapling, and cutting devices, also known as surgical staplers; and electrosurgical vessel sealing devices) have been employed in many different surgical procedures. For example, a surgical stapler can be used to resect a cancerous or anomalous tissue from a gastro-intestinal tract. Many known surgical clamping and cutting instruments, including known surgical staplers, have opposing jaws that clamp tissue and an articulated knife to cut the clamped tissue between the inserted staples.

[0010] The operation of a surgical stapler typically involves the transfer of a relatively high amount of force to the end effector of the surgical stapler. One way of transferring force involves transferring rotary motion from actuators to the end effector. Under-clamping by providing too little force to the end effector can result in less than a complete clamp, leaving a large tissue gap and resulting in inadequately formed staples. Over-clamping by providing too much force to the end effectors can result in increased deflection of the end effector and again result in a large tissue gap, which may result in inadequately formed staples.

[0011] Similar considerations can be applied to vessel sealers. A vessel sealer clamps the tissue, seals two sides, and divides the tissue between the seals with a knife. Again, improper clamping can result in improper sealing of the tissue.

[0012] Therefore, there is a need to control the clamping of an instrument to provide for proper clamping during operation.

SUMMARY

[0013] In accordance with some embodiments of the present invention a calibrated motor assembly is provided. A method of calibrating a motor in a motor assembly according to the present invention includes acquiring an assembled motor assembly; performing an initial calibration of the motor in the motor assembly; wearing in the motor; performing a final calibration of the motor; and storing calibration data in the motor assembly.

[0014] A motor assembly according to some embodiments of the invention can include at least one motor; a memory to store calibrated parameters related to the at least one motor; and electronics coupled to the memory, the at least one motor, the electronics including interfaces to couple with a clamping device and a system to control the operation of the at least one motor. The calibrated parameters are determined for the at least one motor with a procedure that includes performing an initial calibration of the at least one motor; wearing in the at least one motor; performing a final calibration of the at least one motor; and storing calibration data in the memory. In some

embodiments, the at least one motor includes a clamping motor. In some embodiments, the at least one motor includes a firing motor. In some embodiments, lifetime parameters are stored in the memory.

[0015] These and other embodiments are further discussed below with respect to the following figures.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** is a plan view of a minimally invasive robotic surgery system being used to perform a procedure.

[0017] FIG. **2** is a perspective view of a surgeon's control console for a robotic surgery system shown in FIG. **1**.

[0018] FIG. **3** is a perspective view of a robotic surgery system electronics cart shown in FIG. **1**.

[0019] FIG. **4** diagrammatically illustrates a robotic surgery system as shown in FIG. **1**.

[0020] FIG. **5** illustrates a patient side cart of a surgical system as shown in FIG. **1**.

[0021] FIGS. **6**A and **6**B illustrate a surgical stapler.

[0022] FIGS. **6**C and **6**D illustrate a vessel sealer.

[0023] FIG. **7** illustrates coupling of a surgical stapler as illustrated in FIGS. **6**A and **6**B with a motor assembly.

[0024] FIG. **8** illustrates operation of a surgical system utilizing a surgical stapler.

[0025] FIG. **9**A illustrates a method of calibrating a surgical stapler according to some embodiments of the present invention.

[0026] FIG. **9**B illustrates a surgical stapler during calibration.

[0027] FIG. **9**C shows example data obtained during a calibration procedure.

[0028] FIGS. **10**A and **10**B illustrate a procedure for calibrating a motor assembly according to some embodiments of the present invention.

[0029] FIGS. **10**C and **10**D illustrate calibration of a no-load current for motors in a motor assembly according to some embodiments of the present invention.

[0030] FIGS. **10**E and **10**F illustrate calibration of a torque constant for motors in a motor assembly according to some embodiments of the present invention.

[0031] FIG. **11** shows a method of adjusting torque limits for a surgical stapler during operation.

[0032] In the figures, elements provided with the same element number have the same or similar function.

DETAILED DESCRIPTION

[0033] In the following description, specific details are set forth describing some embodiments of the present invention. It will be apparent, however, to one skilled in the art that some embodiments may be practiced without some or all of these specific details. The specific embodiments disclosed herein are meant to be illustrative but not limiting. One skilled in the art may realize other elements that, although not specifically described here, are within the scope and the spirit of this disclosure.

[0034] This description and the accompanying drawings that illustrate inventive aspects and embodiments should not be taken as limiting—the claims define the protected invention. Various mechanical, compositional, structural, and operational changes may be made without departing from the spirit and scope of this description and the claims. In some instances, well-known structures and techniques have not been shown or described in detail in order not to obscure the invention.

[0035] Additionally, the drawings are not to scale. Relative sizes of components are for illustrative purposes only and do not reflect the actual sizes that may occur in any actual embodiment of the invention. Like numbers in two or more figures represent the same or similar elements.

[0036] Further, this description's terminology is not intended to limit the invention. For example, spatially relative terms—such as "beneath", "below", "lower", "above", "upper", "proximal", "distal", and the like—may be used to describe one element's or feature's relationship to another element or feature as illustrated in the figures. These spatially relative terms are intended to encompass different positions (i.e., locations) and orientations (i.e., rotational placements) of a device in use or operation in addition to the position and orientation shown in the figures. For example, if a device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be "above" or "over" the other elements or features. Thus, the exemplary term "below" can encompass both positions and orientations of above and below. A device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly. Likewise, descriptions of movement along and around various axes includes various special device positions and orientations. In addition, the singular forms "a", "an", and "the" are intended to include the plural forms as well, unless the context indicates otherwise. And, the terms "comprises", "comprising", "includes", and the like specify the presence of stated features, steps, operations, elements, and/or components but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups. Components described as coupled may be electrically or mechanically directly coupled, or they may be indirectly coupled via one or more intermediate components.

[0037] Elements and their associated aspects that are described in detail with reference to one embodiment may, whenever practical, be included in other embodiments in which they are not specifically shown or described. For example, if an element is described in detail with reference to one embodiment and is not described with reference to a second embodiment, the element may nevertheless be claimed as included in the second embodiment.

Minimally Invasive Robotic Surgery

[0038] FIG. **1** shows a plan view illustration of a Minimally Invasive Robotic Surgical (MIRS) system **10**, typically used for performing a minimally invasive diagnostic or surgical procedure on a Patient **12** who is lying on an Operating table **14**. The system can include a Surgeon's Console **16** for use by a Surgeon **18** during the procedure. One or more Assistants **20** may also participate in the procedure. The MIRS system **10** can further include a Patient Side Cart **22** (surgical robot) and an Electronics Cart **24**. The Patient Side Cart **22** can manipulate at least one removably coupled tool assembly **26** (hereinafter simply referred to as a "tool") through a minimally invasive incision in the body of the Patient **12** while the Surgeon **18** views the surgical site through the Console **16**. An image of the surgical site can be obtained by an endoscope **28**, such as a stereoscopic endoscope, which can be manipulated by the Patient Side Cart **22** to orient the endoscope **28**. The Electronics Cart **24** can be used to process the images of the surgical site for subsequent display to the Surgeon **18** through the Surgeon's Console **16**. The number of surgical tools **26** used at one time will generally depend on the diagnostic or surgical procedure and the space constraints within the operating room among other factors. If it is necessary to change one or more of the tools **26** being used during a procedure, an Assistant **20** may remove the tool **26** from the Patient Side Cart **22**, and replace it with another tool **26** from a tray **30** in the operating room.

[0039] FIG. **2** is a perspective view of the Surgeon's Console **16**. The Surgeon's Console **16** includes a left eye display **32** and a right eye display **34** for presenting the Surgeon **18** with a coordinated stereo view of the surgical site that enables depth perception. The Console **16** further includes one or more input control devices **36**, which in turn cause the Patient Side Cart **22** (shown in FIG. **1**) to manipulate one or more tools. The input control devices **36** can provide the same degrees of freedom as their associated tools **26** (shown in FIG. **1**) to provide the Surgeon with telepresence, or the perception that the input control devices **36** are integral with the tools **26** so that the Surgeon has a strong sense of directly controlling the tools **26**. To this end, position, force, and tactile feedback sensors (not shown) may be employed to transmit position, force, and tactile sensations from the tools **26** back to the Surgeon's hands through the input control devices **36**.

[0040] The Surgeon's Console **16** is usually located in the same room as the patient so that the Surgeon may directly monitor the procedure, be physically present if necessary, and speak to an Assistant directly rather than over the telephone or other communication medium. However, the Surgeon can be located in a different room, a completely different building, or other remote location from the Patient allowing for remote surgical procedures.

[0041] FIG. **3** is a perspective view of the Electronics Cart **24**. The Electronics Cart **24** can be coupled with the endoscope **28** and can include a processor to process captured images for subsequent display, such as to a Surgeon on the Surgeon's Console, or on another suitable display located locally and/or remotely. For example, where a stereoscopic endoscope is used, the Electronics Cart **24** can process the captured images to present the Surgeon with coordinated stereo images of the surgical site. Such coordination can include alignment between the opposing images and can include adjusting the stereo working distance of the stereoscopic endoscope. As another example, image processing can include the use of previously determined camera calibration parameters to compensate for imaging errors of the image capture device, such as optical aberrations.

[0042] FIG. **4** diagrammatically illustrates a robotic surgery system **50** (such as MIRS system **10** of FIG. **1**). As discussed above, a Surgeon's Console **52** (such as Surgeon's Console **16** in FIG. **1**) can be used by a Surgeon to control a Patient Side Cart (Surgical Robot) **54** (such as Patent Side Cart **22** in FIG. **1**) during a minimally invasive procedure. The Patient Side Cart **54** can use an imaging device, such as a stereoscopic endoscope, to capture images of the procedure site and output the captured images to an Electronics Cart **56** (such as the Electronics Cart **24** in FIG. **1**). As discussed above, the Electronics Cart **56** can process the captured images in a variety of ways prior to any subsequent display. For example, the Electronics Cart **56** can overlay the captured images with a virtual control interface prior to displaying the combined images to the Surgeon via the Surgeon's Console **52**. The Patient Side Cart **54** can output the captured images for processing outside the Electronics Cart **56**. For example, the Patient Side Cart **54** can output the captured images to a processor **58**, which can be used to process the captured images. The images can also be processed by a combination of the Electronics Cart **56** and the processor **58**, which can be coupled together to process the captured images jointly, sequentially, and/or combinations thereof. One or more separate displays **60** can also be coupled with the processor **58** and/or the Electronics Cart **56** for local and/or remote display of images, such as images of the procedure site, or other related images.

[0043] FIG. **5** shows a Patient Side Cart **22**. The Patient Side Cart **22** shown provides for the manipulation of three surgical tools **26** and an imaging device **28**, such as a stereoscopic endoscope used for the capture of images of the site of the procedure. Manipulation is provided by robotic mechanisms having a number of robotic joints. The imaging device **28** and the surgical tools **26** can be positioned and manipulated through incisions in the patient or through an orifice in the patient so that a kinematic remote center is maintained at the incision to minimize the size of the incision. Images of the surgical site can include images of the distal ends of the surgical tools **26** when they are positioned within the field-of-view of the imaging device **28**.

[0044] FIGS. **1**-**5** illustrate a multi-port surgical robot. It should be understood that embodiments of the present invention can also be utilized with a single port surgical robot. In either multiport or single port surgeries, surgical tools **26** are passed through cannulas inserted into patient **12** at the surgical site. The surgical tools **26** are manipulated through patient side cart **22** while the surgeon directs and views the procedure from surgeon's console **16**. Processor **58** and electronics cart **24** can be utilized to translate inputs from the surgeon at the surgeon's console **16** to actual motion of end effectors of surgical tools **26**. Surgical tools that may be typically utilized include clamps, graspers, scissors, staplers, cautery tools, linear cutters, needle holders, and other instruments. Each of the surgical tools **26** is attached to, and driven by, patient side cart **22** under the direction of surgeon **18**, as provided by processor **58** and electronics cart **56**. Processor **58** and electronics cart **16** translate

the inputs from surgeon **18** into driving actions at patient side cart **22** that affect the motions of the end effectors of surgical tools **26**. In particular, surgical tools **26** can include one of a stapler or vessel sealer according to the present invention.

Clamping Instrument

[0045] The surgical tools **26** that can be employed in surgical system **10** can include clamping instruments such as staplers and electronic vessel sealers. Such devices can be used to resect cancerous or anomalous tissue, for example from a gastro-intestinal tract. FIG. **6**A illustrates an example of a stapler **600**. Stapler **600** includes a stapler end effector **602**, a wrist **604**, an instrument shaft **606** and a chassis **608**.

[0046] As shown in FIG. **6**A, stapler end effector **602** includes an anvil **610** and a jaw **612**. A stapler cartridge **614** can be inserted onto jaw **612**. In some embodiments of stapler **600**, a cutting knife blade **616** is configured such that it can travel along the long direction of anvil **610**. Stapler **600** can be utilized as a grasper, however during operation as a stapler jaw **612** is forced against anvil **610** to clamp tissue between jaw **612** and anvil **610**.

[0047] A proper tissue gap, the distance between jaw **612** and anvil **610** during clamping, is important for proper staple formation. If the tissue gap is too large, the staples will not properly form during firing. A large tissue gap can be caused by clamping overly thick material between jaw **612** and anvil **610**. In some cases, stapler end effector **602** can be driven to a predetermined clamp position and the torque required to achieve this position measured. If the torque is too high, then anvil **610** has deflected and the tissue gap will be too big. In some embodiments, a torque limit can be set and end effector **602** can be moved toward a predetermined clamp position. If the torque limit prevents end effector **602** from achieving the predetermined clamp, then an appropriate tissue gap cannot be achieved. In both cases, accurate sensing or control of the torque acting on anvil **610** is important for accurately detecting inadequate tissue gap

[0048] When the stapler is fired, staples are forced through the intervening tissue and into anvil **610** by sled **618** traveling along jaw **612**. The distance between jaw **612** and anvil **610**, which is the tissue gap, determines proper formation of the staples. Controlling the tissue gap can help to ensure proper staple formation. Adequate clamping force between jaw **612** and anvil **610** provides for an appropriate tissue gap for staple formation. Adequate clamping force on the tissue can be a function of cartridge **614**, which determines the length of the staples.

[0049] Additionally, knife blade **616** (which may be formed as an I-Beam or attached to sled **618**) is translated along anvil **610** to separate the stapled tissue. In some embodiments, sled **618** and knife blade **616** are formed within cartridge **614**. If the tissue gap is incorrect, the staples may be improperly formed, causing tissue damage and other complications. In some embodiments, stapler **600** may be a linear stapler. Some embodiments may not include knife blade **616** and therefore perform stapling without transection.

[0050] Achievement of hemostasis and pneumostasis (the sealing of tissue using a stapling device) depends on providing appropriate pressure, which results from the clamping force, on the tissue after firing such that the staples adequately compress the tissue to prevent bleeding and leaks. Providing too much pressure may result in the staples squeezing the tissue hard enough to cut off the blood supply entirely, preventing the tissue from healing and leading to necrosis.

[0051] As discussed above, if too much clamping force is used to position end effector **602** into a predetermined clamp position, then a deflection between the tips of anvil **610** and jaw **612** may result in incorrect clamping. Additionally, too little clamping force and jaw **612** may not fully close against anvil **610** into a predetermined clamp position, again resulting in improper stapling of the tissue.

[0052] Stapler cartridge **614** can be color coded for particular circumstance, including tissue thickness. Although several different colors can be utilized, the following chart of color coding may apply:

TABLE-US-00001 Cartridge Tissue Open Staple Closed Staple Color Thickness Height (mm)

Color	Type	Height (mm)	
Gray	Mesentery/Thin	2.0	0.75
White	Vascular/Thin	2.5	1.0
Blue	Regular	3.5	1.5
Gold	Regular/Thick	3.8	1.8
Green	Thick	4.1	2.0
Black	Very Thick	4.4	2.3

Cartridge **614** may come in various lengths, for example 30, 45, or 60 mm. A single stapler **600** can fire many reloads, with each cartridge being fired once. Cartridge **614** may include data storage that holds, for example, cartridge serial number, cartridge type, part number, style, direction of firing, length of firing, cartridge color, firing torque, maximum deflection and other data. In some embodiments, knife blade **616** and sled **618** are part of cartridge **614** and are replaced with each re-load.

[0053] FIG. **6**B illustrates staple end effector **602** clamped to tissue **650**. As shown in FIG. **6**B, cartridge **614** includes staples **652**. During firing, sled **618** can travel along jaw **612** to drive staples **652** that are housed in cartridge **614** through the clamped tissue and into pockets **654** on anvil **610**. Although FIG. **6**B illustrates an embodiment where each leg of staple **652** can be formed into a portion of the "B"-shape by an individual pocket **654**, in some embodiments staple **652** can be shaped by a single pocket **654**. Pockets **654** are configured to form staples **652** into a "B"-shape, which provides optimal sealing. Knife **616** cuts the tissue between rows of staples to cut the stapled tissue. Cartridge **614** may produce a number of rows of staples, for example two (2) or three (3) rows on each side of the cut formed by knife **616** may be formed.

[0054] The clamping action of jaw **612** and anvil **610** and the firing motion of sled **618** and knife **616** are driven by chassis **608** coupling a torque from external motors (not shown in FIG. **6**A) to couplers **660**. Couplers **660** can be, for example, drive shafts or cables. Couplers **660** travel along shaft **606** and couple to cams, gears, screws, or worm drives in end effector **602** and cartridge **614**. Couplers **660** are also utilized to control wrist **604**. As shown in FIG. **6**A, chassis **608** controls couplers **660** by controlling the tension of cables or rotation of drive shafts that run through instrument shaft **606** to end effector **602**. Clamping of jaw **612** against **610** can be managed with a cam mechanism that rotates jaw **612** into anvil **610** or alternatively rotates anvil **610** into jaw **612**. The firing of sled **618** and knife **616** can, for example, be driven by a lead screw mechanism driven by a drive shaft coupler **660**. In some embodiments, clamping of jaw **612** and anvil **610** and firing of sled **618** and knife **616** can be controlled by rigid drive shafts while control of a normal grip of jaw **612** and anvil **610** as well as the pitch and yaw of wrist **604** can be controlled by cables. In some embodiments, clamping and firing may be controlled by cables.

[0055] In order to provide for proper clamping during firing of stapler **600**, a particular clamping force is provided between jaw **612** and anvil **610**. That clamping force is initially provided by the torque of a motor coupled to chassis **608**. The appropriate torque to provide the clamping force may vary from one stapler to another due to manufacturing variances of chassis **608** and friction that may be present for example in shaft **606**, wrist **604**, and the mechanical operation of jaw **612** and anvil **610**. Furthermore, as stapler **600** wears, the appropriate clamping input torque may drift during the lifetime of stapler **600** and it may take less torque applied to chassis **608** to affect the proper clamping force between jaw **612** and anvil **610**. Since improper clamping force results in improper tissue gap due to improper deflection of the jaw **612** and anvil **610**, if too much torque is applied to chassis **608** or there is improper closing of the jaw **612** and anvil **610** through too little clamping force, then improper formations of staples **652** may occur during firing. Such improper clamping may also damage tissue **650**, both as a result of improper staple formation and improper clamping during the process.

[0056] As discussed above, a common driving mechanism for clamping jaw **612** against anvil **610** is with utilization of a cam mechanism. Appropriate clamping, however, cannot be determined solely by the position of the cam. This is a result of the flexibility of jaw **612** and anvil **610**, which can result in additional separation of the tips of jaw **612** and anvil **610**. When too much clamping torque is applied, the tip separation between jaw **612** and anvil **610**, the tissue gap, may be too high resulting in improper staple formation during firing. Therefore, in some embodiments of the present invention a torque limit is set and applied to stapler **600** such that excessive tip separation

(tissue gap) is prevented during clamping. Firing is only permitted if stapler **600** can reach the fully clamped position while the torque limit is implemented. If the torque limit prevents clamping (stalls), then the tissue cannot be adequately compressed and if clamping were to proceed an excessive tip separation due to the flexibility of the jaw **612** and anvil **610** would result. Stapler **600**, therefore, can be considered to be clamped when jaw **612** and anvil **610** have reached full travel (i.e. by achieving the expected number of turns of a leadscrew or cardan) and the torque limit has not been reached.

[0057] Similar issues occur with a vessel sealer. FIG. **6**C illustrates a vessel sealer **630**. Vessel sealer **630** includes an end effector **632**, wrist **634**, an instrument shaft **636** and a chassis **638**. End effector **632** includes a jaws **642** and **640**, which are clamped onto tissue that is to be sealed. Instead of staples, vessel sealer **630** can utilize an RF method of sealing the tissue clamped between jaws **640** and **642**.

[0058] FIG. **6**D illustrates end effector **632** with jaw **650**, which can be either of jaws **640** or **642**. As shown in FIG. **6**D, jaw **650** includes an electrode **654** embedded in jaw case **652**. Knife **646** can be driven along a track **658** formed in electrode **654**. Jaw case **652** has tips **656** that extend beyond and above electrode **654** such that a minimum gap between electrodes **654** is maintained during the process. In some embodiments, the minimum gap can be, for example, 0.006 inches. When fired, jaws **640** and **642** can be energized to seal the tissue and knife blade **646** can travel along track **658** in jaws **640** and **642** to divide the tissue. Energy is supplied through electrodes **654** in jaws **640** and anvil **642**. In some embodiments, knife blade **646** can be activated separately from the sealing energy.

[0059] A proper clamping force is needed to provide for proper seal formation during electrocautery. Excessive clamping force may damage the driving mechanism, for example a leadscrew mechanism. Therefore, operation of vessel sealer **630** depends on providing enough clamping force to jaws **640** and **642** while not damaging vessel sealer **630** itself. The upper force limit is based on the goals of 1) not damaging vessel sealer **630** and 2) providing consistent performance.

[0060] This disclosure will focus on operation of stapler **600**, although one skilled in the art will recognize that other instruments such as vessel sealer **630** can also benefit. In either stapler **600** or vessel sealer **630**, various motions of the end effector are controlled through the chassis by cables running through the instrument shaft. The chassis is driven in order to affect the couplers in the instrument shaft, which in turn control motions at the end effector. As discussed above with respect to stapler **600**, the couplers that control clamping and firing can be drive shafts, cables, push-pull rods, or other mechanism. The torque on motors that are utilized to drive the chassis translates to forces applied to various components of the end effector.

[0061] FIG. **7** illustrates surgical stapler **600** mounted on a motor assembly **702**. Motor assembly **702** can be mounted to the stapler instrument, which is then mounted to the surgical arms of the patient side cart **22**. Motor assembly **702** can also be mounted to, or made part of, one of the surgical arms of patient side cart **22**. As shown in FIG. **7**, motor assembly **702** includes one or more motors **710** that are mechanically coupled through a mechanical coupler **706** and electronics **712**. Mechanical coupler **706** can be coupled to chassis **608** when stapler **600** is mounted to motor assembly **702**. In some embodiments, the one or more motors **710** may include a clamping motor and a firing motor. The combination of one or more motors **710** and electronics **712** of motor assembly **702** can be referred to as a motor pack. Motors that drive wrist **604** may be included in motor assembly **702** or may be separate from motor assembly **702**. Mechanical coupler **706** transmits the torque from the one or more motors **710** into chassis **608**, where the torque is transmitted to cables **660** by mechanical converter **714**.

[0062] Electronics **708** includes storage memory and interface electronics to store and transmit data to motor assembly **702**. The data stored in electronics **708** include parameters relevant to surgical stapler **600**. Such data can be utilized to identify and control stapler **600** and, for example, may

include the serial number, the instrument type, lifetime (i.e. the number of firings), and other information regarding stapler **600**. Storing instrument data in electronics **708** has been described, for example, in U.S. Pat. No. 6,866,671, which is herein incorporated by reference in its entirety.

[0063] Electronics **708** can also communicate with data storage **716** on cartridge **614** when cartridge **614** is positioned into end effector **602**. Data storage **716** can, for example, store data related to the cartridge, including its identification, cartridge lot number, cartridge type, cartridge serial number, cartridge firing status, cartridge color, length, torque offset, and other data. The data stored in data storage **716** of cartridge **614** can be transmitted to a control system for determining how stapler **600**, cartridge **614**, and motor assembly **702** are to be utilized together.

[0064] Motor assembly **702** can include electronics **712** that exchange data through interface **704** with electronics **708**, communicates that data and other information through patient side cart **54** to other components of system **10**, and receives data and instructions from other components of system **10**. Electronics **712** can also store data related to motor assembly **702**, for example the motor assembly type, serial number, lifetime (i.e. number of firings lifetime), and other information regarding the operation of motor assembly **702**. Electronics **712** may also provide input to the one or more motors **710** that are mechanically coupled to stapler **600** as well as receiving data from sensors monitoring the position of the motors or other components of the mechanism. Such input may be to control and limit the current provided to the one or more motors **710** and may including one or more current loop control circuits and/or position loop control circuits.

[0065] FIG. **8** illustrates operation of a surgical system with stapler **600**, although another clamping instrument such as a vessel sealer may be utilized. As shown in FIG. **8**, electronics **708** of chassis **608** includes a memory **808** and electronics **806**. Memory **808** includes non-volatile memory that can store parameters regarding stapler **600**. As discussed above, such parameters may include operating parameters of stapler **600**, lifetime of stapler **600**, type of stapler **600**, and other parameters. Electronics **806** is also coupled to read data storage **716** from cartridge **614** and relay those parameters. Electronics **806** can read parameters from memory **808** and parameters from data storage **716** in response to signals received through interface **704**.

[0066] In some embodiments, interface **704** includes electrical connections between chassis **608** and motor assembly **702**. Electronics **806** can include a processor and other electronics that read data from and write data to memory **808**.

[0067] Electronics **712** of motor assembly **702** includes electronics **810** and memory **812**. Electronics **810** can be a processor or other electronics that interfaces to electronics **806** through interface **704**. As shown in FIG. **8**, electronics **810** also provides control signals to the one or more motors **710**. FIG. **8** shows motors **802** and **804**. Motors **802** and **804** drive mechanical converter **714** in order that the functions of stapler **602** are performed.

[0068] In particular, motor **804** is a clamping motor and operates stapler **600** to provide clamping between jaw **612** and anvil **610** against tissue **650**. Motor **802** is a firing motor and operates stapler **600** and cartridge **614** to fire stapler **600**. Stapler **600** is fired when the stapler **600** is clamped. A clamped condition can be determined when the output position of motor **804** reaches the appropriate clamp position while simultaneously a torque limit is implemented to prevent excessive tip separation. The torque provided by motor **804** can be controlled by the current provided to motor **804**. The current provided to motor **804** can be controlled by electronics **810**. In operation, torque limits are provided for motor **804** based upon the instrument and motor assembly (or motor pack) it is used with. Clamping can be determined when the appropriate position of motor **804** is reached while the appropriate torque limit is implemented. The torque limit is directly related to a current limit for motor **804**, and therefore the torque limit is reached when the current draw of motor **804** reaches a corresponding current limit.

[0069] Electronics **810** may include processors and electronics that execute instructions stored in memory **812**. As such, electronics **810** can include current controllers and position controllers for controlling motors **804** and **802**, which can be the clamping motor **804** and firing motor **802**,

respectively. As is further shown in FIG. **8**, electronics **810** can include various sensors **820** that monitor the performance of motor assembly **702**. Sensors **820** can, for example, include temperature sensors to measure the motor assembly temperature, current sensors to measure the current drawn by each of the at least one motors **710**, and position sensors to measure the output position of each of the at least one motors **710**.

[0070] Memory **812** may include a combination of volatile and non-volatile memory and may store data and executable instructions for controlling the one or more motors **710**. Memory **812** can include parameters related to motor assembly **702**, including serial number, part number, version number, configuration information (type, style, expiration information, current controller gains, position controller gains, gear ratio), temperature coefficients, wear coefficients, friction coefficients, motor KT (the parameter that relates torque to current) and other information.

[0071] Other functions of stapler **600**, for example operation of wrist **604** and translation of sled **618** and knife **616** during firing, can be provided by other motors or combinations of motors operating with mechanical converter **714**. As is understood, mechanical converter **714** can be combinations of gears and cams that are coupled to cables **660** to provide the appropriate motions. Current to other motors, such as firing motor **802** or other driving motors, can also be controlled by electronics **810**.

[0072] Electronics **810** is further coupled to receive instructions and provide data to system **800**. System **800** can represent a combination of surgeon's console **52**, electronics cart **56**, processor **58**, and display **60** of system **50** in FIG. **4**. As such, system **800** includes one or more processors **802**, memory **804**, data storage **814**, and a user interface **816**. User interface **816** can be surgeon's console **52**, display **60**, keyboards, touchscreens, or other suitable input devices. Storage **814** can be any data storage system such as flash memory, a hard drive, CD reader or reader of other storage media, or other device for storing data. Memory **804** can include volatile and non-volatile memory for storage of data and processing steps. In some cases, memory **804** can be loaded with data, including programming steps, from storage **814**.

[0073] In some embodiments, electronics **810** and electronics **806** may support integer math. Algorithms operating on electronics **806** and **810** can be scaled appropriately to perform mathematical operations assigned to them while controlling motors **804** and **802**.

[0074] In operation, parameters regarding the operation of stapler **600** are read from memory **808** and provided to electronics **810** and processor **802**. Surgeon input is received at user interface **816**. Processor **802** executes instructions to translate the input to instructions for operation of stapler **600** and provides instructions to electronics **810**. In some embodiments, the parameters read from memory **808** can be utilized in determining the instructions provided to electronics **810**. Electronics **810** provides signals to the one or more motors **710** to provide the motions indicated by processor **802**. Those motions are then translated to end effector **602**. The signals provided to the one or more motors **710** may also be predicated on parameters read from memory **808**. In some cases, processor **802** may provide or rewrite parameters in memory **808** to be utilized during the next utilization of stapler **600**.

[0075] In general, motor assembly (or motor packs), staplers, and cartridges are not matched. During a procedure, any motor assembly can be utilized with any stapler and any of the various cartridges can be utilized in the stapler. Therefore, data storage **716** holds parameters associated with the stapler cartridge **614**, memory **808** stores parameters associated with that particular stapler **600**, and memory **812** stores parameters associated with that particular motor assembly **702**.

Initialization of the Stapler

[0076] As discussed above, staple cartridges (also referred to as reloads) are available in a variety of sizes that are identified by color. Each color cartridge corresponds to a particular staple leg length. Common cartridges include green (4.3 mm leg length), blue (2.5 mm leg length), and white (1.5 mm leg length) cartridges **614**. In order to properly form staples, anvil **610** and jaw **612** need to be positioned within close proximity to ensure that staples **652** hit pockets **654** in anvil **610** and

form the desired "B" shape (FIG. **6**B). Stapler **600** utilizes a "cantilever" style of clamping and, as discussed above, if the clamping torque limit is too high it is possible to deflect the tip of anvil **610** and jaws **612** away from each other to the point where staples **652** will not properly form when staples **652** are pushed out of cartridge **614** during the firing process. This situation may develop if there is too much tissue in the jaws during clamping with too much torque. To prevent this and ensure the proper tip gap is maintained, the clamping torque is limited.

[0077] Under ideal circumstances, if each of staplers **600** where identical, all staplers **600** would use the same torque limits. However, manufacturing variations and tolerances can result in significant variation between different staplers **600**. According to the present invention, the torque limit can be customized for each of staplers **600**. As a result, memory **808** can store the particular torque limit associated with that particular stapler **600**. Furthermore, the torque limit can vary within an individual stapler **600** according to cartridge **614**. Therefore, adjustments for type of cartridge **614** can also be stored in memory **808**. In some embodiments, adjustments for type of cartridge **614** may not vary between staplers **600** and therefore a set cartridge variation can be provided by system **800** or stored in data storage **716** of each cartridge **614**. During manufacturing, each stapler **600** is assembled and then operated to "wear-in" the clamping behavior.

[0078] In accordance with the present invention, a specific torque limit is determined for each stapler **600** and stored in memory **808** of chassis **608**. FIG. **9**A illustrates a procedure for initializing the torque limit for a particular stapler **600**. In step **902**, stapler **902** is assembled. After assembly, in step **904**, stapler **600** is "worn-in" by repeatedly performing a clamping procedure. Stapler **600** is worn in when the torque required to clamp is relatively stable (i.e., does not change significantly between activations). In step **906**, a series of shims of differing heights is utilized to enforce a known deflection of the tips of jaw **612** and anvil **610** during clamping. A data set of clamping torque as a function of tip deflection is then obtained.

[0079] FIG. **9**B illustrates deflecting the tips by a known amount with shim **914**. As is shown in FIG. **9**B, shim **914** enforces a particular tip separation while jaw **612** and anvil **610** are clamped. In step **906**, a series of tests with different shims **914** are accomplished to produce the data set as shown in FIG. **9**C. As shown in FIG. **9**C, the X-axis represents the tip deflection enforced by each individual shim **914**. The Y axis is the recorded torque data from a motor **918** in motor assembly **916** that drives chassis **608** of stapler **602** during the test to achieve a clamping condition. In some embodiments, a relationship between the feedback current of motor **918** and the torque applied by motor **918** and the resulting force between jaw **912** and anvil **610** is known based on previously acquired calibration data utilizing motor **918** and numerous instruments.

[0080] In step **908**, the data can be fit to a function. In the example shown in FIG. **9**C, the data is fit to a linear function $Y=mx+b$. A linear, least-squares method can be utilized to estimate the slope m and the offset b. In this linear equation, Y is the torque required and X is the tip deflection. As shown in FIG. **9**C, torque is provided in milliNewton-meter (mNm) and deflection is provided in millimeters (mm). In the particular example provided in FIG. **9**C, the slope m is determined to be 21.5 mNm/mm and the offset b is 50 mNm. As discussed above, the values for m and b vary due to manufacturing variance between different staplers.

[0081] In step **910** the maximum torque value is determined for stapler **600**. In some embodiments, the maximum torque is determined by limiting the maximum tip deflection to 0.70 mm. The 0.70 mm is the tip separation that is appropriate for a blue cartridge **614**, which can be considered to establish a safe baseline for a blue cartridge. This example value prevents improper formation of the staple during firing due to tip separation. As can be seen from FIG. **9**C, or calculated by the above linear relationship, the particular stapler **600** illustrated in FIG. **9**C has a maximum torque value of 65 mNm. Torque values above this may allow too much tip deflection (and therefore too large a tissue gap) for proper staple formation. By enforcing a torque limit, enough torque is supplied to the clamp, but too much torque is not allowed, which prevents larger tip deflections that result in improper staple formation.

[0082] In step **912**, the maximum torque value for stapler **600** is stored in memory **808** of chassis **608** of stapler **600**. The maximum torque value can then be read from memory **808** during operation of system **10**, as illustrated in FIG. **8**, and utilized to control the maximum torque supplied by motor **804** to end effector **602** during a stapling procedure.

[0083] In some embodiments, the calibrated maximum torque value, which can be designated as τ.sub.cal is used as a baseline torque limit value for stapler **600**. From this baseline, during operation, the actual torque can be adjusted for particular cartridges **614**. The adjustment can be based on a large body of previously collected experimental and analytical data acquired utilizing multiple cartridges and multiple staplers that are loaded into system **800**. As an example, adjustments for various cartridges **614** can be White=−3 mNm; Blue=+2 mNm; and Green=+9 mNm. These values are added to the maximum torque value and the adjusted value utilized to control the torque output of motor **804** of motor assembly **702**. For example, if cartridge **614** was a blue cartridge, then the maximum torque value utilized during clamping is adjusted to 94 mNm.

[0084] The actual numbers utilized in the above description are for illustration only and should not be considering limiting. Each of stapler **600** may have a different maximum torque value. Additionally, in some embodiments different safe tip deflections or other parameters can be utilized. Further, adjustments for cartridge types may vary. Also, although the above discussion focused on a stapler instrument, similar calibrations can be performed on other instruments, for example vessel sealers.

[0085] Other parameters can also be set during calibration. For example, the calibrated torque limit can be set at a particular reference temperature T.sub.ref. Other parameters may include wear coefficients, instrument life coefficients, and other parameters that relate to the particular stapler **600**.

[0086] Adjusting and calibrating the maximum torque limit for each instrument allows more precise control of tip deflection during clamping. This can maximize instrument performance. By calibrating each instrument, a smaller margin can be utilized than if a single constant parameter was used uniformly across all instruments. Additionally, the uncertainty in the tip deflection during clamping can be reduced by more precisely controlling clamping. Further, manufacturing yields can be increased by reducing dependence on manufacturing tolerances and adjusting for manufacturing variations.

Initialization of Motors in the Motor Assembly

[0087] In addition to calibrating and initializing stapler **600**, motor assembly **702** can also be calibrated and initialized to adjust for manufacturing variations. Manufacturing variances in clamping motor **804** and firing motor **802** as well as in mechanical converter **714** lead to variations between motor assemblies. During motor assembly calibration, motor speed vs no-load current relationships INL and the torque constant KT for each of clamping motor **804** and firing motor **802** are determined.

[0088] FIG. **10**A illustrates a calibration method **1000** that can be utilized to calibrate each of motors **804** and **802** of motor assembly **702**. As shown in method **1000**, step **1002** is to acquire an assembled motor assembly **702**. In step **1004**, an initial calibration is performed. An example of a calibration procedure is illustrated in FIG. **10**B. In step **1006**, motors **802** and **804** of motor assembly **702** are worn in. During the wear-in process, each of motors **802** and **804** are driven many cycles against a constant torque in order to break in the geartrain of mechanical converter **714** and ensure that the grease is evenly distributed. In step **1008**, a final calibration is performed. The final calibration of step **1008** and the initial calibration of step **1004** can be the same calibration method, an example of which is shown in FIG. **10**B. In step **1010**, the calibrated parameters are stored in memory **812** of motor assembly **702**.

[0089] FIG. **10**B illustrates an example of a calibration procedure **1012** that can be utilized in steps **1004** and **1008** of FIG. **10**A. As shown in FIG. **10**B, step **1014** is to acquire no-load data for the motor, which could be either clamping motor **804** or firing motor **802**. To determine the

relationship between motor speed and no-load current for a motor, the motor is driven at various speeds, one at a time in the forward direction first then in the backward direction. No-load current draw data is measured, as well as the temperature of motor assembly **702** while achieving each of the various speeds. In some cases, the no load current draw can be adjusted for temperature. As an example, the speed progression in **104** rotations per minute (rpm) may be [2.5, 1.5, 2.25, 0.5, 2.0, 0.75, 1.0, 1.75, 0.25, 1.25, and 0.125]. However, other data taking progressions can be utilized. FIG. **10**C illustrates data for a clamp motor **804** current as a function of motor speed in the forward (fwd) and backward (bak) directions.

[0090] In step **1016** the data is fit to a function, for example an exponential function or a linear function, to determine a relationship between motor current and motor speed. For example, a linear function with non-polynomial terms that can be used to fit the data can be given by:

[00001] $y = c1 + c2 * e^{-x * x_{scale}} + c3 * x * e^{-x * x_{scale}}$

where c**1**, c**2**, c**3** are coefficients and x scale is a constant.

[0091] In FIG. **10**C, the solid curves represent a curve fit to the data. The data may be adjusted for temperature and filtered prior to fitting. In some embodiments, the raw data can be adjusted as a function of temperature based on previous modeling of motors as a function of temperature. Additionally, the raw data can be filtered as a function of time to reduce noise and provide averaging.

[0092] In some embodiments, a linear piecewise approximation can be optimized to fit the function in order to ease further computation. A linear piecewise approximation to the curve fit functions shown in FIG. **10**C is illustrated in FIG. **10**D. The linear piecewise approximation can eventually be stored in memory **812** as INL.

[0093] Once the no-load current calibration is completed, procedure **1012** proceeds to determination of a torque constant KT (the torque output per current input). As shown in FIG. **10**B, step **1018** includes acquiring torque loading data. In acquiring the torque loading data, the motor being calibrated (clamping motor **804** or firing motor **802**) is driven first against no load and then the load is ramped up to a known torque loading and then ramped back down to no-load. The known torque loading can be provided by an external source such as a brake or dynamometer, for example. Data (i.e. torque output vs. current load) is gathered in both the forward and backward directions for the motor being calibrated. Multiple sets of data can be taken for each of clamping motor **804** and firing motor **802**.

[0094] In step **1020**, the torque data is analyzed to determine the torque constant KT. The data can be filtered and the torque constant KT determined by comparing the change in torque (no load to known torque loading) to the change in current (current at no load to the current at the torque loading). Calculations for the multiple sets of data taken during step **1018** can be averaged to determine the final calibration torque constant value.

[0095] FIG. **10**E illustrates an example of motor speed and torque versus time for a motor during data acquisition step **1018** according to some embodiments of the present invention. FIG. **10**F illustrates motor speed, current, and cardan position as a function of time corresponding to the data shown in FIG. **10**E. As shown in FIG. **10**F, the current data can be filtered to obtain a continuous function of current versus time for the test.

[0096] As illustrated in FIG. **10**A, in step **1010** after the final calibration step **1008** both the no-load current calibration data INL and the torque loading calibration data KT can be stored in memory **812** of motor assembly **702** and can be utilized during further calculations of torque limits for motor assembly **702** as discussed further below.

Torque Limit Compensation

[0097] Referring back to FIG. **8**, stapler **600** is only allowed to fire when stapler **600** reaches a full clamp condition. The amount of torque provided by motor **804** to reach a complete clamp condition is limited by software. This torque limit is generally set as a current limit, which is a limit on the current that motor **804** is allowed to draw during the clamping process. The current limit is a

function of the calibration data for the stapler **600**, as discussed above. In other words, initially the torque limit is set at τ.sub.cal as indicated above, adjusted according to the color of cartridge **614**.

[0098] However, with repeated use of stapler **600**, the effective torque limit can drift and deviate from the original calibration data. In other words, the same torque that it takes to clamp stapler **600** after several uses is different from, and typically less than, the torque that it took to clamp stapler **600** at its initial calibration state. If the torque limit were left unchanged, stapler **600** might be allowed to reach a complete clamp actuation on challenge materials that it was not intended for, causing unintentional increased deflection of the tips between jaws **612** and anvil **610**. The increased tip deflection, as discussed above, provides for an inadequate tissue gap and improperly formed staples if the stapler were fired.

[0099] In accordance with some embodiments of the present invention, the torque limit utilized for stapler **600** is adjusted according to multiple operating parameters. The multiple operating parameters can, for example, include the temperature of motor assembly **702**, the articulation angle of wrist **604**, the lifetime use of motor assembly **702** (e.g. the number of stapler firings affected by motor assembly **702**), and the lifetime use of stapler **600** (e.g. the number of stapler firings using stapler **600**). The actual torque limit can be adjusted during operation in order to adjust for the age and operating condition of stapler **600**.

[0100] FIG. **11** illustrates an algorithm **1100** for performing such an operation. Algorithm **1100** can be performed by system **800** or system **800** in combination with processor **810** in motor assembly **702**. As shown in step **1002**, algorithm **1100** is started when a command is received to clamp, prior to firing, stapler **600** in step **1102**.

[0101] In step **1104**, the parameters that are specific to stapler **600**, which are stored in memory **808** of chassis **608**, the parameters that are specific to motor assembly **702**, which are stored in memory **812** of motor assembly **702**, and the parameters that are specific to cartridge **614**, which are stored in data storage **716**, are retrieved. In step **1106**, the adjusted maximum torque limit is determined. The adjusted maximum torque limit can be determined based on a number of parameters and a model that fits the wear characteristics of motor assembly **702** and stapler **600** in combination with a particular cartridge **614**. As discussed above, some of the factors that can be including in the model include the temperature of motor assembly **702** (T), the lifetime of motor assembly **702** measured by the number of stapler firings (L.sub.MP), the lifetime of stapler **600** measured by the number of stapler firings (L.sub.inst), and the angle of wrist **604** (θ). In general, a set of parameters {Parameters} can be defined that affect the torque limit utilized. In some embodiments, the set can be defined as {T, L.sub.MP, L.sub.inst, θ, . . . } Other parameters may also be utilized in the model.

[0102] Therefore, the adjusted maximum torque limit can be given by

[00002] $_{com} = F(\{Parameters\})$

where the function F defines the model that best fits the behavior of clamp **600** and motor assembly **702** over their lifetimes. The function F can be determined empirically over a large set of staplers **600** and motor assemblies **702** to accurately represent the wear characteristics over time. In some cases, factors related to the various parameters may be scalars in the model while in other cases a better model has certain factors being additive while other factors are scalars. For example, a model for calculating the maximum torque limit may be given by

[00003] $_{com} = F(\{Parameters\}) =$
$$f(T) * g(L_{MP}) * h(L_{inst}) * y(\ ) + z(T) + k(L_{MP}) + x(L_{inst}) + p(\ ) + C,$$

where f, g, h, y, z, k, x, and p represent particular functions of the indicated parameters and C represents a general offset term. As shown in the above equation, the corrections can include scalar components and additive components for each of the parameters in the parameter set. In some models, certain of functions f, g, h, and y can be set to one (1) if that parameter is not a scalar component while functions z, k, x, and p are set to 0 if the corresponding parameter is not an additive component. The above example of F {Parameters} is not limiting and other functions can

be utilized in the modeling. Some particular example models are presented in further detail below.

[0103] In step **1108**, the motor current limit is determined from the torque limit. As an approximation, there is a linear relationship between the current and the desired torque for motor **804**. Therefore, conversion from torque limit to current limit involves scaling the torque limit according to the linear relationship to determine the current limit for motor **804** in the clamping process.

[0104] In step **1110**, stapler **600** is clamped utilizing the adjusted motor current limit described above. As discussed above, stapler **600** is clamped when motor **804** achieves a particular position while not exceeding the adjusted motor current limit. Once stapler **600** is in a clamped condition, then stapler **600** can be fired. In step **1112**, after a successful clamping is achieved, algorithm **1100** waits for a user input or confirmation prior to firing. In step **1114**, stapler **600** is fired.

[0105] As shown in FIG. **11**, in some embodiments firing step **1114** can include determining the firing torque limit **1120**, determining the firing motor current limit **1122**, and firing using the firing motor current limit **1124**. Excessive torque applied to a fire cardan joint in stapler **600** can pose a problem to breaking the fire cardan joint or breaking the leadscrew in cartridge **614**. Excessive torque could also cause knife **616** in cartridge **614** to be jammed against a hard stop with too much force, possibly breaking a piece of knife **616** into the patient. Both the drive train and cartridge leadscrew and knife mechanisms should include an adequate safety margin to prevent breakage during operation. The firing torque limit (the torque limit of firing motor **802**) can be adjusted to prevent the torque being applied to the mechanism to approach a level that damages stapler cartridge **614** or cartridge drivetrain components.

[0106] Determining the firing torque limit for firing motor **802** in step **1120** can be similar to determining the torque limit for clamping motor **804** as discussed above with respect to step **1106**. As discussed above, the firing torque limit for firing motor **802** can be adjusted using a function of, for example, temperature, motor assembly life, instrument life, and other parameters. The same forms of the adjustment equations, in some cases with different coefficients, can be used in adjusting the torque limit for firing motor **802** as those discussed above can be used for adjusting the torque limit for clamping motor **804**. Further, the same form of equation for determining the motor current limit as discussed above with step **1108** can be utilized in step **1122**. Firing step **1124** is complete when firing motor **802** reaches a particular position while not exceeding the firing motor current limit.

[0107] In step **1116**, parameters are adjusted to reflect the firing. For example the parameters L.sub.MP and L.sub.inst can both be incremented. In step **1118**, the adjusted parameters can be stored for future use. For example, L.sub.MP is stored in memory **812** and L.sub.inst is stored in memory **808** for use in the next stapling procedure involving motor assembly **702** or stapler **600**.

[0108] As discussed above, the torque limit can be translated to a current limit for motor **804** in step **1108**. In some cases, the relationship between the current limit and the torque limit can be given by:

[00004] $I_{\text{limit}} = I_{\text{NL}} + \frac{\tau_{\text{com}}}{K_T}$,

where I.sub.limit is the current limit provided to motor **804**, INL is the no-load current for motor **804** at the time of calibration, KT is a torque constant characteristic of the motor assembly drive train, and τ.sub.com, as discussed above, represents a modeled and compensated torque limit provided to minimize error in clamping. INL represents the friction compensation for the motor assembly and can be a function of speed. The parameter KT is related to the conversion of torque to current in motor **804**. Initial KT at a reference temperature τ.sub.ref may be determined during a calibration of motor assembly **702** as discussed above. In some models, KT can be given by

[00005] $K_T = K_{\text{Tcal}} * [1 - \eta * (T - T_{\text{ref}})]$,

where K.sub.Teal is the calibrated conversion coefficient and η is a temperature coefficient related to the operation of motor **804**. In some models, the value for I.sub.NL can be given by:

[00006] $I_{\text{NL}} = I_{\text{cal}} * [1 - \eta * (T - T_{\text{ref}})] * [1 - \eta * (L_{\text{MP}})]$,

where I.sub.cal is the calibrated no-load current draw representing the loss in the motor assembly **702** as a function of speed, u is the temperature coefficient, T is the temperature of motor assembly **702** (measured by electronics **810**), T.sub.ref is a reference temperature, K is the motor assembly life coefficient, and L.sub.MP is the number of times that motor assembly **702** has fired a stapler. The reference temperature T.sub.ref can, for example, be the temperature at which motor assembly **702** is calibrated and can be stored in memory **812**. As can be seen from the above equations in this model, the calibrated current limit for stapler **600** at T=T.sub.ref is given by I.sub.limit I.sub.cal+τ.sub.cal/K.sub.Teal, which can be used in the initial calibration phase to determine both I.sub.cal and K.sub.Teal. The values of I.sub.cal and K.sub.Teal can, in some embodiments, be stored in memory **812**.

[0109] In some models, the adjusted torque limit can be given by

[00007]
$$\tau_{com} = \tau_{des} * W(\theta) * [1 - \alpha * (T - T_{ref})] * [1 - \beta * (L_{MP})] * [1 - \gamma * (L_{ins})] + \delta * (T - T_{ref}) + \varepsilon$$

where α is a temperature coefficient, β is the life coefficient of motor assembly **702**, γ is the life coefficient of stapler **600**, δ is the constant offset temperature coefficient and ε is a constant offset. The value of τ.sub.des can be given by the sum of T.sub.cal and cartridge adjustment, as discussed above.

[0110] The function W reflects the added friction when wrist **604** is articulated. In some embodiments, the function W is a cosine function of the angle θ through which wrist **604** is articulated. As such, in some embodiments W can be given by

[00008]$W(\theta) = \frac{1}{1 - \xi(1 - \cos(\theta))}$

[0111] where θ is the wrist angle of wrist **604** as shown in FIG. **8** and ξ is the parameter that determines the influence of the wrist angle on the torque limit. As illustrated, at θ=0 degrees, W(θ) will be **1**. As the angle increases, however, the friction at wrist **604** increases, resulting in a multiplicative increase in τ.sub.com by W(θ). In some embodiments, the function W(θ) can be implemented as a look-up table. The torque limit wrist adjustment W(θ) can be utilized for any surgical instrument with a wrist and the need to transmit a force through the wrist.

[0112] The various scalar coefficients shown above can be adjusted to best model the lifetime behavior of motor assembly **702** and of stapler **600**. These coefficients include the temperature coefficients η, μ, α, and δ; the lifetime coefficients κ, β and γ; additive coefficient ε; and wrist coefficient ξ and can be determined through repeated testing of various ones of stapler **600** and motor assembly **702** through their lifetimes or in some cases can be customized through calibrations done on individual motor assemblies or instruments. In some embodiments, if the coefficients are determined by averaging over a large number of motor assemblies and staplers and do not vary between individual motor assemblies or staplers, then they can be stored in system **800** where the modeling is calculated. Otherwise, the coefficients can be stored with their individual components. For example, the temperature coefficients η, μ, α, and δ; the lifetime coefficients κ and β can be stored in memory **812** while the lifetime coefficient γ can be stored in memory **808**.

[0113] As indicated above, for example δ can be set to 0 if temperature is a scalar component not an additive component and a can be set to 0 if temperature is an additive component and not a scalar component. In this model, with α and δ both non zero temperature is both a scalar and additive factor. In some embodiments, the coefficients can be within the following ranges: $0<\alpha\leq1$; $0<\beta<1$; $0<\delta<1$; $-10<\varepsilon<10$; $0<\gamma<1$; $0<\mu<1$; $0<\kappa<1$; $0<\eta<1$; and $0\leq\xi\leq1$. In many cases, the coefficients are less than about 10^{-2}.

[0114] The primarily scalar model example provided above is not the only model that can be utilized to adjust the torque limits for operation of stapler **600** for lifetime drift as a function of temperature. Other models may utilize, for example, a primarily additive model or combinations of additive and scalar components can be added, or nonlinear models could be used. Models can be expanded as needed to include combinations of multiplicative and additive factors in order to best

model the behavior of stapler **600** during its lifetime of use.

[0115] As suggested above, there is a variety of models that can be utilized to model the adjustment to the torque limits. As suggested above, depending on the system, certain variables may be modeled as an additive effect and others may be modeled as a multiplicative effect. In some embodiments, the model can be tailored for the lifetime of a particular stapler system. This can be accomplished by setting some of the parameters to zero and some to non-zero values. In some embodiments, the modeling equation for τ.sub.com can be expanded to include more additive factors and further combinations of additive and multiplicative factors in the modeling.

[0116] The current limit utilized to control clamp motor **804**, I.sub.limit, can be provided to electronics **810** in order to control motor **804**. The model utilized to provide the adjusted current limit operates to provide proper clamping throughout the operable lifetimes of stapler **600** and of motor assembly **702**. The torque compensation algorithm described above allows the surgical system utilizing stapler **600** to effectively and safely clamp on appropriate materials (and thicknesses) while maintaining appropriate tissue gap and may prevent a full clamp on materials (and thicknesses) that would cause inadequate tissue gap. This operation helps to prevent excessive tip deflection and also prevents firing and causing improperly formed staples and surgical intervention that would result from improperly formed staples.

Homing Adjustments

[0117] In some embodiments of the invention, a homing procedure can be provided to further adjust the torque limits. The homing procedure is implemented when stapler **600** and motor assembly **702** is first attached to patient side cart **22**. In some embodiments, system **800** can drive stapler **600** through a preset range of motions and tests while monitoring the corresponding performance of stapler **600** and motor assembly **702**. Current, position, and torque of motors **804** and **802** can be monitored by electronics **810** and communicated to processor **800**. Processor **800** can adjust coefficients and parameters to correct for the measured behavior of stapler **600** and motor assembly **702** during homing. Those corrected coefficients and parameters can be utilized while operating stapler **600** with motor assembly **702** as described above.

[0118] Individual parameters can be adjusted according to the performance tests. As such, the calibration data, for example T.sub.cal, can be adjusted as a result of the homing process in addition to the factors described above prior to utilization of stapler **600**.

[0119] The above detailed description is provided to illustrate specific embodiments of the present invention and is not intended to be limiting. Numerous variations and modifications within the scope of the present invention are possible. The present invention is set forth in the following claims.

Claims

1. A control system comprising: a first memory storing instructions; and a processor, which when executing the instructions, is configured to: receive one or more motor parameters stored in a second memory of a motor assembly, the motor assembly being coupled to the control system; receive one or more instrument parameters stored in a third memory of an instrument, the instrument being coupled to the motor assembly; determine an instruction for a motor of the motor assembly based on at least the one or more motor parameters and the one or more instrument parameters, the instruction for controlling motion of an end effector of the instrument using the motor; and transmit the instruction to the motor assembly.

2. The control system of claim 1, wherein the one or more motor parameters comprise a torque constant.

3. The control system of claim 1, wherein the one or more motor parameters comprise a motor speed versus no-load current relationship for the motor.

4. The control system of claim 3, wherein the motor speed versus no-load current relationship

comprises a linear function, an exponential function, or a linear piecewise function.

5. The control system of claim 3, wherein the motor speed versus no-load current relationship is adjusted based on a temperature of the motor assembly.

6. The control system of claim 1, wherein the one or more motor parameters comprise a motor assembly lifetime.

7. The control system of claim 1, wherein the one or more instrument parameters comprise a torque limit for the instrument.

8. The control system of claim 1, wherein the one or more instrument parameters comprise a torque adjustment based on a type of stapler cartridge loaded in the instrument.

9. The control system of claim 1, wherein the processor is further configured to: receive one or more cartridge parameters stored in a fourth memory of a staple cartridge located in the instrument; and further determine the instruction for the motor based on the one or more cartridge parameters.

10. The control system of claim 1, wherein the motor is a clamping motor or a firing motor.

11. A method for controlling an instrument, the method comprising: receiving, by a processor of a control system, one or more motor parameters stored in a first memory of a motor assembly, the motor assembly being coupled to the control system; receiving, by the processor, one or more instrument parameters stored in a second memory of an instrument, the instrument being coupled to the motor assembly; determining, by the processor, an instruction for a motor of the motor assembly based on at least the one or more motor parameters and the one or more instrument parameters, the instruction for controlling motion of an end effector of the instrument using the motor; and transmitting, by the processor, the instruction to the motor assembly.

12. The method of claim 11, wherein the one or more motor parameters comprise a torque constant.

13. The method of claim 11, wherein the one or more motor parameters comprise a motor speed versus no-load current relationship for the motor.

14. The method of claim 13, wherein the motor speed versus no-load current relationship comprises a linear function, an exponential function, or a linear piecewise function.

15. The method of claim 13, wherein the motor speed versus no-load current relationship is adjusted based on a temperature of the motor assembly.

16. The method of claim 11, wherein the one or more motor parameters comprise a motor assembly lifetime.

17. The method of claim 11, wherein the one or more instrument parameters comprise a torque limit for the instrument.

18. The method of claim 11, wherein the one or more instrument parameters comprise a torque adjustment based on a type of stapler cartridge loaded in the instrument.

19. The method of claim 11, further comprising: receiving, by the processor, one or more cartridge parameters stored in a third memory of a staple cartridge located in the instrument; and further determining, by the processor, the instruction for the motor based on the one or more cartridge parameters.

20. The method of claim 11, wherein the motor is a clamping motor or a firing motor.