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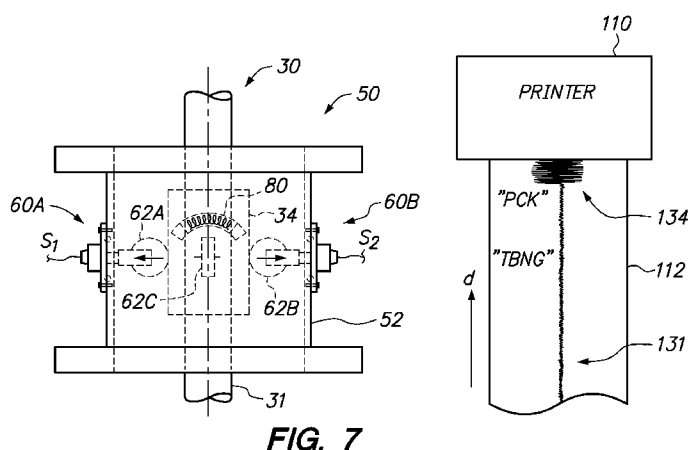


FIG. 7

(57) Abstract: An apparatus (50), system, method, and software are taught for measuring and evaluating a tubular member (30), such as a tubing string, being positioned downhole. One embodiment includes a spool (52) having a through bore (55) and one or more connectors for removably coupling the spool to a blowout preventer assembly (40). A displacement sensor (60, 160) and a tubing feature sensor (80) are both mounted to the spool in proximity to the through bore. The displacement sensor is responsive to an axial displacement of the tubular member within the through bore of the spool. The tubing feature sensor is responsive to a cross-sectional parameter of the received tubular member in proximity to the tubing feature sensor. The displacement sensor and tubing sensor may be used separately or in combination, such as to identify and locate features of a tubing string and to ascertain the depth of a well.

MEASUREMENT AND EVALUATION OF TUBING STRINGS WHILE LOWERING INTO A WELLBORE

BACKGROUND

Field of the Invention

[0001] The present invention relates to measuring and evaluating components of a tubing string as they are lowered into a wellbore.

Background of the Related Art

[0002] A hydrocarbon recovery well is a man-made hole in the earth's surface used to recover petroleum hydrocarbons, such as oil and gas, from an underground formation. The well site may be located anywhere along the earth's surface that a hydrocarbon formation is known or suspected, which may be on dry land or beneath a body of water. On land, the well is drilled by a crew operating a drilling rig. At a relatively shallow water site, the well may be drilled from a bottom-founded facility like a jack-up drilling rig or fixed offshore structure. In deepwater, the well may be drilled from a floating drilling vessel. In all cases, the creation and subsequent operation of an oil well involves a large expenditure in capital and human labor over the course of multiple phases, from drilling the well, to completing the well, and finally to operating the oil well to recover hydrocarbons. Safety is paramount at every phase of drilling and production, since the many people involved work with heavy machinery and with potential exposure to powerful natural phenomena, such as high subterranean pressures.

[0003] Various kinds of tubing are instrumental in constructing and operating a hydrocarbon recovery well. A tubing string is often formed by joining tubing segments of a particular type end to end. For example, a wellbore is initially formed using a drill string comprising tubular drill pipe segments. A bottom hole assembly (BHA) having a drill bit is provided at the lower end of the drill string, and the wellbore is formed by rotating the drill bit to liberate earthen materials, either by rotating the entire drill string from the surface or by rotating the bit relative to the drill string using a downhole motor. The hollow drill string allows drilling fluid ("mud") to be pumped downhole through the

tubular drill string to help remove the liberated earthen materials from the wellbore. As the wellbore is drilled and the drill string advances downhole, additional segments of drilling pipe are assembled from above until the desired depth is reached. In preparing a cased-hole completion, the borehole is lined with a casing string that provides structural integrity to the drilled wellbore and isolates high pressure zones. A production tubing string may then be installed downhole, which serves as a conduit for retrieving the oil and gas. Like drill strings, casing strings and production tubing strings are also formed from segments joined end to end. Another type of tubing used in the oil and gas industry is coiled tubing, which is provided on a reel in a long, continuous supply, rather than as separate segments. Coiled tubing is often used in completion and production operations.

[0004] The depth of a well and the depth of various tubular components positioned downhole are very relevant to completing and operating a well. Some conventional depth measurements are a “driller’s depth” and a “logger’s depth.” Driller’s depth is associated with drilling operations and related activities, such as logging while drilling, measurement while drilling, and coring. Driller’s depth is typically determined by individually measuring the separate drill string components above ground, before they are connected to the drill string. The individual lengths of components, such as drill pipe segments, drill pipe connectors, and components of the bottom hole assembly are manually measured and recorded, such as using a measuring tape or laser tool. This manual process is exposed to many opportunities for human error. A logger’s depth may be obtained by tripping wireline equipment downhole, and is generally regarded as a more accurate measurement.

BRIEF SUMMARY

[0005] A first embodiment is an apparatus that comprises a spool having a through bore and one or more connectors for removably coupling the spool to a blowout preventer assembly. A displacement sensor and a tubing feature sensor are both mounted to the spool in proximity to the through bore. The displacement sensor is configured to sense an axial displacement of a tubular member within the through bore of the spool and to generate a signal in response to the axial displacement. The tubing feature sensor is

configured to sense a cross-sectional parameter of the received tubular member in proximity to the tubing feature sensor and to generate a signal in relation to the cross-sectional parameter of the received tubular member.

[0006] A second embodiment is a system that comprises a blowout preventer assembly in sealed fluid communication with a wellhead. A spool coupled to the BOP assembly includes a through bore in fluid communication with respective through bores of the BOP assembly and the wellhead such that a tubular member lowered into the wellhead through the BOP assembly passes through the spool. A displacement sensor mounted to the spool in proximity to the through bore of the spool is configured for sensing an axial displacement of the tubular member within the through bore of the spool and generating a signal in relation to the sensed axial displacement. A tubing feature sensor mounted to the spool in proximity to the through bore is responsive to a cross-sectional parameter of the received tubular member in proximity to the tubing feature sensor and is configured for generating a signal in relation to the cross-sectional parameter of the received tubular member. A computer in electronic communication with the displacement sensor and the tubing feature sensor includes control logic for identifying and locating variations in the cross-sectional property of the tubular member with the sensed linear displacement of the tubular member.

[0007] A third embodiment is a method. A linear displacement of a tubing string is sensed, relative to a fixed location of a wellhead apparatus. A signal is generated in response to the linear displacement. A change in a cross-sectional parameter of the tubing string is sensed in proximity to the fixed location, in response to which another signal is generated. Variations in the cross-sectional property of the tubular member with the sensed linear displacement of the tubular member are identified and located.

[0008] A related embodiment comprises software for performing the method. The software may comprise computer usable program code embodied on a computer usable storage medium. The software may reside on a portable field computer, such as a tablet or laptop computer.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0009] FIG. 1 is a generalized diagram of a well service rig installing a tubing string downhole in a well.

[0010] FIG. 2 is a side view of a specific example embodiment of the tubing measurement and evaluation system that includes a pair of opposing, roller-based displacement sensors and one tubing feature sensor.

[0011] FIG. 3 is a partially cut-away side view further detailing one embodiment of a roller type displacement sensor.

[0012] FIG. 4 is a side view of another example embodiment of the tubing measurement and evaluation system having an optical displacement sensor in lieu of a roller-type sensor.

[0013] FIG. 5 is a schematic diagram of a field computer for receiving and interpreting the signals generated by the tubing measurement and evaluation systems of FIGS. 2 and 4.

[0014] FIG. 6 is an elevation view of the tubing measurement and evaluation system of FIG. 2 along with a selected portion of a tubing log corresponding to a portion of the tubing string currently under evaluation.

[0015] FIG. 7 is an elevation view of the tubing measurement and evaluation system, with the tubing string having been lowered to where a packer is positioned within the spool.

[0016] FIG. 8 is a flowchart generally outlining one example embodiment of a method for measuring and evaluating a tubing string.

DETAILED DESCRIPTION

[0017] A system, apparatus, method, and software are disclosed for automatically measuring and evaluating a tubing string as the tubing string is gradually lowered into a wellbore. One embodiment provides a special spool having integrated sensors for obtaining both the displacement of the tubing string and a varying local cross-sectional

parameter of the tubing string as it passes by the sensors. The displacement and cross-sectional parameter may be used to obtain various information about the tubing string, such as the length of the tubing string, the number of segments of the tubing string, and to identify and locate various features of the tubing string. The spool may be referred to as a tubing feature locator (TFL) spool. The TFL spool may be coupled within a blowout preventer (BOP) assembly, such as above some BOP rams and below a stripper/rubber assembly. In use, the TFL spool is therefore at a fixed position relative to the floor of the well service rig. As a tubing string passes through the BOP assembly and wellhead while being lowered into the wellbore, the tubing string passes through the TFL spool.

[0018] A displacement sensor provided in the TFL spool senses an axial displacement of the tubular member within the TFL spool. The displacement sensor may include, for example, a spring-loaded roller biased into frictional engagement with the tubing string. A second type of sensor provided in the TFL spool is referred to as a tubing feature sensor. The tubing feature sensor is responsive to a local cross-sectional parameter of the tubular member, such as a density, thickness, and/or local volume of the tubular member. As the tubing string moves within the TFL spool, the TFL spool thereby provides both a positional signal responsive to an axial displacement of the tubular member and another signal responsive to a changing local parameter of the tubular member. These signals may be transmitted to a computer operating special-purpose software for evaluating the signals to obtain information, such as to determine the depth of the well and the length of the tubing string, to identify and distinguish different features of the tubing string, and to ascertain the positions of the identified features relative to the tubing string or to the well.

[0019] In one embodiment, the signals are communicated to a field computer system, which may incorporate a portable computer such as a laptop or tablet computer. The portable computer may be connected to a computer dock powered by a rechargeable battery and/or a photovoltaic cell. Specialized software provided on the computer analyzes how the sensed cross-sectional parameter varies over the length of the tubing string, to distinguish different features of the tubing string. The features that may be sensed and identified include features of the tubing segments, such as upset portions and collars used to join consecutive tubing segments, and tubular components such as packers secured to

an OD of the tubing string. Other features that may be sensed and identified include components of the bottom hole assembly (BHA) which are coupled to a lower end of the tubing string. The computer may further correlate the length and cross-sectional parameter to ascertain the positions of the sensed features either respect to the tubing string or a fixed datum like the rig floor. By sensing the collars or upset portions at the ends of the tubing segments, the computer may also automatically count (i.e. tally) the individual tubing segments. This enables automated, accurate, and detailed cataloging of the tubing string components and their relative positions.

[0020] The automated aspect of such a system, apparatus, method, and software may eliminate the costly and time-consuming step of having human operators individually measure each tubing string component separately before assembling the components within the tubing string. The measurements obtained are also more accurate, since high-precision displacement and tubing feature sensors may be incorporated within the TFL spool, and because these sensors respond automatically to movement of the tubing string relative to the TFL spool. Accuracy is further enhanced because the measurements obtained account for the cumulative weight and associated elongation of the tubing string suspended within the wellbore.

[0021] FIG. 1 is a generalized diagram of a well service rig **10** used for installing and/or retrieving a tubing string **30** downhole in a well **12**. A tubing measurement and evaluation system **50** according to an embodiment of the invention is coupled within the BOP assembly **40** over the well **12**. The tubing measurement and evaluation system **50** is used to automatically measure and evaluate the tubing string **30**, such as to obtain an insertion length of the tubing string **30** and to locate and identify different components of the tubing string **30** as the tubing string **30** is lowered. In this example, the tubing string **30** is a production tubing string, which may be installed in a casing-lined wellbore. However, one of ordinary skill in the art will recognize that the principles by which the system **50** measures and evaluates the production tubing string **30** in this example may be extended to measuring and evaluating other types of tubing strings, including casing strings, drill strings, and even coiled tubing. The term “tubular member” as used herein encompasses, but is not limited to, individual tubing segments, tubing strings, tubular components mounted on a tubing string, coiled tubing, and combinations thereof. Some

description and details follow regarding how the service rig **10** is used to install the production tubing string **30**, as context for the subsequent discussion of the system **50** being used to measure and evaluate the tubing string **30** as it is positioned downhole.

[0022] A drilling rig (not shown) was initially provided at the well site to drill the well **12** in the ground **11**. After the wellbore was drilled, the drilling rig was moved off of the well **12** and the service rig **10** was moved into place for completing the well **12** and to commence production. The service rig **10** may also be used for subsequent workover operations of the completed well **12**. The well service rig **10** may be a mobile service rig (i.e. having wheels) for being driven to the site, or may be built on-site over the well **12**. The well service rig **10** includes a rig platform **15** supported above ground **11**. A towering structure supported on or near the rig platform **15** is referred to herein as a “mast” **14**, which may be provided with a mobile service rig. The towering structure may alternatively be referred to as a “derrick” in the context of a service rig built on-site. The mast **14** has a trussed construction suitable for supporting large, heavy equipment used in well completion and workover operations. As generally understood in the art, a draw works supported from the mast **14** includes a crown block (not shown) at an upper end of the mast **14** and a traveling block **16** suspended from the crown block on a large diameter wire rope **18**. A system of sheaves or pulleys provide a mechanical advantage for raising and lowering the traveling block **16** along with anything suspended from the traveling block **16**. The traveling block **16** may be used to raise and lower various types of tubing and equipment used in completion and production.

[0023] An elevator **20** currently coupled to the traveling block **16** is specially adapted for use with production tubing. Production tubing tends to have a smaller diameter and less mass than a drill string used to drill the well or the casing used to line the well. Each tubing segment **31** has upset portions **32** at the ends where the diameter increases, at which the connection between tubing segments **31** is to be made. The upset portion **32** helps ensure that any failure of the tubing segment **31** occurs away from the upset portion **32**. The elevator **20** has a hinge at one end and a latch at the other end, and is closed about the upset portion to grab it. In the closed position, the elevator arms are latched together to form a load-bearing ring around the component to be lifted, which in this case is the upset portion **32** of the tubing segment **31**. The upset portion **32** on the tubing

segment **31** is larger than the inside diameter of the closed elevator **20**, so that the elevator **20** engages the shoulder or taper of the upset portion **32**. The elevator **20** may be subsequently opened to release the tubing segment **31** or other component to be lifted, and may be swung away from the component. Note that on a drilling rig equipped with a top-drive, an elevator adapted for use with drill pipe can instead be secured to the top drive and used to raise and lower a drill string.

[0024] To add another tubing segment to the tubing string **30**, the tubing string **30** may be temporarily suspended from slips **42**, which are provided in the BOP assembly **40** in this example. As generally understood in the art, slips **42** include a set of dies having a tapered surface matching an internal taper of a bowl. A radially-inwardly facing surface of the dies include teeth for frictionally engaging an outer surface of the tubing to be suspended. The slips are said to be self-energizing, whereby the friction between the tubing and the slips allows the tubing to urge the slips downward and radially inward along the tapered surface of the bowl, into gripping engagement with the tubing. Commonly, as few as four sets of dies may be used in the slips **42**. Larger diameter tubing may be supported by slips having a greater number of dies. An assembly commonly known as a “spider” has many sets of dies, such as twenty or more sets of dies, and operates according to the same basic principles as slips. The slips **42** temporarily suspend the tubing string **30** from a support location below an upper end **33** of the tubing string, leaving the upper end **33** accessible by the elevator **20** on the traveling block **16**.

[0025] With the tubing string **30** temporarily suspended from the slips **42**, the elevator **20** may be unlatched from the tubing string **30**. A tubing segment, or a “stand” consisting of up to three tubing segments already connected end-to-end, may be added to the upper end **33** of the tubing string **30**. The additional tubing segments or stands may be provided on the catwalk (not shown) of the services rig **10**. In one scenario, a tubing segment or stand is pushed up a “V-door” comprising an opening in the derrick or mast at the rig floor **15**. This brings one end of the segment or stand upward so that a crew member may latch the elevator **20** about the segment or stand. The traveling block **16** may then be controlled to position the retrieved segment or stand above the tubing string **30**. The lower end of the suspended tubing segment or stand may be threadedly coupled

to the upper end of the tubing string **30** using a connection tool **22**. The connection tool **22** may be a power tong **22**. In the present context of a well service rig, the power tong **22** is typically suspended by a cable **24** from the crown block. In the context of a drilling rig, a power tong may instead be supported on a rig floor. After connecting the stand or segment to the upper end of the tubing string **30**, the slips **42** may be disengaged from the tubing string **30** so that the tubing string **30** may be further lowered into the well **12** by the traveling block **16**. This process may be repeated for adding any number of tubing segments to the tubing string **30** until the desired depth is reached within the well **12**.

[0026] When the desired length of the tubing string **30** and corresponding depth is reached, the tubing string **30** may be suspended indefinitely on a tubing hanger in the wellhead **48**. The tubing hanger may be installed by a hanger running tool that lowers the hanger down the production bore of the wellhead **48** until it lands on a stop shoulder. The stop shoulder is formed by a decreased inner diameter portion defining a section of the production bore of the wellhead. The tubing string **30** may remain in place on the tubing hanger, suspended under its own weight, during production of hydrocarbons from the well **12**.

[0027] To subsequently remove the tubing string **30** from the well **12**, the process is essentially reversed. The elevator **20** is closed around an upper end of the tubing string **30** and the traveling block **16** is raised to lift the entire tubing string **30** until one or more tubing segments are exposed above the rig platform **15**. Then the tubing string **30** is temporarily supported on the slips **42** while the one or more exposed tubing segments are disconnected from the tubing string **30** using the connection tool **22**. The traveling block is then moved back down to grip the current uppermost tubing segment. The slips **42** are disengaged from the tubing string **30** and the tubing string is raised by the traveling block **16** to draw one or more additional tubing segments out of the well. The process of successively removing tubing segments and raising the tubing string **30** may be repeated until the entire tubing string **30** has been removed from the well **12** and disassembled.

[0028] The above description of lowering the tubing string into a well and alternately removing the tubing string from the well is just one example of how tubing may be lowered into a well and subsequently raised from a well. One of ordinary skill in the art

will recognize that a myriad of different service rigs and rig equipment may be provided for assembling, lowering, raising, and disassembling different types of tubing, including tubing strings and coiled tubing. One of ordinary skill in the art will also appreciate that different equipment may be used for different types and sizes of tubing.

[0029] Referring still to FIG. 1, the BOP assembly **40** positioned over the wellhead **48** is used for controlling downhole pressures. The BOP assembly **40** comprises a plurality of components with concentric bores, such as the slips **42**, a stripper **44**, one or more BOPs **46**, as well as the tubing measurement and evaluation system **50** that has been connected within the BOP assembly in this embodiment. Note that the bore of any component in the BOP assembly is not limited to being manufactured by the manufacturing step of a boring operation, and may instead be formed by other manufacturing steps such as molding. The concentric bores of these parts allow the tubing string **30** and tubular components supported on the tubing string **30** to be tripped down into the well **12** through the BOP assembly **40**. Although the hydrocarbon fluids such as oil and gas are generally produced through the tubing string **30**, the concentric bores of the BOP assembly **40**, wellhead **48**, and the well **12** provides a flow path for produced fluids in some circumstances that are beyond the scope of the present discussion. The one or more BOPs **46** may provide one or more sets of rams **47**. For example, blind rams may be provided for selectively closing the annulus between the casing and the tubing string **30**, and shear rams may be provided for shearing any tubing suspended in the well and completely shutting off flow in the event of an emergency. Standard BOP components such as rams are generally known in the art and do not require further discussion here.

[0030] The tubing measurement and evaluation system **50** includes a TFL spool **52** removably secured within the BOP assembly **40**. Thus, the TFL spool **52** may be subsequently removed from the BOP assembly **40**, such as for servicing the tubing measurement and evaluation system **50** or for subsequently using the tubing measurement and evaluation system **50** at another well site after the well **12** reaches the end of its useful service life. The upper and lower flanges **54**, **56** may be used to secure the TFL spool **52** to corresponding flanges of other components in the BOP assembly **40**. Corresponding flanges of components abutting the TFL spool **52** may be joined with the

flanges **54**, **56** using threaded fasteners. The TFL spool **52** is located above the BOP rams **47** but below the stripper **44**, so that the stripper **44** may remove excess debris from the tubing string **30** prior to entering the TFL spool **52**. The stripper **44** in this embodiment is unique to the particular service rig **10** and may be periodically discarded and replaced during well operations.

[0031] The TFL spool **52** includes at least one internally-mounted displacement sensor **60** and at least one tubing feature sensor **80** mounted within the TFL spool **52**. The displacement sensor **60** is responsive to a linear, axial displacement of the tubing string **30** within the TFL spool **52**. The tubing feature sensor **80** is responsive to a local cross-sectional parameter of the tubing string **30**, such as a thickness or a density. It should be noted that, at its installed position within the BOP assembly **40**, the TFL spool **52** is stationary while the tubing string **30** is moved relative to the stationary TFL spool **52**. As the tubing string **30** is lowered or raised, the displacement sensor **60** generates a signal responsive to the linear, axial displacement of the tubing string, while the tubing feature sensor **80** simultaneously generates a signal responsive to the local thickness, density, volume, or other cross-sectional parameter of the tubing string **30**.

[0032] FIG. 2 is a more detailed side view of a specific example embodiment of the tubing measurement and evaluation system **50** having a pair of opposing, roller-based displacement sensors **60A** and **60B**, and one tubing feature sensor **80**. Each displacement sensors **60A**, **60B** includes an electrical connector **64**, commonly referred to as an encoder, for connecting a signal wire or data cable external to the spool for carrying a signal representative of the sensed linear displacement of the tubing string. The TFL spool **52** includes a through bore **55** allowing the tubing string to pass through the TFL spool **52**. The TFL spool **52** may be provided in different sizes, each accommodating a different tubing diameter or range of tubing diameters. In one example, the TFL spool **52** may have a nominal internal diameter (ID) of 7-1/16 inches and may be rated for a nominal maximum of 5,000 pounds per square inch (psi) of fluid pressure. A 7-1/16 spool ID is suitable for use with production tubing of a nominal 2-3/8 inch or 2-7/8 inch nominal tubing OD commonly used in the field. A TFL spool with a particular size and pressure rating may accommodate a range of different sizes and/or types of tubing

strings. To accommodate an even greater range of size and type of tubing, the TFL spool may also be offered in a variety of different sizes and configurations.

[0033] The displacement sensors **60A**, **60B** in this example embodiment comprise spring-loaded rollers **62** that physically contact the tubing string as it moves within the through bore **55**. The two displacement sensors **60A**, **60B** in this embodiment may be essentially identical, including respective spring-loaded rollers **62A**, **62B** of the same size. An additional spring-loaded roller **62C** (without any electronic sensor elements) is also optionally mounted within the spool **52** to provide additional stabilization and centering to the tubing string. In the present example of a 7-1/16" TFL spool rated for 5,000 psi, each roller **62A-C** may have a roller diameter of approximately 15 inches. The displacement sensors **60A**, **60B** and the additional, non-sensor, spring-loaded roller **62C** are secured to the TFL spool **52** to internally position the rollers **62** within the through bore **55**, so that the rollers **62** are in constant contact with a tubing string component positioned within the TFL spool **52**. The rollers **62**, as further detailed in FIG. 3, are free to travel radially to accommodate a changing OD of the tubing string as it is moved within the TFL spool **52**. The rollers **62** may have an increased-friction surface, such as rubber-coated-steel rollers, to provide reliable frictional engagement with the tubing string.

[0034] In embodiments such as FIG. 2 having a plurality of roller-based displacement sensors, the rollers are circumferentially spaced around an axis of the spool **52**. By way of example, the embodiment of FIG. 2 includes the two roller-based displacement sensors **60A**, **60B** mounted within the TFL spool **52** that are evenly spaced circumferentially, i.e., at approximately 180 degrees apart with respect to a central axis of the through bore **55**. The additional, non-sensor, spring-loaded roller **62C** is mounted within the spool **52** at about 90 degrees to the spring-loaded rollers **62A**, **62B** so the tubing string is simultaneously contacted at three different locations by the two sensor-containing rollers **62A**, **62B** and the non-sensor roller **62C**. The use of the two (or more) displacement sensors **60A**, **60B** provides a redundant linear displacement measurement for improved reliability. The use of a plurality of circumferentially-spaced, spring-loaded rollers provides an additional centralizing feature, whereby the rollers **62** help to maintain a tubing string component centered within the through bore **55** of the TFL spool **52**.

Centering the tubing string within the TFL spool **52** helps minimize friction between the tubing string and the TFL spool **52** and other concentric bores of the BOP assembly in which the TFL spool **52** may be installed.

[0035] The displacement sensors **60A**, **60B** may be removably mounted to the TFL spool **52**, so that the displacement sensors **60A**, **60B** may be serviced or replaced if necessary. Optional displacement sensor ports **58** are defined by the TFL spool **52**, which extend from an outer surface **59** of the TFL spool **52** to the through bore **55**. The displacement sensor ports **58** allow the respective displacement sensors **60A**, **60B** to be secured on the TFL spool **52** from the outside of the spool **52**. Once inserted, the displacement sensors **60A**, **60B** are then mechanically secured to the TFL spool **52** at a mounting plate **66**, such as using threaded connections **57**. For example, threaded holes may partially extend through the wall of the TFL spool **52** without extending all the way to the through bore. Corresponding through holes on the mounting plate may align with the threaded holes on the TFL spool **52** for receiving a threaded fastener that mate with the threaded holes on the TFL spool **52**. A sealing member such as an elastomeric O-ring may be provided to seal between the TFL spool **52** and the mounting plate **66**. The displacement sensors **60A**, **60B**, the displacement sensor ports **58**, and the mounting plate **66** are sized and located in consideration of the particular spool dimensions and intended tubing type to provide the desired positioning of the rollers **62A**, **62B** within the TFL spool **52**. The non-sensor, spring-loaded roller **62C** may be similarly mounted.

[0036] While the displacement sensors **60A**, **60B** are responsive to the linear displacement of the tubing string, the tubing feature sensor **80** provided in the TFL spool **52** is simultaneously responsive to a local cross-sectional parameter of the tubing string **30** in proximity to the tubing feature sensor **80**. The tubing feature sensor **80** may be directly or indirectly responsive to a local thickness, effective density, or volume, which changes along the length of the tubing string **30**. For example, the thickness, volume, and/or effective density of a tubing segment is increased at locations of the upset ends of abutting tubing segments. The thickness, volume, and/or effective density will also increase at locations where a tubular component, such as a packer, is secured to the tubing string. The tubing feature sensor **80** generates a signal responsive to such changes in the cross-sectional parameter of the tubing string.

[0037] In one embodiment, the tubing feature sensor **80** comprises spaced-apart magnets **82, 84** and a coil **86** mounted between the magnets **82, 84**. As the tubing string is moved axially within the TFL spool it moves relative to the tubing feature sensor **80**. The tubing feature sensor **80** is responsive to a change in metal thickness or volume, whereby lines of magnetic flux between the two opposing magnets **82, 84** are disturbed. The disturbance in the magnetic flux lines induces a low frequency voltage or electromagnetic field (EMF) in the coil **86**, which is incorporated into a signal output by the tubing feature sensor **80**.

[0038] A prototype was constructed wherein a commercially available “casing collar locator” (CCL) was mounted within the TFL spool **52** for use as a component of the tubing feature sensor. Such a commercially available CCL is conventionally tripped downhole, such as on wireline. In a production embodiment, the electronic components of the tubing feature sensor **80** may be provided and positioned within a special compartment or cavity of the spool body. The spacing of the magnets **82, 84** and the tuning of the coil **86** in a production embodiment may be specially selected and empirically determined for optimal use with the particular type of tubing to be used with the tubing measurement and evaluation system **50**.

[0039] The displacement sensors **60** generate signals in relation to the sensed axial displacement of the tubing. The tubing feature sensor **80** simultaneously generates a signal in relation to the changing local cross-sectional parameter of the tubing. These signals are output to a field computer **100** for analysis and interpretation. The analysis and interpretation, as further discussed below, may include both the present depth of the tubing string within a well, the identification of components mounted in the tubing string, the number of tubing segments, and the relative positions of the identified components within the tubing string.

[0040] The displacement sensors **60** work better when there is a relatively clean surface of the tubing string **30** for the rollers **62** to roll on. The replaceable rubber stripper **44** may be provided as a separate component above the spool **52** for scraping the tubing string **30** just before it enters the spool **52**. The stripper **44** thereby helps clean the tubing string **30** when lowering the tubing string **30** into the well. One or more wire

brush **51** is also provided at the lower end of the spool **52** in this embodiment, below the rollers **62**, to help prevent debris from accumulating on or between the rollers **62** and for cleaning the tubing string **30** as it comes out of the bore hole. The one or more wire brush **51** may comprise a plurality of separate brushes that are mounted internally to the spool **52** and spaced circumferentially about the bore **55** of the spool **52**. Alternatively, the wire brush **51** may comprise a continuous ring-shaped brush centered within the bore **55** of the spool **52** so that the tubing string **30** is scraped uniformly along its circumference when raising the tubing string **30** out of the well. The rubber stripper **44** at the upper end of the spool **52** and the one or more wire brush **51** at the lower end of the spool **52** below the rollers **62** are field-replaceable and may be relatively inexpensive.

[0041] FIG. 3 is a partially cut-away side view further detailing one of the roller type displacement sensors **60**. The displacement sensor **60** includes a spring-loaded extension mechanism that includes a first extension member **70** slidably received on a second extension member **72**. The second extension member **72** is coupled to the mounting plate **66**. The extension mechanism may comprise a track, a piston-cylinder type arrangement, or other such arrangement whereby the second extension member **72** is moveable relative to the first extension member between an extended position and a retracted position, while remaining mechanically coupled to one another. In the example configuration of FIG. 3, the first and second extension members **70**, **72** operate as a piston and cylinder, respectively. A spring **74** disposed between the first and second extension members **74** urges the first and second extension members **70**, **72** toward the extended position, whereas a force applied by the tubing **31** in the TFL spool (FIG. 2) urges the extension mechanism toward a retracted position against an opposing spring force provided by the spring **74**. The roller **62** is rotatably coupled to the first extension member **70** on an axle **63**. The extension mechanism is shown in a partially-retracted position in FIG. 3, with the spring **74** having been compressed due to the force being applied by the tubing **31** to the roller **62**. As the tubing **31** is moved in an axial direction, i.e. in a direction of a central axis of the tubing **31** into or out of the sheet of FIG. 3, any changes in the diameter of the tubing **31** along its length are accommodated by radial movement of the roller **62** on the spring-loaded extension mechanism, so that the roller **62** rolls along and maintains contact with an outer surface of the tubing **31**. A sensor element **78** mounted

in proximity to the roller **62** is responsive to a rotational displacement of the roller **62**. The sensor element **78** is used to obtain a linear, axial displacement of the tubing **31** as a function of the rotational displacement of the roller **62**. The non-sensor roller **62C** (see FIG. **2**) may be similarly constructed in terms of a spring-loaded mechanism, but without the need for any electronic sensor elements **78**.

[0042] An optional roller pre-positioning mechanism is further illustrated in the example configuration of FIG. **3**. The pre-positioning mechanism **75** allows a user to adjust the position of the roller **62** when the extension mechanism is in a relaxed state, e.g. with the tubing **31** removed from the bore of the TFL spool of FIG. **2**. This adjustment correspondingly controls the amount by which the spring **74** is compressed when the tubing **31** is inserted within the TFL spool. In the example configuration, the pre-positioning mechanism **75** comprises an outer sleeve **76** threadedly engaged with an inner shaft **77**. Rotating the outer sleeve **76**, such as by hand or using a tool, causes a corresponding translational movement of the inner shaft **77**, in a radial direction with respect to the spool bore. The inner shaft **77** is connected to the first extension member **70**. Rotating the outer sleeve **76** in one direction thereby moves the roller **62** closer to a central axis of the TFL spool (FIG. **2**), whereas rotating the outer sleeve **76** in the other direction conversely moves the roller **62** away from the central axis of the TFL spool.

[0043] One use of the roller pre-positioning mechanism is to adjust the starting position of the roller **62** for use with different diameters of tubing. To accommodate a larger diameter tubing, the user may adjust the pre-positioning mechanism **75** to move the roller **62** away from the central axis of the TFL spool, whereas to accommodate a smaller diameter tubing, the user may conversely adjust the pre-positioning mechanism **75** to move the roller **62** closer to the central axis of the TFL spool. Another use of the pre-positioning mechanism is to adjust the amount of pre-load of the spring **74** and the corresponding force of the roller **62** against the tubing **31**. Increasing the amount of pre-load may help the roller **62** maintain contact with the tubing to prevent slippage and to closely track the outer profile of the tubing **31**, whereas decreasing the amount of pre-load may reduce the wear on the roller **62**.

[0044] FIG. 4 is a side view of another example embodiment of the tubing measurement and evaluation system **50** having an optical displacement sensor **160** in lieu of the roller-type sensors of FIG. 2. The optical displacement sensor **160** obtains a linear displacement of the tubing **31** without physically contacting the tubing **31**. In one configuration, the optical displacement sensor **160** includes an optoelectronic sensor element **162** to image texture in the tubing **31** and any matter accumulated on the tubing **31**. The sensor element **162** may incorporate a light-emitting diode (LED) or infrared laser diode to illuminate a surface of the tubing **31**. The illuminated surfaces, when lit at a grazing angle, cast distinct shadows. Images of these surfaces may be captured in continuous succession and compared with each other to determine how far the tubing **31** has moved. The optical displacement sensor **160** may also detect direction of movement, such that the signal generated by the optical displacement sensor **160** includes both the displacement and the direction of the displacement. The optical displacement sensor **160** may also include a mounting plate **166** for mounting to the TFL spool **52**. In this example embodiment, there is one signal S_1 generated by the optical displacement sensor **160** and one signal S_2 generated by the tubing feature sensor **80**.

[0045] FIG. 5 is a schematic diagram of an embodiment of the field computer **100** for receiving and interpreting the signals generated by the tubing measurement and evaluation systems of FIGS. 2 and 4. The field computer **100** includes a computer dock **102** for optionally connecting to a portable computer **120**. The portable computer **120** may be a tablet computer or laptop computer, for example. A power supply may include a battery **104** and/or photovoltaic cell **106** for supplying power to the computer dock **102**. The battery **104** may be rechargeable. The photovoltaic cell **106** converts radiant electromagnetic energy (e.g. sunlight) to electricity. The photovoltaic cell **106** may directly power the portable computer **120** or may be used to charge the battery **104**. A printer **110** may also be provided for outputting the results of analysis performed by the computer **120**. The results of the analysis may include a “tubing log” **112** as described further below. The tubing log **112** may graphically describe the length of the tubing positioned downhole and the relative positioning of various tubing features (e.g. joints and packers) within a tubing string.

[0046] The portable computer **120** contains data analysis software **122** comprising computer usable program code. The software **122** may embody control logic specifically developed for use with the tubing measurement and evaluation system **50**. This control logic may be used to analyze any number of signal input signals S_1 to S_n generated by the displacement and tubing feature sensors in the tubing measurement and evaluation system. In a broad sense, the control logic may analyze the signals to identify and/or locate variations in the cross-sectional property of the tubing string with the sensed linear displacement of the tubing string. Example control logic modules include a length/depth determination module **124** for determining well depth and/or tubing string length, a feature identification module **126** for identifying features of the tubing string, and a feature position determination module **128** for determining the position of the identified features either relative to the tubing string or to a fixed datum such as the rig floor. The data analysis software **122** may also include an electronic lookup table **130** embodying a predetermined correlation between various tubing features and their expected signal responses. As a tubing string is positioned downhole (See FIG. 1), the signal response from the displacement and tubing feature sensors are output to the computer **120**, which invokes the various logic modules **124**, **126**, **128** to measure and evaluate the tubing string and features thereof.

[0047] The length/depth determination module **124** uses the displacement sensor signal(s) to monitor the relative displacement of the tubing string as it moves within the TFL spool (see FIG. 1). As the tubing string is lowered or raised within the well, the displacement sensor senses both the magnitude of the displacement and the direction of the displacement of the tubing string. A downward displacement of the tubing string increases a well depth measurement and a tubing length measurement. An upward displacement of the tubing string correspondingly decreases the well depth measurement and the tubing length measurement. When lowering and installing the tubing string into the well, there may be occasions when the tubing string is partially raised by some amount, such as to adjust the height of the tubing string for adding a tubing segment or stand, or to raise and re-lower the tubing string to correct the position of a tubular component mounted on the tubing string. Therefore, the ability to track the direction of the displacement allows any upward displacements to be subtracted from the depth and

length measurements. Also, when removing a tubing string from the well, such as during workover operations, a decreasing depth measurement may also be tracked.

[0048] A datum or reference is selected for each of the length measurement and depth measurement. For example, the lower end of the tubing string, which is first to enter the well, may be selected as the starting point for the length measurement. The lower end of the tubing string may be sensed by the tubing feature sensor, triggering an automatic reference point to start measuring the tubing string. Alternatively, the moment of initial entry of the lower end of the tubing string may be sensed by the displacement sensor(s) when they begin sensing movement of the tubing string. For the depth measurement, any fixed location relative to ground may be selected as the datum. The rig floor or the TFL spool, for example, may be selected as the datum. If the rig floor is to be used as the datum for the depth measurement, a vertical spacing between the rig floor and the sensors in the TFL spool may be entered into the computer **120** by a well operator. This vertical distance may be added to the length measurement of the tubing string to obtain the depth measurement.

[0049] The feature identification module **126** is configured for identifying a tubing feature based on as few as one input signal, from the tubing feature sensor. A tubing feature in this context refers to any physical feature of the tubing string that may be distinguished from another physical feature of the tubing string. A first example of a tubing feature is a portion of a tubing segment having a constant cross-section. A second example of a tubing feature is an upset portion, flange, or collar of a tubing segment, which has a larger OD than the constant cross-section portion between upset portions. A third example of a tubing feature is a tubular component coupled to the tubing string other than a tubing segment. One examples of such a tubular component is a packer, which may be secured to an OD of a selected tubing segment and tripped downhole to seal an annulus between the casing and the tubing string in a selected formation zone. The identification of upset portions or collars at the end of each segment may be further used to count, i.e. tally, the tubing segments in the tubing string.

[0050] The feature identification module **126** receives a signal from the tubing feature sensor, which changes along the length of the tubing string, and analyzes the

changing signal to identify a particular feature. Each feature may have a different characteristic signal response. For example, a straight section of a tubing segment may be expected to have a generally constant or uniform signal response from the tubing feature sensor. The signal from the tubing feature sensor is expected to change, such as to increase in magnitude, in transitioning from the straight section of the tubing segment to the upset portions of the tubing segment. The signal from the tubing feature sensor is expected to further change in proximity to a tubular component secured to the tubing string. For example, the characteristic response of the tubing feature sensor in proximity to a packer is expected to be distinct from the characteristic response of the tubing feature sensor in proximity to either a straight portion or upset portion of a tubing segment. The feature identification module **126** therefore analyzes these changes to distinguish between different features of the tubing string and/or to identify the specific features of the tubing string.

[0051] The feature identification module **126** may perform this analysis using as few as one signal provided by one tubing feature sensor. That is, the characteristic response from the tubing feature sensor may be sufficient in some cases to distinguish one type of feature from another feature, such as to distinguish a packer from an upset portion or to distinguish an upset portion from a straight section of tubing. However, the feature identification module **126** may be further informed by the signal from one or more displacement sensors. For example, a packer may have a characteristic length parameter in addition to a characteristic cross-sectional parameter. The length parameter may be determined by analyzing the signal from a displacement sensor. The length parameter of a particular feature may corroborate the identification of the component or further characterize the identified component. In one example, if the tubing feature sensor outputs a signal indicative of the cross-sectional parameter of a packer (e.g. the expected diameter, density, or volume of a packer), the length over which that characteristic signal is received may confirm or disconfirm that the sensed feature is a packer. In another example, two different features may have similar cross-sectional parameters but significantly different lengths, so a length determination may differentiate those two features.

[0052] The predetermined correlation lookup table **130** embodying a predetermined correlation between tubing features and their expected signal response may be referenced by any of the logic modules. The predetermined correlation lookup table **130** may be referenced by the feature identification module **126** in distinguishing between features or identifying specific features of the tubing string under evaluation. The predetermined correlation lookup table **130** may include a set of different tubing features, such as straight-sections of tubing, upset portions of tubing, tubing collars, and one or more tubular components that may be secured to the tubing string. For each tubing feature in the table **130**, a set of expected parameters may be provided. For example, each tubing feature in the table **130** may be uniquely associated with an expected cross-sectional parameter and/or length parameter, or specified ranges of these respective parameters.

[0053] The position determination module **128** may be invoked by the computer **120** to determine the position of an identified tubing feature. The position determination module uses the signal from at least one displacement sensor to determine the relative position of each feature identified by the feature identification module **126**. The position may be expressed with respect to the tubing string. For example, the position of each feature may be expressed relative to a leading/lower end of the tubing string. Alternatively, the position of each feature may be expressed as a depth, such as with respect to the rig floor (FIG. **1**). The position determination module **128** may be further used in the process of recording where various components are located downhole. For example, the location of a packer relative to the tubing string may be noted, and when the tubing string is in its final installed position, the precise depth of the packer within the well may be determined according to the packer's position on the tubing string.

[0054] Information contained within the tubing log **112** includes changes in the local cross-sectional parameter of the tubing string as the tubing string is moved within the TFL spool. The central pattern plotted in the tubing log **112** reflects the displacement and local cross-sectional parameter obtained by the spool-mounted sensors. The narrowest part of the plotted pattern in the tubing log **112** generally corresponds to straight sections of the tubing segments, which are numerous and constitute a large percentage of the total length of the tubing string. Portions of the tubing log **112** where the plotted pattern suddenly widens are referred to as "kicks" **115**. Each kick **115** typically represents a

feature other than a simple, straight section of tubing, at which the density, thickness, and/or volume of the tubing string at that location has increased. The kicks **115** may represent upset portions of tubing segments or tubular components such as packers mounted on the tubing string. The width of each kick **115** is related to the increased cross-sectional parameter, as reflected in the magnitude of the signal from the tubing feature sensor. The length of each kick **115** and spacing between kicks **115** is related to the displacement, and is reflected in the signal from the displacement sensor(s). Thus, the pattern plotted in the tubing log **112** may be proportional to the actual dimensions of the tubing string and features thereof.

[0055] FIG. 6 is an elevation view of the tubing measurement and evaluation system **50** of FIG. 2 along with a selected portion of a tubing log **112** corresponding to a portion of the tubing string **30** currently under evaluation. The tubing log **112** is shown being generated by the printer **110** for purpose of illustration, but could also be electronically generated as an image viewable on a display screen and stored as an electronic record. The tubing string **30** is shown here with a packer **34** supported on an OD of a segment **31** of the tubing string **30**. A straight section of the tubing segment **31** is currently passing through the TFL spool **52**. The packer **34** is above the TFL spool **52** and has not yet been registered on the tubing log **112**. The rollers **62** of the displacement sensors **60A**, **60B** and the non-sensor roller **62C** are in frictional contact with the tubing segment **31** so that as the tubing string **30** moves downward, the rollers **62** roll along an exterior of the tubing segment **31**. With respect to the orientation of FIG. 6, a clockwise rotation of the roller **60** on the first displacement sensor **60A** and a counter-clockwise rotation of the roller **60** on the second displacement sensor **60B** generate signals each corresponding to an increasing (+) axial displacement of the tubing string **30**. Simultaneously, the tubing feature sensor **80** outputs a relatively steady signal magnitude corresponding to the relatively constant cross-section of the tubing segment **31**. This relatively constant signal output is manifested in a first portion **131** of the tubing log **112** having a correspondingly uniform width “w.”

[0056] FIG. 7 is an elevation view of the tubing measurement and evaluation system **50**, with the tubing string **30** having been lowered to where the packer **34** is positioned within the TFL spool **52**. The packer is currently in proximity to the sensors **60A**, **60B**,

80. The rollers **62A**, **62B** of the respective spring-loaded displacement sensors **60A**, **60B** and the non-sensor roller **62C** are urged to a retracted position in response to the rollers **62** having rolled from the straight section of the tubing segment **31** to the larger diameter of the packer **34**. The tubing feature sensor **80** responds to the increased cross-section of the tubing string **30** in the location of the packer **34** with an increased signal magnitude. A second portion **134** of the tubing log **112** is a “kick” corresponding to the packer **34**. The second portion **134** is visibly wider than the first section **131** corresponding to the narrower tubing segment **31**.

[0057] The signals may be analyzed, as discussed in connection with FIG. 5, to identify that the first portion **131** of the tubing log **112** corresponds to a straight tubing segment section and that the second portion **134** of the tubing log **112** corresponds to the packer **34**. These sections are optionally labeled on the tubing log **112** as “PCK” for packer and “TBNG” for tubing, respectively. The tubing feature identifications may alternatively be displayed on a display screen or stored and cataloged in electronic memory.

[0058] FIG. 8 is a flowchart generally outlining one example embodiment of a method for measuring and evaluating a tubing string as the tubing string is moved downhole, such as while installing production tubing in a well. Many variations of this method are also within the scope of the present disclosure, which are not all limited to the particular selection and order of steps in the flowchart FIG. 8. The steps in the flowchart may be further informed by the above discussion of the tubing measurement and evaluation system of FIGS. 1-7 and its manner of use.

[0059] According to step **200**, an axial displacement of a tubing string is monitored. The tubing string may comprise tubing segments connected end-to-end and one or more components secured to the tubing string. The axial displacement of the tubing string is monitored with respect to a fixed location, such as at a specific sensor location in a BOP assembly. More specifically, the axial displacement of the tubing string may be measured by a displacement sensor mounted in proximity to the bore of a TFL spool in the BOP assembly. The displacement sensor may be, for example, a roller-type

displacement sensor that frictionally engages an outer surface of the tubing string, or a non-contact displacement sensor, such as an optical displacement sensor.

[0060] According to step **202**, a cross-sectional parameter “CX” of the tubing string is also measured. The cross-sectional parameter may be measured by a tubing feature sensor from about the same axial location with respect to the BOP assembly as the displacement sensor. The displacement sensor and tubing feature sensor are both preferably positioned in proximity to a through bore of a TFL spool in the BOP assembly. Although steps **200** and **202** are illustrated in series, the displacement measured in step **200** and the cross-sectional parameter measured in step **202** may be obtained simultaneously, in parallel.

[0061] A graphical representation of the measured cross-sectional parameter is plotted in step **204**. For example, this pattern may be a tubing log, printed on paper or displayed as a graphical object on a computer display. The graphical representation may further include a description of identified features. The graphical object may be electronically stored in computer memory. The cross-sectional parameter may be plotted as a function of the sensed displacement, providing a to-scale representation of the tubing string and features thereof. The width of the plot may be related to the varying magnitude of the sensed cross-sectional parameter. Thus, features such as upset tubing portions or tubular components may be represented by wider kicks. The spacing between detected features of the tubing string and the spacing between kicks may likewise be to-scale.

[0062] A well depth and/or tubing string length is obtained according to step **206**. The length or depth is related to the sensed displacement. The length of the tubing string may be determined as the net positive displacement of the tubing string as it advances beyond the fixed location in the BOP assembly. The well depth may expressed with respect to a datum, such as a wellhead or rig platform. The well depth may be computed, for example, as the length of the tubing string plus the difference in height between the datum and the fixed location at which the displacement is sensed.

[0063] Conditional step **208** involves dynamically sensing any appreciable changes in the cross-sectional parameter of the tubing string. Straight sections of a tubing segment

are expected to be substantially uniform, and do not generally constitute an appreciable change in the cross-sectional parameter. However, other features, such as the upset ends of a tubing segment and tubular components secured to the tubing string, such as packers, generally do result in an appreciable increase in the cross-sectional parameter. Whether or not such an increase is detected at any given instant, the flowchart dynamically performs steps **200** and **202**, thereby continually sensing of the displacement and the cross-sectional parameter.

[0064] If an increase in CX is detected at any given instant or location, conditional step **208** leads to generating a kick according to step **210**. The kick represents the detection of a feature other than a straight, narrow section of a tubing segment. The kick may be plotted on paper or on a display screen. The location of the kick within the plot may be used to represent the location of the sensed feature with respect to the tubing string, which may be to-scale.

[0065] In step **212**, the feature associated with the kick may be identified. In some cases, the feature may be identified as a function of the magnitude of the cross-sectional parameter CX, alone. For example, the value of CX for a particular feature may have a certain magnitude or narrow range of magnitude associated with it, which is sufficient to distinguish that feature from other features. In other cases, the feature may be identified as a function of both the cross-sectional parameter CX and the displacement “d.” The magnitude of CX (corresponding to a width of the kick) may indicate a specific component or narrow the list of probable components, while the displacement d (corresponding to a length of the kick) may help narrow the possible features to one particular type of feature/component or to a particular sub-type. For example, the magnitude of CX may indicate the detection of a packer, whereas the length of the detected packer may further narrow the feature identification to a particular type or size of packer.

[0066] According to step **214**, the relative position of the detected feature within the tubing string may be ascertained as a function of the displacement d. The tubing log may graphically position the kick at the same relative position as the detected feature is in the actual tubing string.

[0067] As will be appreciated by one skilled in the art, aspects of the present invention may be embodied as a system, method or computer program product. Accordingly, aspects of the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a “circuit,” “module” or “system.” Furthermore, aspects of the present invention may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

[0068] Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

[0069] A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device.

[0070] Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

[0071] Computer program code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

[0072] Aspects of the present invention are described below with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0073] These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including

instructions which implement the function/act specified in the flowchart and/or block diagram block or blocks.

[0074] The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0075] The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

[0076] The corresponding structures, materials, acts, and equivalents of all means or steps plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but it is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiments were chosen and described in order to best explain the

principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

CLAIMS

What is claimed is:

1. An apparatus, comprising:
 - a spool including a through bore and one or more connectors for removably coupling the spool to a blowout preventer assembly;
 - a displacement sensor mounted to the spool in proximity to the through bore, the displacement sensor configured for sensing an axial displacement of a tubular member within the through bore of the spool and generating a signal in relation to the sensed axial displacement; and
 - a tubing feature sensor mounted to the spool in proximity to the through bore, the tubing feature sensor configured for sensing a cross-sectional parameter of the received tubular member in proximity to the tubing feature sensor and generating a signal in relation to the cross-sectional parameter of the received tubular member.
2. The apparatus of claim 1, wherein the tubing feature sensor is responsive to one or more of the cross-sectional parameters consisting of a thickness, a density, and a volume of the received tubular member in proximity to the tubing feature sensor.
3. The apparatus of claim 2, wherein the tubing feature sensor further comprises:
 - first and second magnets separated by a coil and configured such that a difference in metal thickness or effective density of the tubular member adjacent to the two magnets induces a current spike in the coil.
4. The apparatus of claim 1, wherein the displacement sensor comprises:
 - a roller;
 - a biasing member configured to bias the roller radially inwardly into frictional engagement with the tubular member when received within the through bore; and
 - a sensor element configured for obtaining a linear displacement of the tubular member as a function of a rotational displacement of the roller.

5. The apparatus of claim 1, wherein the displacement sensor comprises:
 - a plurality of rollers circumferentially spaced along the through bore of the spool, wherein each roller is positioned to frictionally engage the tubular member when received within the through bore; and
 - a plurality of sensor elements each configured for obtaining a linear displacement of the tubular member as a function of a rotational displacement of a respective one of the rollers.
6. The apparatus of claim 1, further comprising:
 - a computer in electronic communication with the displacement sensor and the tubing feature sensor, the computer including control logic for identifying and locating variations in the cross-sectional property of the tubular member with the sensed linear displacement of the tubular member.
7. The apparatus of claim 6, further comprising:
 - a computer dock in electrical communication with the displacement sensor and the tubing feature sensor, the computer dock configured for removably connecting with the computer to place the computer in electronic communication with the displacement sensor and the tubing feature sensor.
8. The apparatus of claim 6, further comprising:
 - one or both of a portable rechargeable battery pack configured for supplying stored electrical energy to the computer dock and a photovoltaic cell configured for converting ambient electromagnetic radiation to electrical energy and supplying the electrical energy to the computer dock.
9. The apparatus of claim 1, further comprising:
 - a displacement sensor port defined by the spool, extending from an outer surface of the spool to the through bore of the spool;
 - a sensor mounting plate configured for removably mounting the displacement sensor to the spool and closing the displacement sensor port; and

a sealing member configured for fluidly sealing between the spool and the sensor mounting plate.

10. A system, comprising

a blowout preventer (BOP) assembly in sealed fluid communication with a wellhead;

a spool coupled to the BOP assembly, the spool including a through bore in fluid communication with respective through bores of the BOP assembly and the wellhead such that a tubular member lowered into the wellhead through the BOP assembly passes through the spool;

a displacement sensor mounted to the spool in proximity to the through bore of the spool, the displacement sensor configured for sensing an axial displacement of the tubular member within the through bore of the spool and generating a signal in relation to the sensed axial displacement;

a tubing feature sensor mounted to the spool in proximity to the through bore, the tubing feature sensor responsive to a cross-sectional parameter of the received tubular member in proximity to the tubing feature sensor and configured for generating a signal in relation to the cross-sectional parameter of the received tubular member; and

a computer in electronic communication with the displacement sensor and the tubing feature sensor, the computer including control logic for identifying and locating variations in the cross-sectional property of the tubular member with the sensed linear displacement of the tubular member.

11. The system of claim 10, wherein the BOP assembly comprises:

one or more sets of rams;

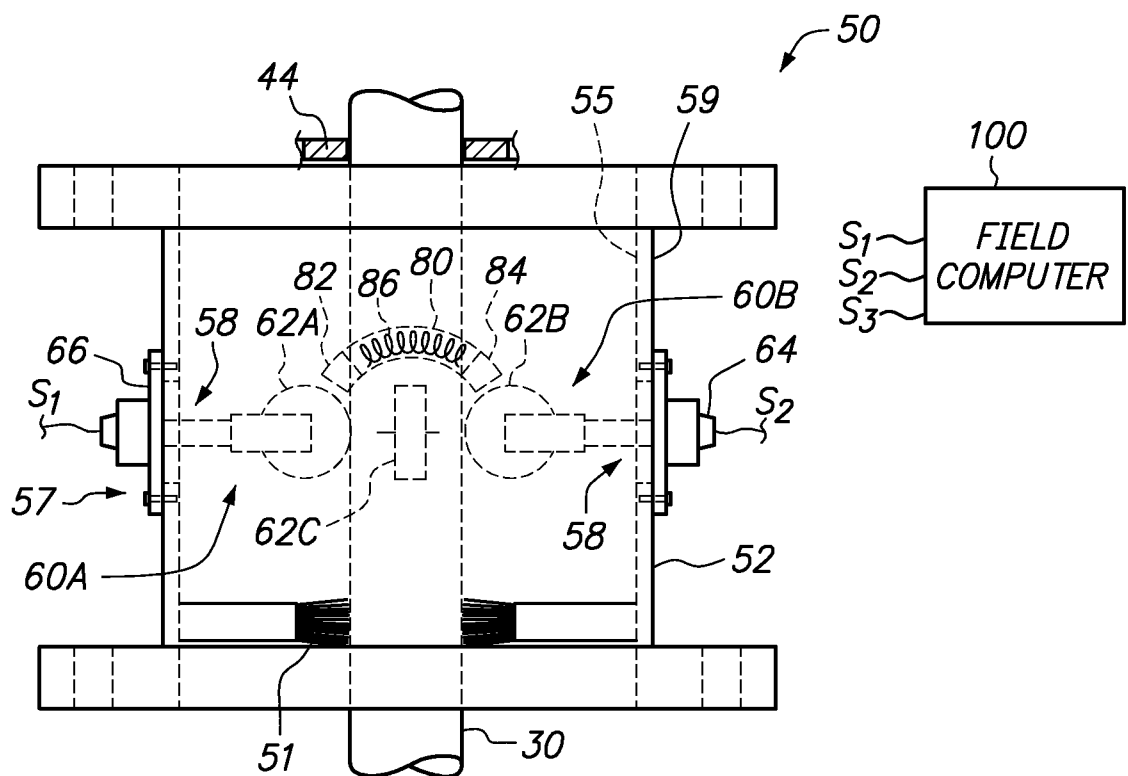
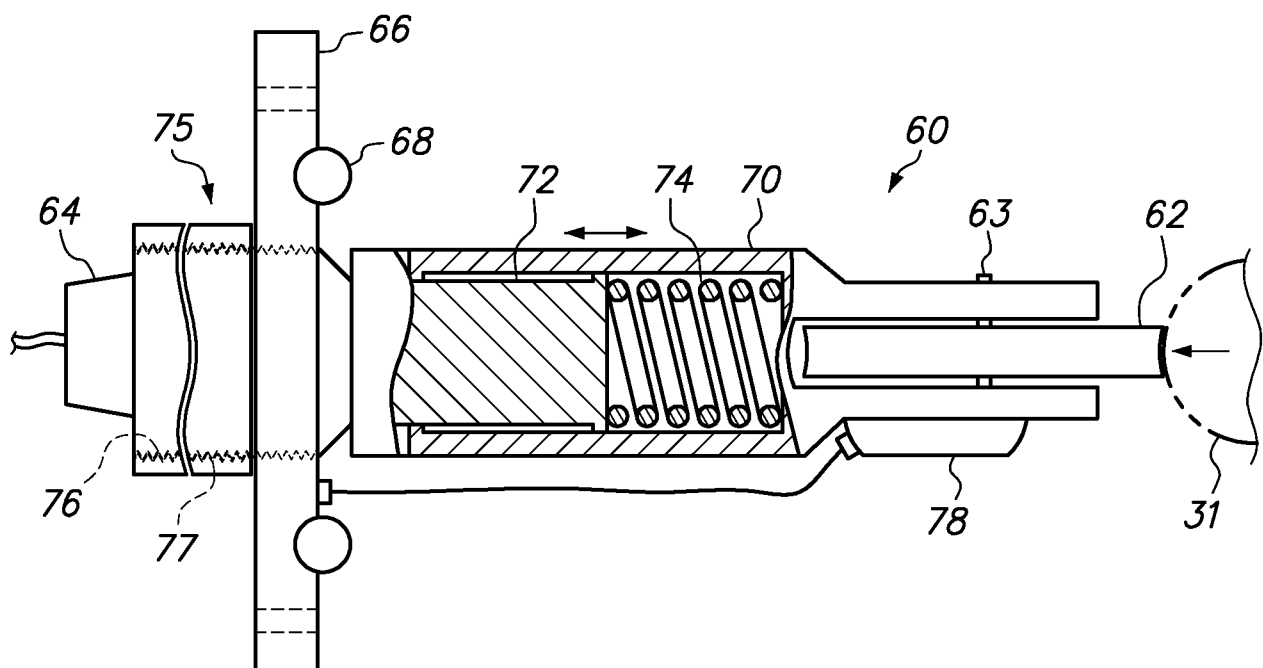
a stripper positioned above the one or more sets of rams and configured for circumferentially engaging the tubular member; and

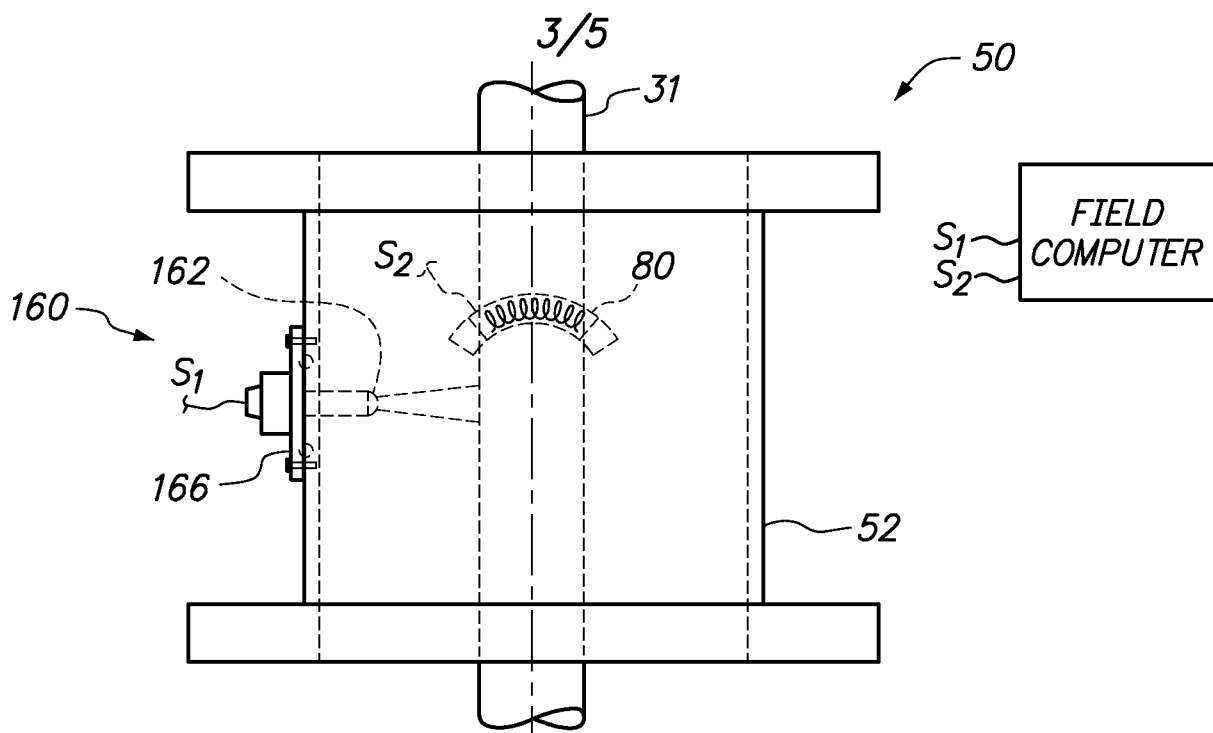
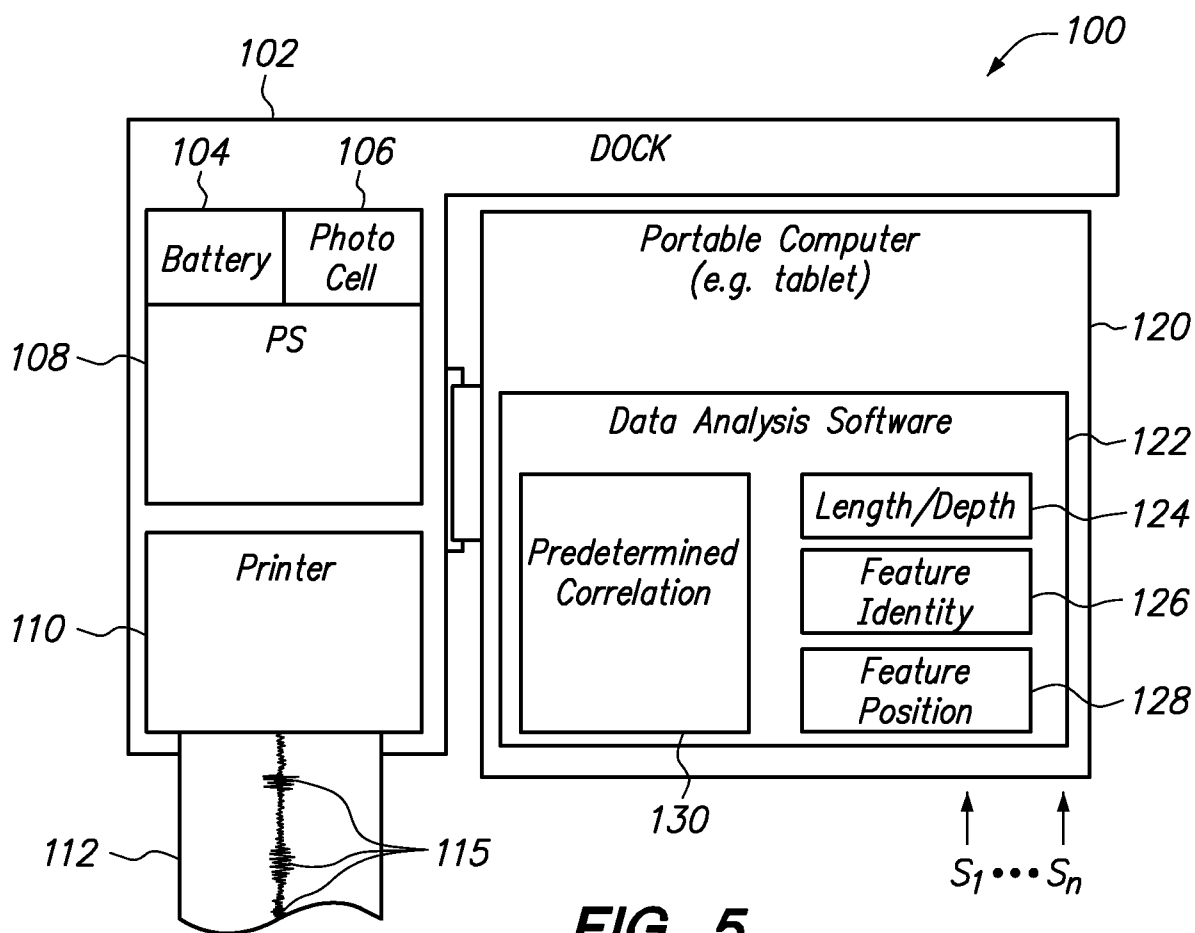
wherein the spool is coupled to the BOP assembly above the one or more sets of rams and below the stripper.

12. A method, comprising:
 - sensing a linear displacement of a tubing string relative to a fixed location of a wellhead apparatus and generating a signal in response to the linear displacement;
 - sensing a change in a cross-sectional parameter of the tubing string in proximity to the fixed location and generating another signal in response thereto; and
 - identifying and locating variations in the cross-sectional property of the tubing string with the sensed linear displacement of the tubing string.
13. The method of claim 12, further comprising:
 - obtaining a well depth of the tubing string according to the sensed linear displacement of the tubing string.
14. The method of claim 12, further comprising:
 - identifying a tubing string component according to the value of the cross-sectional parameter at the location of the tubing string component.
15. The method of claim 14, further comprising:
 - confirming an identified tubing string component or identifying a particular sub-type of the identified tubing string component according to the linear displacement in combination with the cross-sectional parameter.
16. The method of claim 12, further comprising:
 - obtaining a predetermined set of cross-sectional parameters for a plurality of tubing components stored in electronic memory; and
 - comparing the sensed cross-sectional parameter with the predetermined set of cross-sectional parameters to identify a component of the tubing string at the sensed linear displacement.
17. The method of claim 12, further comprising:
 - distinguishing between first and second tubing features according to a difference between the cross-sectional parameters.

18. The method of claim 12, further comprising:
distinguishing between a tubing segment in a tubing string and a tubular component secured to the tubing string according to a difference between the cross-sectional parameters of the tubing segment and the tubular component.
19. The method of claim 18, wherein the tubular component secured to the OD of the tubing string comprises a packer.
20. A computer program product including computer usable program code embodied on a computer usable storage medium, the computer program product comprising:
computer usable program code for receiving a first signal representative of a linear displacement of a tubing string relative to a fixed location of a wellhead apparatus;
computer usable program code for receiving a second signal representative of a cross-sectional parameter of the tubing string in proximity to the fixed location; and
computer usable program code for interpreting the first and second signals to identify and locate variations in the cross-sectional property of the tubing string with the sensed linear displacement of the tubing string.

2/5

**FIG. 2****FIG. 3**

**FIG. 4****FIG. 5**

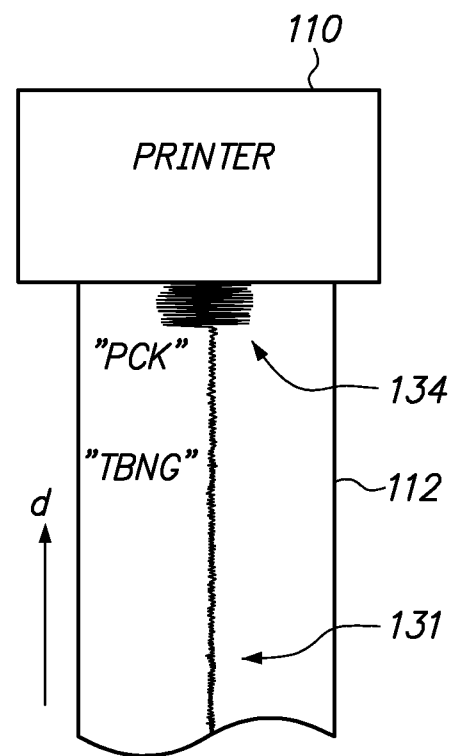
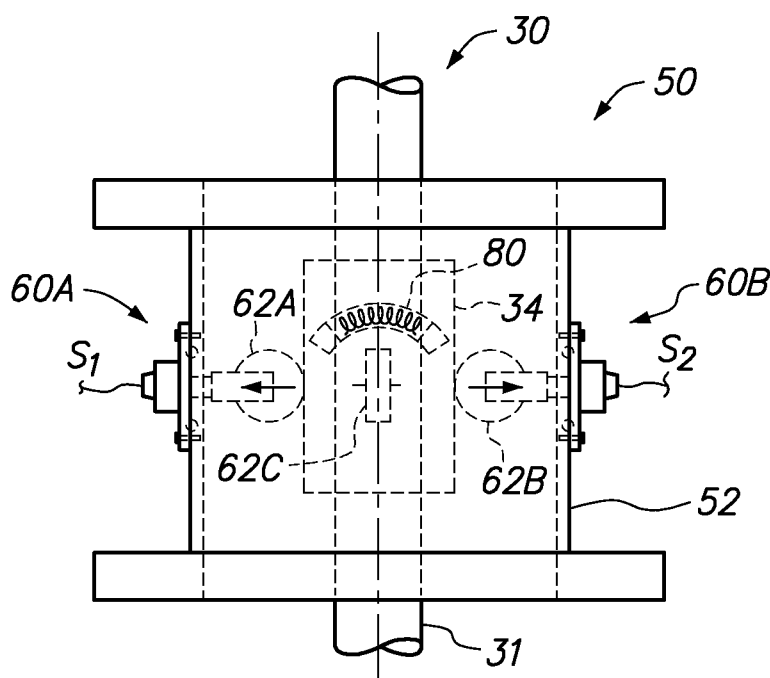
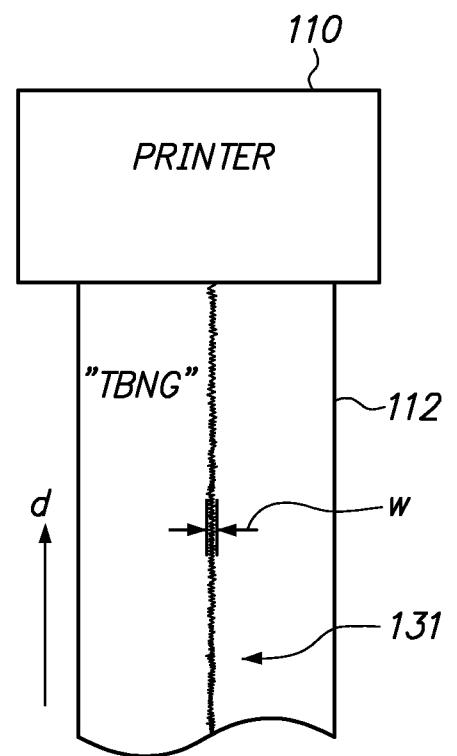
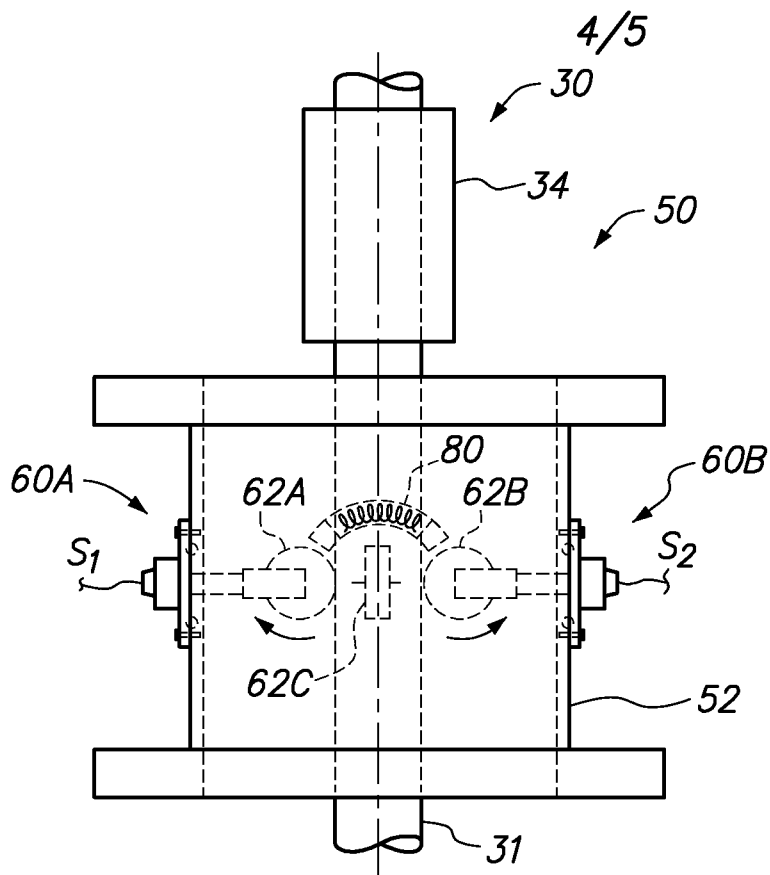
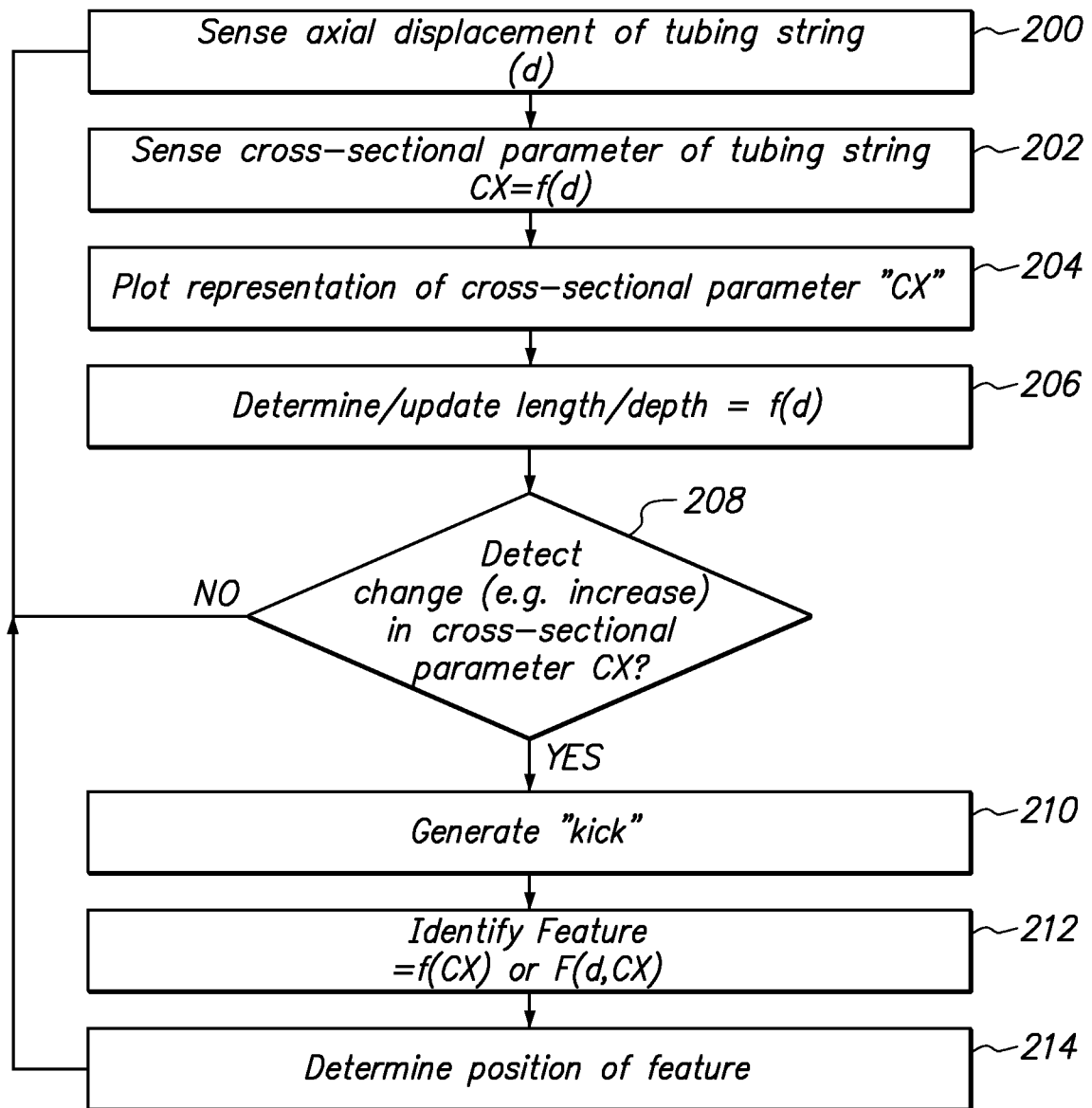


FIG. 7

5/5

**FIG. 8**

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/032005

A. CLASSIFICATION OF SUBJECT MATTER INV. E21B47/04 E21B47/09 E21B47/10 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) E21B G01B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 321 596 B1 (NEWMAN KENNETH R [US]) 27 November 2001 (2001-11-27) abstract figures 1-3 column 2, line 39 - line 65 column 3, line 18 - line 32 column 4, line 13 - line 31 column 5, line 53 - column 6, line 22 column 6, line 51 - line 55 -----	1-3,6-20
X A	EP 1 319 800 A1 (COOPER CAMERON CORP [US]) 18 June 2003 (2003-06-18) abstract figures 1-3,9-11 paragraph [0056] paragraph [0070] - paragraph [0071] ----- -/-	1,6-8, 10,12,20 2-5,9, 11,13-19
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 2 December 2013		Date of mailing of the international search report 10/12/2013
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Hustedt, Bernhard

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/032005

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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