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(54) FATIGUE MONITORING OF COILED TUBING IN DOWNLINE DEPLOYMENTS

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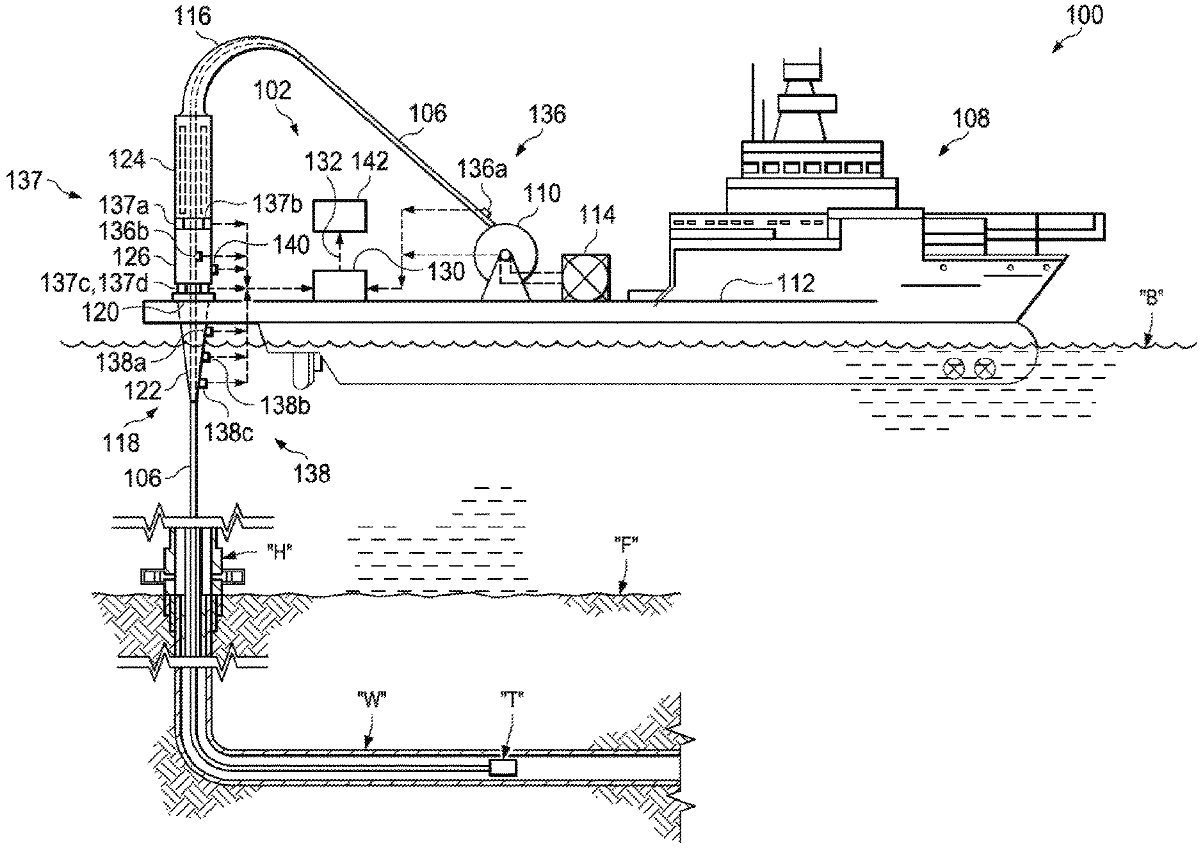
(57) ABSTRACT

Methods for real-time coiled tubing fatigue monitoring can establish a remaining operational life of a coiled tubing strand. Standard or low-cycle plastic fatigue in bending is measured each time the coiled tubing strand is deployed through a guide arch. Also, smaller, but higher frequency loads, e.g., high cycle loads imparted to the coiled tubing strand due to interaction with an oceanic environment, are also measured. A plurality of weight detectors may be coupled to a support frame below the guide for monitoring the high-cycle loads. The remaining operational life of the coiled tubing strand may be calculated based on both the plastic strains using a low-cycle fatigue analysis and the elastic strains using a high-cycle fatigue analysis. An operator may retire a coiled tubing strand prior to failure based on the calculated remaining operational life.



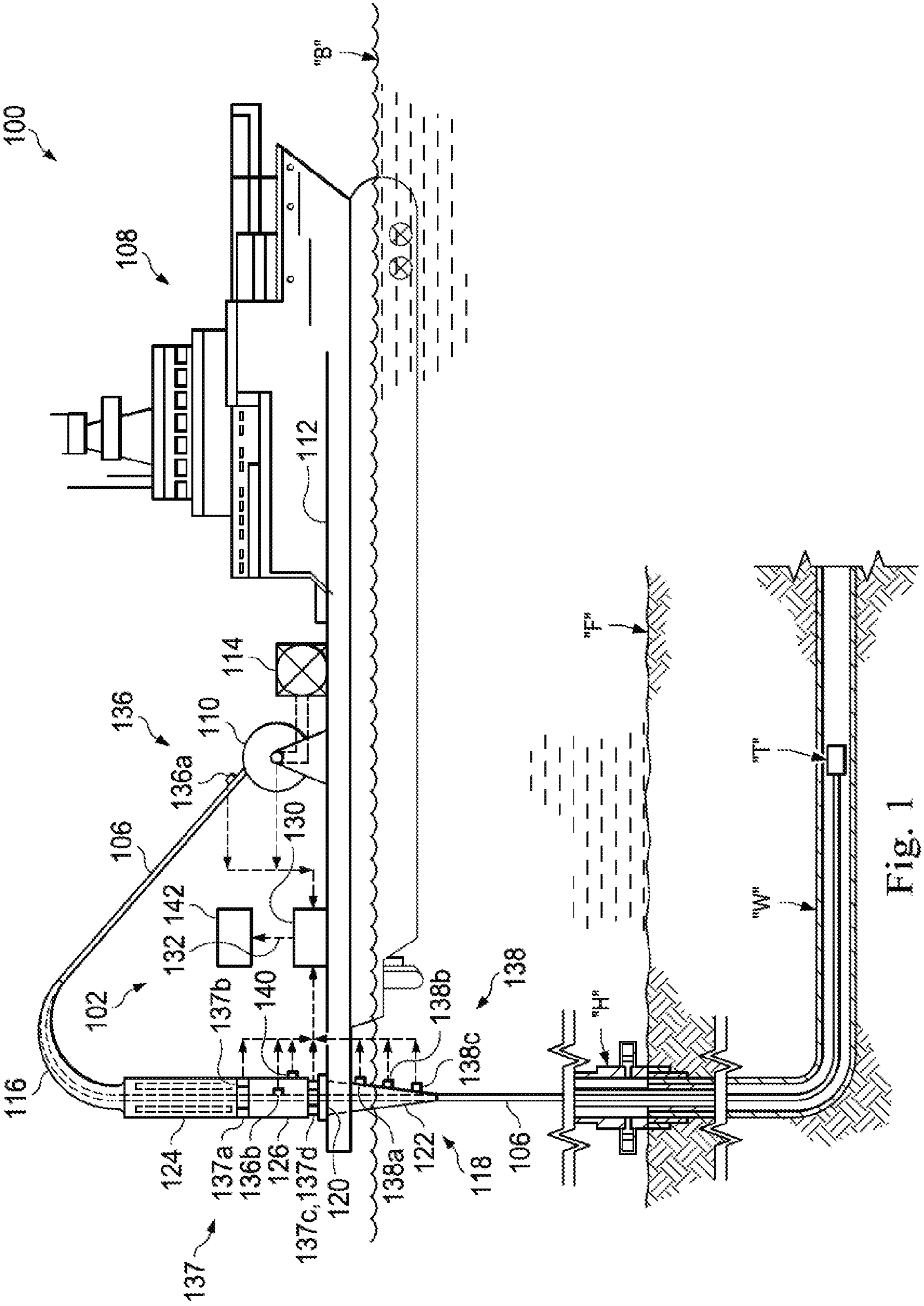

100
108
"B"
112
114
110
136
136a
106
130
142
132
102
140
137b
116
124
137a
136b
126
137c,137d
120
138a
122
118
106
138c
138b
138
"H"
"F"
"T"
"W"
137

Fig. 1

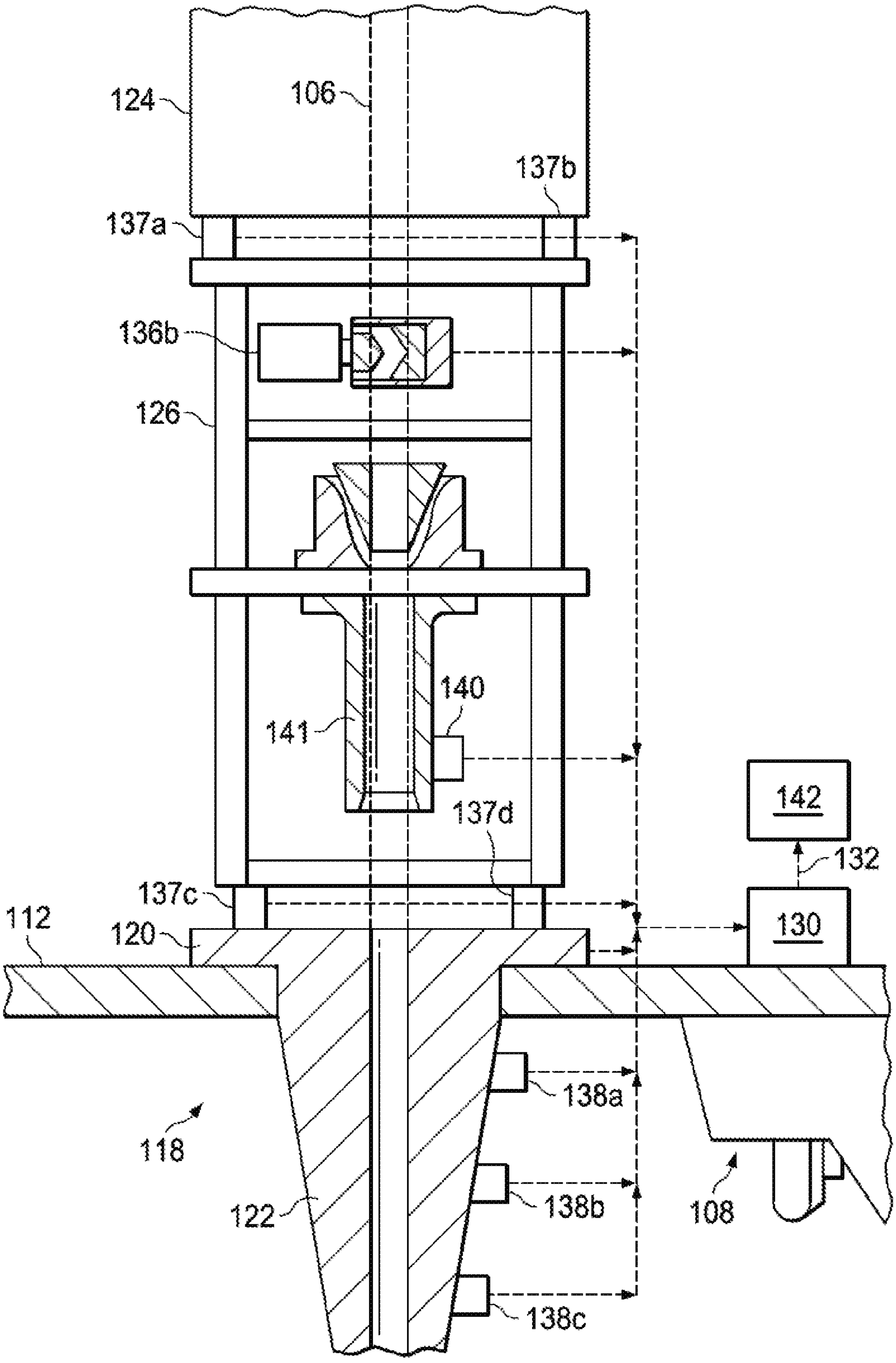

124
106
137b
137a
136b
126
140
141
142
137d
132
137c
112
120
130
138a
118
138b
108
122
138c

Fig. 2

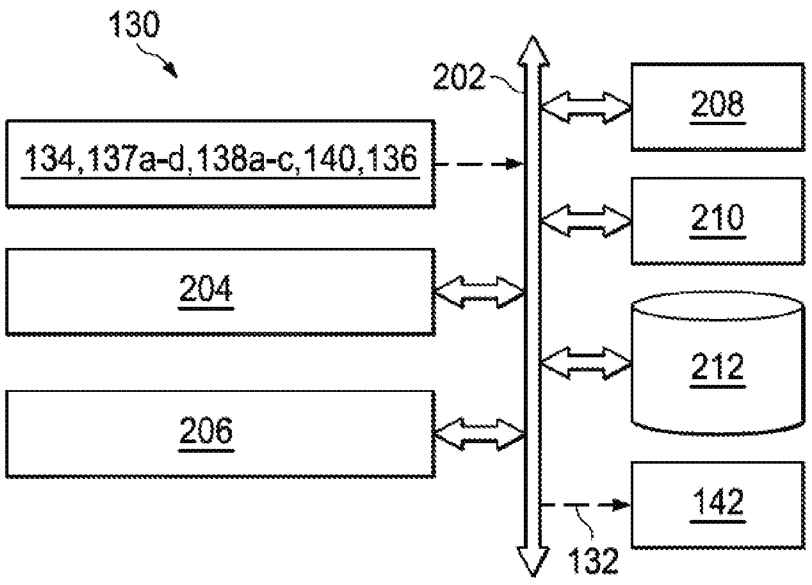


Fig. 3

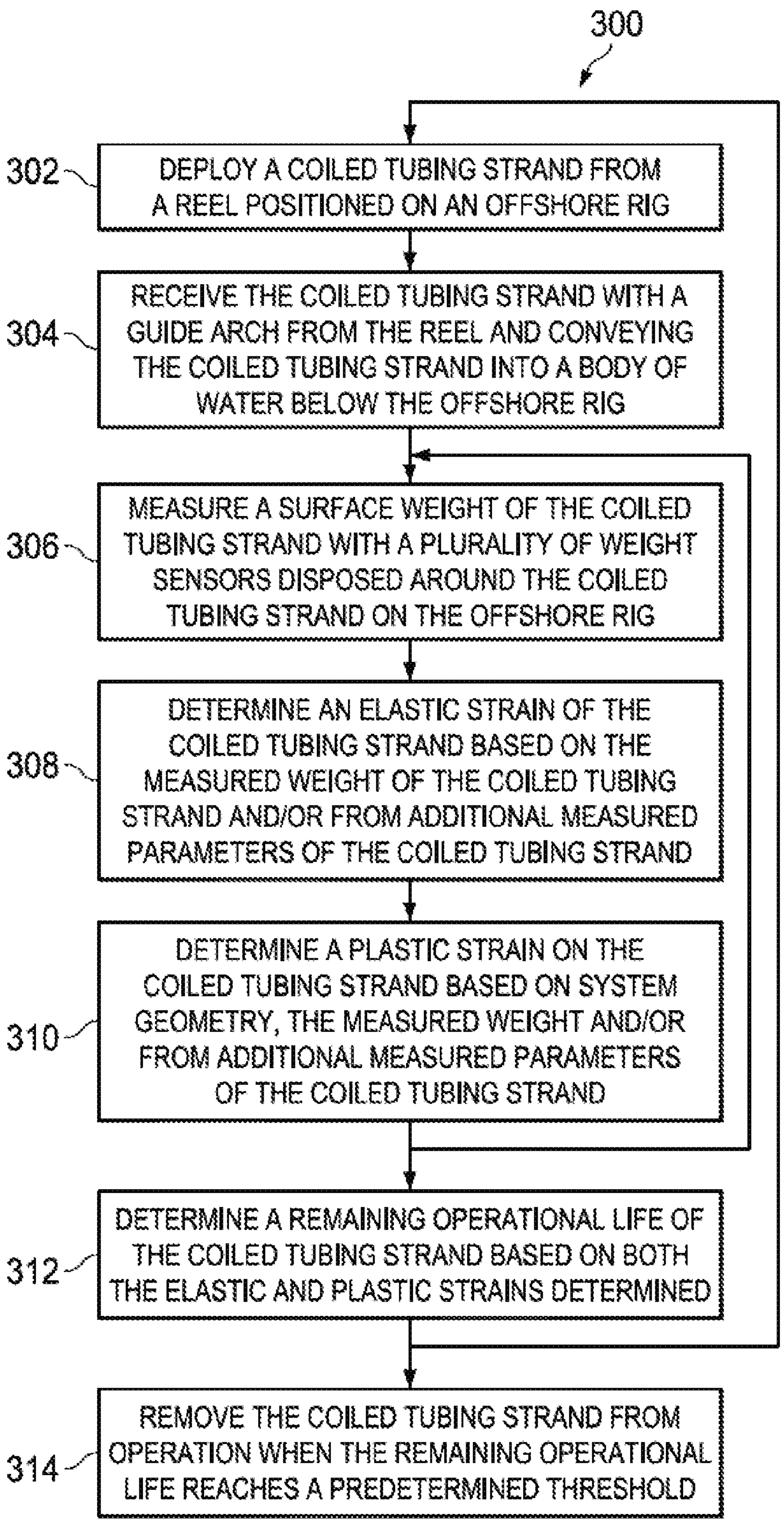

300
302
DEPLOY A COILED TUBING STRAND FROM A REEL POSITIONED ON AN OFFSHORE RIG
304
RECEIVE THE COILED TUBING STRAND WITH A GUIDE ARCH FROM THE REEL AND CONVEYING THE COILED TUBING STRAND INTO A BODY OF WATER BELOW THE OFFSHORE RIG
306
MEASURE A SURFACE WEIGHT OF THE COILED TUBING STRAND WITH A PLURALITY OF WEIGHT SENSORS DISPOSED AROUND THE COILED TUBING STRAND ON THE OFFSHORE RIG
308
DETERMINE AN ELASTIC STRAIN OF THE COILED TUBING STRAND BASED ON THE MEASURED WEIGHT OF THE COILED TUBING STRAND AND/OR FROM ADDITIONAL MEASURED PARAMETERS OF THE COILED TUBING STRAND
310
DETERMINE A PLASTIC STRAIN ON THE COILED TUBING STRAND BASED ON SYSTEM GEOMETRY, THE MEASURED WEIGHT AND/OR FROM ADDITIONAL MEASURED PARAMETERS OF THE COILED TUBING STRAND
312
DETERMINE A REMAINING OPERATIONAL LIFE OF THE COILED TUBING STRAND BASED ON BOTH THE ELASTIC AND PLASTIC STRAINS DETERMINED
314
REMOVE THE COILED TUBING STRAND FROM OPERATION WHEN THE REMAINING OPERATIONAL LIFE REACHES A PREDETERMINED THRESHOLD

Fig. 4

FATIGUE MONITORING OF COILED TUBING IN DOWNLINE DEPLOYMENTS

BACKGROUND

[0001] The present disclosure relates generally to monitoring operational forces imparted to a coiled tubing strand, e.g., a coiled tubing strand employed for oil and gas exploration, drilling and production. More particularly, embodiments of the disclosure relate to systems and methods for real-time monitoring of high-cycle fatigue in the coiled tubing strand.

[0002] In operations related to the production of hydrocarbons from subterranean geologic formations, coiled tubing is often employed to facilitate wellbore drilling, maintenance, treatment, stimulation and other wellbore processes. Coiled tubing generally includes a continuous strand of a flexible tube that may be wound and unwound from a reel. The length of a coiled tubing strand may be in the range of about 100 feet to over 30,000 feet in some instances, and thus, the coiled tubing strand may be unwound from a spool to readily lower a downhole tool to a subterranean and/or subsea location.

[0003] Operational forces may fatigue the coiled tubing strand, which affects the operational life of the coiled tubing strand. Low-cycle fatigue is characterized by high amplitude and low frequency plastic strains, which may be imparted to a coiled tubing strand, e.g., by winding and unwinding the coiled tubing strand from the reel. High-cycle fatigue is characterized by low amplitude and high frequency elastic strains, which may be imparted to a coiled tubing strand, e.g., by waves and ocean currents in an offshore deployment. Both low-cycle fatigue and high-cycle fatigue affect the operational life span of a particular coiled tubing strand.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The disclosure is described in detail hereinafter, by way of example only, on the basis of examples represented in the accompanying figures, in which:

[0005] FIG. **1** is a partially cross-sectional side view of an offshore coiled tubing deployment system including a fatigue tracking system for monitoring high-cycle fatigue and low-cycle fatigue of a coiled tubing strand;

[0006] FIG. **2** is an enlarged view of a data acquisition system of the fatigue tracking system of FIG. **1** illustrating various sensors for detecting operational stresses imparted to the coiled tubing strand;

[0007] FIG. **3** is a block diagram of the data acquisition system of FIG. **2**; and

[0008] FIG. **4** is a flowchart illustrating an operational procedure for monitoring both high-cycle fatigue and low-cycle fatigue of the coiled tubing strand of FIG. **1**.

DETAILED DESCRIPTION

[0009] The present disclosure includes systems and methods for real-time coiled tubing fatigue monitoring that can establish the remaining operational life of a coiled tubing strand. Each time the coiled tubing strand is deployed, the coiled tubing strand incurs standard (low-cycle) plastic fatigue in bending as the coiled tubing string bends from a reel through a guide arch. Also, the coiled tubing strand experiences smaller, but higher frequency loads (high-cycle) that impart elastic strains in the coiled tubing, e.g., due to interaction with an oceanic environment. A plurality of weight detectors may be coupled to a support frame below the guide arch that receives the coiled tubing strand from the reel. Signals provided by the plurality of weight detectors may be monitored to determine the directionality and magnitude of forces that impart elastic strains to coiled tubing strand. The remaining operational life may be calculated based in part on the elastic strains using a high-cycle fatigue analysis. Plastic strains may also be monitored with strain and/or gyroscopic sensors coupled to a tubing guide or to other equipment. The remaining operational life of the coiled tubing strand may be calculated based on both the elastic and plastic strains. As a result, an operator may be provided with an accurate fatigue history file that maps the fatigue assumed by the coiled tubing at any given point along its length.

[0010] FIG. **1** is a partially cross-sectional side view of an offshore coiled tubing deployment system **100** including a fatigue tracking system **102** for monitoring high-cycle and low cycle fatigue of a coiled tubing strand **106**. The coiled tubing deployment system **100** may include or otherwise be used in conjunction with an offshore rig or vessel **108** configured to operate in an offshore environment that includes a body of water "B." In some embodiments, as illustrated, the offshore vessel **108** may comprise a floating service vessel or boat. In other embodiments, however, the offshore vessel **108** may comprise any offshore platform, structure, or vessel used in subsea intervention operations common to the oil and gas industry. The body of water "B" may include, but is not limited to, an ocean, a lake, a river, a stream, or any combination thereof. In other embodiments (not shown), the coiled tubing deployment system **100** may be used in conjunction with an onshore or terrestrial surface reference location.

[0011] The offshore vessel **108** may be used to deploy the coiled tubing strand **106** into a deployed location such as the body of water "B" for various subsea purposes. For example, the coiled tubing string **106** may be deployed for intervention in a subterranean wellbore "W" with a well intervention tool "T." The wellbore intervention tool "T" may be lowered on the coiled tubing strand **106** through a subsea wellhead "H" positioned on the ocean floor "F." In the embodiments illustrated in FIG. **1**, the wellbore intervention tool "T" is employed in a riser-less subsea operation wherein the coiled tubing strand **106** extends directly through the body of water "B." In other embodiments, the coiled tubing strand **106** may extend through a riser (not shown) extending between the offshore vessel **108** and the wellhead "H." In some embodiments, the coiled tubing strand **106** may comprise a conduit or umbilical used to convey fluids or power to the wellhead "H," a submerged platform (not shown), a subsea pipeline (not shown) or to any other subsea location. The coiled tubing strand **106** may be made of a variety of deformable materials including, but not limited to, a steel alloy, stainless steel, titanium, other suitable metal-based materials, thermoplastics, composite materials (e.g., carbon fiber-based materials), and any combination thereof. The coiled tubing strand **106** may exhibit a diameter of about 3.5 inches, but may alternatively exhibit a diameter that is greater or less than 3.5 inches, without departing from the scope of the disclosure.

[0012] The coiled tubing strand **106** may be deployed from a reel **110** positioned on a deck **112** of the offshore vessel **108**. The coiled tubing strand **106** may be wound multiple times around the reel **110** for ease of transport. In some embodiments, a fluid source **114** may be communicably coupled to the coiled tubing strand **106** via a fluid conduit **116**. The fluid source **114** may be configured to convey a pressurized fluid, such as a gas or a liquid, into the coiled tubing strand **106**. The presence and amount of pressure in the coiled tubing strand **106** may affect the mechanical strength of the coiled tubing strand **106**. For instance, depending on whether or not the coiled tubing strand **106** is pressurized, more or less bending may be imparted in the coiled tubing strand **106** during operation. Low fluid pressure will result in a first bending potential, while higher fluid pressure will result in a second bending potential.

[0013] From the reel **110**, the coiled tubing strand **106** may be fed into a guide arch **116**, commonly referred to in the oil and gas industry as a "gooseneck." The guide arch **116** redirects the coiled tubing strand **106** toward an optional tubing guide **118**, which is operatively coupled to the guide arch **116** and fixed to a frame or the deck **112** of the offshore vessel **108**. As used herein, the term "operatively coupled" refers to a direct or indirect coupling engagement between component parts of the coiled tubing deployment system **100**. In some embodiments, for instance, the tubing guide **118** may be directly coupled to the guide arch **116**. In other embodiments, as illustrated, the tubing guide **118** may be indirectly coupled to the guide arch **116** with one or more structural components interposing the tubing guide **118** and the guide arch **116**. The guide arch **116** may comprise a rigid structure that exhibits a known radius. As the coiled tubing strand **106** is conveyed through the guide arch **116**, the coiled tubing strand **106** may be plastically deformed and otherwise re-shaped and re-directed for receipt by the tubing guide **118** located there below.

[0014] The tubing guide **118** may be any device or structure used to convey the coiled tubing strand **106** into the body of water "B." In some embodiments, the tubing guide **118** may comprise a "bend stiffener," for example. In the illustrated embodiment, the tubing guide **118** may include an optional flange **120** and an optional tapering body **122**. The flange may rest on the deck **112** of the offshore vessel **108**, and the tapering body **122** may extend from the flange **120** through the deck **112** of the offshore vessel **108**. In some embodiments, as illustrated, the tapering body **122** may extend to the body of water "B" such that the coiled tubing strand **106** is deployed directly into the body of water "B".

[0015] The flange **120** may operate to support the tubing guide **118** on the offshore vessel **108**, and may also provide a connection location to attach the components located thereabove. Thus, a type of riser is effectively formed for the coiled tubing strand **106**, i.e., the coiled tubing strand **106** extends through components located above the tubing guide and through the tubing guide **118** into the body of water "B". Accordingly, the flange **120** may be characterized as any box-type frame or other structure capable of accomplishing the aforementioned tasks. Moreover, it will be appreciated, that the tubing guide **118** may be alternatively secured to the offshore vessel **108** in a variety of other ways, without departing from the scope of the disclosure. For instance, in some embodiments, the offshore vessel **108** may include a moon pool (not shown) and the tubing guide **118** may be secured to the offshore vessel **108** at or near the moon pool such that the coiled tubing strand **106** is deployed into the body of water "B" through the moon pool.

[0016] The tubing guide **118** may be configured to protect the coiled tubing strand **106** at a critical point of high stress assumed by the coiled tubing strand **106**. The tubing guide **118** may be made of a material similar to that of the coiled tubing strand **106** and, therefore, the tubing guide **118** may be configured to reinforce the mechanical properties (e.g., rigidity) of the coiled tubing strand **106** as the coiled tubing strand **106** traverses the tubing guide **118**. The size of the tubing guide **118**, such as the thickness of the tapering body **122**, may serve to spread critical loads assumed by the coiled tubing strand **106** over the length of the tubing guide **118**, which may help improve the working life of the coiled tubing strand **106**. In some embodiments, the tubing guide **118** may include a liner (not shown) that directly contacts the coiled tubing strand **106** as it passes through the tubing guide **118**. As will be appreciated, this may prove advantageous in preventing the materials of the tubing guide **118** and the coiled tubing strand **106** from abrasive contact against one another.

[0017] In some embodiments, as illustrated, an injector **124** and a support frame **126** may be secured to the offshore vessel **108**, and both the injector **124** and the support frame **126** may interpose the guide arch **116** and the tubing guide **118**. In some embodiments, the support frame **126** may be included to couple the injector **124** to the tubing guide **118**. The injector **124** may be configured to advance or retract the coiled tubing strand **106** during deployment of the coiled tubing strand **106**. In some embodiments, for example, the injector **124** may include a plurality of internal gripping elements or wheels (not shown) configured to engage the outer surface of the coiled tubing strand **106** to either pull the coiled tubing strand **106** from the reel **110** and into the tubing guide **118**, or retract the coiled tubing strand **106** from the body of water "B" to be wound again on the reel **110**. In some embodiments, however, the injector **124** may be omitted. For example, the weight of the coiled tubing strand **106** may instead be relied upon for deployment of the coiled tubing strand into the body of water "B," and the reel **110** may be motorized to retract the coiled tubing strand **106**.

[0018] The support frame **126** may be configured to transfer the weight assumed by the injector **124** to the deck **112** of the offshore vessel **108**. In embodiments where the injector **124** is omitted, the support frame **126** may couple the guide arch **116** to the tubing guide **118** or directly to the deck **112** of the offshore vessel **108**.

[0019] As the coiled tubing strand **106** is unwound from the reel **110** and fed through the guide arch **116** and the tubing guide **118**, it is plastically deformed. This cycled bending is naturally repeated in reverse upon retracting the coiled tubing strand **106** to be wound back around the reel **110**. Moreover, additional forces and bending stresses can be assumed by the coiled tubing strand **106** as it enters the body of water "B," particularly in riser-less subsea applications, as illustrated in FIG. **1**. More particularly, in cases where the body of water "B" is open ocean, subsea currents, ocean heaving, waves, and other dynamic oceanic phenomena can all place strain and bending stress on the coiled tubing strand **106** as it is deployed. Over time, these bend cycles include both plastic and elastic strains in the coiled tubing strand **106**, which may result in considerable fatigue, ultimately affecting the overall operational life of the coiled tubing strand **106**.

[0020] Bending forces assumed by the coiled tubing strand **106** between the reel **110** and the injector **124** can be generally ascertained using known parameters, such as the diameter of the coiled tubing strand **106**, the radius of the guide arch **116**, and the pressure within the coiled tubing strand **106**. Ascertaining the bending forces assumed by the coiled tubing strand **106** at or following the tubing guide **118**, however, can be less certain in view of the unpredictable dynamic environment of the body of water "B," which provides essentially no known variables. According to embodiments of the present disclosure, the bending forces assumed by the coiled tubing strand **106** at or following the tubing guide **118** may be monitored and quantified in real-time and those measurements may be mapped along the length of the coiled tubing strand **106** to determine fatigue life of the coiled tubing strand **106**.

[0021] To monitor the bending and fatigue of the coiled tubing strand **106** in real-time, the fatigue tracking system **102** is provided with the coiled tubing deployment system **100**. The fatigue tracking system **102** may provide a reliable method for establishing and recording, both in real-time and in memory mode, the bending forces that induce both plastic and elastic strains assumed by the coiled tubing strand **106**, e.g., at or near the tubing guide **118** and otherwise in the region between the reel **110** and the body of water "B." As described below, the fatigue tracking system **102** may be configured to record the resultant forces and bending levels encountered by the coiled tubing strand **106** and link those measurements back to the location along the length of the coiled tubing strand **106** where the forces were assumed. As a result, induced fatigue and the corresponding level of bending for each section of the coiled tubing strand **106** run through the coiled tubing deployment system **100** may be established and mapped back into a fatigue history file. Once segments of the coiled tubing strand **106** begin to reach predetermined fatigue limits as based on the fatigue history file, an operator may consider retiring the coiled tubing strand **106** to avoid failure.

[0022] As illustrated, the fatigue tracking system **102** may include a plurality of load cells, sensors and/or other devices, each communicably coupled to a data acquisition system **130**. The data acquisition system **130** is configured to receive and process signals deriving from each load cell, sensor and/or device. The data acquisition system **130** may be a computer system, for example, that includes a memory, a processor, and computer readable instructions that, when executed by the processor, process the sensor signals to provide an output signal **132**. Data corresponding to the construction parameters of the coiled tubing strand **106** may be provided to the data acquisition system **130** for reference. For instance, construction parameters of the coiled tubing strand **106** loaded into the data acquisition system **130** may include material grade, length, outer diameter, and inner diameter of the coiled tubing strand **106**. Additional construction parameters that may be loaded into the data acquisition system **130** include the location of segment welds or joints along the body of the coiled tubing strand **106**. The construction parameters may be used by the data acquisition system **130** as reference points in generating the fatigue history file.

[0023] The fatigue tracking system **102** may further include a pressure transducer or sensor **134** used to measure the real-time pressure within the coiled tubing strand **106** during operation. The pressure sensor **134** may be fluidly coupled to the coiled tubing strand **106** and, more particularly, communicably coupled to the coiled tubing strand **106** at the fluid conduit **116**, which, as mentioned above, provides pressurized fluid into the coiled tubing strand **106** from the fluid source **114**. The real-time pressure detected by the pressure sensor **134** may be transmitted to the data acquisition system **130** for processing. More particularly, the data acquisition system **130** may take into consideration the detected pressure in calculating fatigue on the coiled tubing strand **106** since the internal pressure may affect the mechanical strength of the coiled tubing strand **106**.

[0024] In the illustrated embodiment, the fatigue tracking system **102** may also include one or more depth counters **136***a*, **136***b* (collectively **136**) located at fixed points along the path traversed by the coiled tubing strand **106** through the coiled tubing deployment system **100**. In some embodiments, a first depth counter **136***a* may be located at or immediately after the reel **110**. Additionally or alternatively, a second depth counter **136***b* may be located immediately below the injector **124** and otherwise between the reel **110** and the tubing guide **118**. The depth counters **136***a*, **136***b* may comprise any measurement devices capable of monitoring how much length of the coiled tubing strand **106** is deployed from the reel **110** and bypasses the depth counters **136***a*, **136***b*. In some embodiments, for instance, the depth counters **136***a*, **136***b* may include a depth wheel that physically engages the coiled tubing strand **106** while it turns to register the traversed length of the coiled tubing strand **106**. In some other embodiments, however, the depth counters **136***a*, **136***b* may comprise an optical measurement device, such as a laser sight capable of converting optical images into distance measurements.

[0025] Measurements obtained by the depth counters **136***a*, **136** may be transmitted to the data acquisition system **130** for processing. As will be appreciated, knowing the length of the coiled tubing strand **106** deployed, may allow the data acquisition system **130** to map the coiled tubing strand **106** and correlate specific real-time weight, strain or bend measurements with the precise location where such forces were assumed by the coiled tubing strand **106**. Accordingly, the measured distance or length may be mapped over time and correlated to high-cycle and low-cycle fatigue at known points along the coiled tubing strand **106**, which form part of the fatigue history file.

[0026] FIG. **2** is an enlarged view of the data acquisition system **130** of the fatigue tracking system **102** illustrating various sensors disposed below the guide arch **116** for detecting operational stresses imparted to the coiled tubing strand **106**. With reference to FIG. **2** and continued reference to FIG. **1**, the fatigue tracking system **102** includes one or more load cells, transducers, weight sensors or other weight detectors **137***a*, **137***b*, **137***c* **137***d* (collectively **137**) that may be employed to measure a characteristic value indicative of the real-time surface weight of the coiled tubing strand **106**, e.g., a portion of the weight of the coiled tubing strand **106** carried by the guide arch **116**, during operation of the coiled tubing deployment system **100**. In some embodiments, the characteristic value may include acceleration, deceleration, stress, strain and/or, of course, weight. The weight detectors **137** may be sensitive to real-time changes in mass, acceleration and force on the guide arch **116**, and may be coupled indirectly to the guide arch **116** and/or coiled tubing strand **106**. More particularly, the weight detectors **137** may be coupled to structural components between the guide arch **116** and the deck **110** of the offshore vessel **108** that transfers the weight of the coiled tubing **106** onto the deck **110**. In some embodiments, a first plurality of weight detectors **137***a,* **137***b* are disposed between the injector **124** and the support frame **116**. The weight detectors **137***a,* **137***b* are disposed at distinct locations around the coiled tubing strand **106**, and thus, a directionality of forces imparted to the coiled tubing strand may be determined from the weight detectors **137***a,* **137***b*. Although only two weight detectors **137***a* and **137***b* are illustrated between the injector **124** and the support frame **126**, three or more weight detectors **137** may be disposed in a circular array around the coiled tubing strand **106**. In some embodiments, e.g., embodiments where the injector **124** is omitted, the weight detectors **137** may additionally or alternatively be coupled between the support frame **126** and the deck **112** as illustrated by weight detectors **137***c,* **137***d.*

[0027] Additional or alternative weight detectors **137** may be provided via a mechanism (not shown) that transfers the weight of the coiled tubing strand **106** onto the deck **112** of the offshore vessel **108**. Such a mechanism may comprise, for example, a work window into which a set of slip rams can be used to hold stationary the coiled tubing strand **106** or via a load cell located directly below the guide arch **116**. The real-time weight measurements detected by the weight detector **137** may be transmitted to the data acquisition system **130** for processing and the data acquisition system **130** may take into consideration the detected weight in calculating fatigue on the coiled tubing strand **106**. It has been determined that weight measurements may be particularly indicative of the forces imparting elastic strains to the coiled tubing strand **106**. Weight measurements provided by the weight detectors **137** may also be employed to detect heave and movement of the offshore vessel **108**, thereby permitting the fatigue tracking system **102** to remove or allow for motion effects of the offshore vessel **108** from the weight measurement signals and/or accelerometer signals.

[0028] The fatigue tracking system **102** may optionally include a plurality of bend sensors **138***a*, **138***b,* **138***c* (collectively, bend sensors **138**). A first set of bend sensors **138***a* is located at a first location on the tubing guide **118**. More particularly, the first set of bend sensors **138***a* may be coupled to the tapered body **122** below the flange **120** and may be configured to measure real-time strain assumed by the coiled tubing strand **106** as it is deployed into the body of water "B". The first set of bend sensors **138***a* may include at least one of a strain sensor and a gyroscopic sensor used to determine the strain on the coiled tubing strand **106** at the first location. The highest strain readings and critical bending points for the coiled tubing strand **106** following the guide arch **116** will be at the tubing guide **118** just below the flange **120**. And since the coiled tubing strand **106** may be continuously or continually be moving through the tubing guide **118**, the first set of bend sensors **138***a* may be coupled to the tubing guide **118** at the first location, and the strain measured on the tubing guide **118** may be indicative of the strain assumed by a particular section of the coiled tubing strand **106** as that particular section passes through the first location on the tubing guide. Sensor signals derived from the first set of bend sensors **138***a* may be transmitted to the data acquisition system **130** for processing.

[0029] In some embodiments, the fatigue tracking system **102** may additionally or alternatively include additional bend sensors **138**, illustrated as a second set of bend sensors **138***b* located at a second location on the tubing guide **118**, and a third set of bend sensors **138***c* located at a third location on the tubing guide **118**. The second and third locations may be below the first location and otherwise at locations along the tapered body **122** that exhibit smaller thicknesses as compared to the first location. Similar to the first set of bend sensors **138***a,* the first and/or second sets of bend sensors **138***b,* **138***cc* may include at least one of a strain sensor and a gyroscopic sensor used to determine the strain on the coiled tubing strand **106** at the second and third locations, respectively. As will be appreciated, the bending assumed by the coiled tubing strand **106** may be more severe or pronounced nearer the end of the tubing guide **118**. The second and third sets of bend sensors **138***b,* **138***c* may be configured to detect and report this resultant movement. Sensor signals derived from the second and third sets of bend sensors **138***b,* **138***c* may be transmitted to the data acquisition system **130** for processing. As will be appreciated, the length of the tubing guide **118** may vary from project to project and, as a result, the number of sets of bend sensors **138***a-c* may also vary for optimization. Moreover, since the obtained data will be recorded and matched to known segments or intervals of the coiled tubing strand **106**, an increased number of locations to collect data points along the tubing guide **118** may enable increased accuracy.

[0030] In some embodiments, the fatigue tracking system **102** may further include a set of reference sensors **140** located at generally stationary position with respect to the deck **112** of the offshore vessel **108**, e.g., at a point on the support frame **126** just above the tubing guide **118**, or otherwise above the anticipated critical bending point in the coiled tubing strand **106**. The reference sensors **140** may include a strain sensor, an accelerometer, and/or a weight detector to monitor and detect heave and movement of the surface vessel **102** during operation. Sensor signals derived from the reference sensors **140** may be transmitted to the data acquisition system **130** for processing. As illustrated, the reference sensors **140** are depicted as being coupled to the support frame **126**. However, the reference sensors **140** may alternatively be coupled at any fixed point above the tubing guide **118** and below the guide arch **116**, without departing from the scope of the disclosure. In some embodiments, a strain sensor of the reference sensors **140** may be located between the guide arch **116** and the tubing guide **118**, while an accelerometer and/or weight detectors (not shown) of the reference sensors **140** may be fixedly attached to the deck **112** of the offshore vessel **108**, or at another location remote from the strain sensor **108** to detect the heave and movement of the offshore vessel **108** during operation.

[0031] Referring to FIG. **2**, the reference sensors **140** are illustrated as being positioned on a spool riser **141** coupled to the support frame **126** above the tubing guide. The support frame **126** is depicted as interposing the injector **124** and the tubing guide **118**, and, according to one or more embodiments, the support frame **126** may operate as a work window and thereby facilitate access to the coiled tubing strand **106** and reference sensors **140**. In some embodiments, the fatigue tracking system **102** may include multiple sets of reference sensors **140**, without departing from the scope of the disclosure. In some embodiments, the fatigue tracking system **102** may include multiple sets of sensors **137**, but have no injector **124**, without departing from the scope of the disclosure.

[0032] The measurements obtained by the reference sensors **140** may provide a control point or offset that may be applied to the measurements obtained by the weight detectors **137** and/or bend sensors **138**. More particularly, the data acquisition system **130** may apply the measurements derived from the reference sensors **140** to the measurements derived from the weight detectors **137** and bend sensors **138** to remove the effects of motion of the offshore vessel **108** and the effects of forces and strains imparted to the coiled tubing strand at locations remote from the weight detectors **137** and bend sensors **138**. Accordingly, in some embodiments, the data acquisition system **130** may process the sensor signals derived from the weight detectors **137** and bend sensors **138** in view of reference measurements derived from the reference sensors **140**.

[0033] Each of the sensors **134**, **137**, **138**, **140** and the depth counter **136** may be communicably coupled to the data acquisition system **130** and configured to transmit corresponding measurements thereto in real-time via any known means of telecommunication or data transmission. In some embodiments, for instance, the data acquisition system **130** may be physically wired to one or more of the sensors **134**, **137**, **138**, **140** and the depth counter **136**, e.g., through electrical or fiber optic lines. In other embodiments, one or more of the sensors **134**, **137**, **138**, **140** and the depth counter **136** may be configured to wirelessly communicate with the data acquisition system **130**, such as via electromagnetic telemetry, acoustic telemetry, ultrasonic telemetry, radio frequency transmission, or any combination thereof.

[0034] In some embodiments, as illustrated, the data acquisition system **130** may be arranged at or near the offshore vessel **108**. In other embodiments, the data acquisition system **130** may be remotely located and the sensors **134**, **137**, **138**, **140** and the depth counter **136** may be configured to communicate remotely with the data acquisition system **130** (either wired or wirelessly). The data acquisition system **130** may be configured to receive and process the various signals from the sensors **134**, **137**, **138**, **140** and the depth counter **136** in conjunction with the construction parameters of the coiled tubing strand **106**. The relative distances between the sensors **134**, **137**, **138**, **140** and the depth counter **136** may also be used as configurable parameters within the data acquisition system **130** in generating the output signal **132**.

[0035] The output signal **132** may comprise real-time elastic and plastic bending data corresponding to specific locations along the length of the coiled tubing strand **106**. In some embodiments, such data may be stored for future reference or consideration. In other embodiments, however, the output signal **132** may be transmitted to a peripheral device **142** for consideration and/or review by an operator in real-time. The peripheral device **142** may include, but is not limited to, a monitor (e.g., a display, a GUI, a handheld device, a tablet, etc.), a printer, an alarm, additional storage memory, etc. In some embodiments, the peripheral device **142** may be configured to provide the operator with a graphical output or display that charts or maps the length of the coiled tubing strand **106** versus estimated fatigue on the coiled tubing strand **106** at any given location. Accordingly, given that fatigue life of the coiled tubing strand **106** is largely a matter of repeated usage, the data acquired by the data acquisition system **130** may be stored and historically tied to the specific coiled tubing strand **106** and thereby form part of the fatigue history file corresponding to the coiled tubing strand **106**.

[0036] FIG. **3** is a block diagram of the data acquisition system **130**. With reference to FIG. **3**, and continued reference to FIG. **1**, the data acquisition system **130** may include a bus **202**, a communications unit **204**, one or more controllers **206**, a non-transitory computer readable medium (i.e., a memory) **208**, a computer program **210**, and a library or database **212**. The bus **202** may provide electrical conductivity and a communication pathway among the various components of the data acquisition system **130**. The communications unit **204** may employ wired or wireless communication technologies, or a combination thereof. The communications unit **204** can include communications operable among land locations, sea surface locations both fixed and mobile, and undersea locations both fixed and mobile. The computer program **210** may be stored partially or wholly in the memory **208** and, as generally known in the art, it may be in the form of microcode, programs, routines, or graphical programming.

[0037] The bus **202** is communicatively coupled to the sensors **134**, **137**, **138**, **140** and the depth counters **136** such that the data acquisition system **130** may receive and sample one or more signals derived from the sensors **134**, **137**, **138**, **140** and the depth counters **136**. The controller **206** may be configured to transfer the sensor signals to the memory **208**, which may encompass at least one of volatile or non-volatile memory. The computer program **210** may be configured to access the memory **208** and process the sensor signals in real-time. In some embodiments, however, the sensor signals may be logged or otherwise stored in the memory **208** or the database **212** for post-processing review or analysis.

[0038] In processing the sensor signals, the computer program **210** may be configured to digitize the sensor signal and generate digital data. The computer program **210** may employ pre or post-acquisition processing by applying one or more signal amplifiers and/or signal filters (e.g., low, medium, and/or high-pass frequency filters) in hardware or software. In some embodiments, the computer program **210** may be configured to output the acquired signal in the time domain, thereby providing a time domain output. In another embodiment, the computer program **210** may also be capable of transforming and outputting the digital data in the frequency domain, thereby providing a frequency domain output. This transformation into the frequency domain may be accomplished using several different frequency-based processing methods including, but not limited to, fast Fourier transforms (FFTs), short-time Fourier transforms (STFTs), wavelets, the Goertzel algorithm, or any other domain conversion methods or algorithms known by those skilled in the art. In some embodiments, one or both of the time domain and frequency domain signals may be filtered using at least one of a low-pass filter, a medium-pass filter, and a high-pass filter or other types of filtering techniques, without departing from the scope of the disclosure.

[0039] The computer program **210** may further be configured to query the database **212** for stored data corresponding to construction parameters of the coiled tubing strand **106** and relative distances between the sensors **134**, **137**, **138**, **140** and the depth counters **136**. Upon querying the database **212**, the computer program **210** may be able to apply the construction parameters and relative distances to the measured signals. The computer program **210** may then deliver the output signal **132** comprising real-time, elastic strain and plastic strain bending data corresponding to specific locations along the length of the coiled tubing strand **106**. In some cases, as indicated above, the output signal **132** may be provided to the peripheral device **142** for display. In other embodiments, or in addition thereto, the data acquired by the data acquisition system **130** may be stored and historically tied to the fatigue history file corresponding to the coiled tubing strand **106**.

[0040] FIG. **4** is a flowchart illustrating an operational procedure **300** for monitoring both high-cycle fatigue and low-cycle fatigue of the coiled tubing strand **106**. Referring to FIG. **4**, and with continued reference to FIGS. **1-3**, the operational procedure **300** begins at step **302** where the coiled tubing strand **106** is deployed from the reel **110** on the offshore vessel **108**. The coiled tubing strand **106** is received over the guide arch **116** and is conveyed into the body of water "B" below the offshore vessel **108** (step **304**). In some embodiments, the coiled tubing strand **106** may be conveyed directly through the body of water "B" and into a wellbore "W" to support a wellbore intervention tool "T" therein.

[0041] Next, at step **306**, a surface weight of the coiled tubing **106**, e.g., a real-time weight of the coiled tubing strand **106** carried by the guide arch **116**, is measured with a plurality of weight detectors **137** disposed around the coiled tubing strand **106**. The measured surface weight has been determined to be a more reliable indicator of elastic strain than other measurable parameters related to the deployment of the coiled tubing strand **106**. Thus, an elastic strain of the coiled tubing strand **106** is determined, estimated or calculated based on the measured weight of the coiled tubing strand **106** (step **308**). A directionality of the elastic strain imparted to the coiled tubing strand **106** may be determined from the measurement of the surface weight from a plurality of weight detectors **137** disposed at distinct locations surrounding the coiled tubing strand **106**. The elastic strain may be determined, estimated or calculated based on the measured weight of the coiled tubing strand, and/or from additional measured parameters of the coiled tubing strand. For example, measurements from bend sensors **138** may be more indicative of elastic strains than the measurements of the weight detectors **137**. Thus, the bend sensors **138** may be additionally or alternatively employed to determine the elastic strains.

[0042] At step **310**, a plastic strain on the coiled tubing strand **106** may be determined from a combination of the geometries of the components of the offshore coiled tubing deployment system **100** (known or measured) together with parameters measured by the fatigue tracking system **102**. For example, the known radius associated with the guide arch **116**, the dimensions of the reel **110**, and the known geometry of the coiled tubing strand **106** stored on the reel **110** may be used together with the internal pressure inside the coiled tubing strand **106** measured by the pressure sensor **134**, the measurements of the weight detectors **137** and/or bend sensors **138** to determine the plastic strain.

[0043] Steps **306-310** may be continuously or continually repeated throughout a deployment of the coiled tubing strand **106**. A fatigue history file that maps the fatigue assumed by the coiled tubing at any given point along its length may be generated for the particular deployment, and the fatigue history file may be associated with the particular coiled tubing strand **106**.

[0044] A remaining operational life of the coiled tubing strand **106** based on both the elastic and plastic strains may be determined (step **312**). The remaining life may be determined at any point in the procedure **300**, and not necessarily at the end of a particular deployment. If it is determined that the remaining operational life is above a predetermined threshold, the procedure may return to step **302** for an additional deployment of the coiled tubing strand **106**. When it is determined that the remaining operational life has reached or fallen below a predetermined threshold, the procedure **300** may advance to step **314** where the coiled tubing strand **106** is removed from operation and retired.

[0045] The aspects of the disclosure described below are provided to describe a selection of concepts in a simplified form that are described in greater detail above. This section is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0046] In one aspect, the disclosure is directed to a method of evaluating a coiled tubing strand. The method includes (a) deploying the coiled tubing strand from a reel positioned at a surface reference location, (b) receiving the coiled tubing strand with a guide arch positioned on surface reference location and conveying the coiled tubing strand below the surface reference location, (c) measuring one or more characteristic values indicative of a weight of the coiled tubing strand carried by the guide arch with at least one weight detector disposed between the guide arch and the surface reference location, thereby generating one or more weight measurement signals, (d) receiving the one or more weight measurement signals with a data acquisition system communicably coupled to the at least one weight detector, (e) processing the one or more weight measurement signals with the data acquisition system to estimate an elastic strain imparted to the coiled tubing strand, and (f) generating an output signal with the data acquisition system indicative of real-time bending fatigue of the coiled tubing strand based on the elastic strain estimated from the one or more weight measurement signals.

[0047] In one or more example embodiments, measuring the characteristic values indicative of the weight of the coiled tubing strand further includes measuring the characteristic value with a plurality of weight detectors disposed at distinct fixed locations with respect to the surface reference location. In some embodiments, the surface reference location is a deck of an offshore vessel, and the method further includes detecting heave and movement of the offshore vessel and allowing for motion effects of the offshore vessel in at least one of the weight measurement signals, an accelerometer signal and a reference sensor signal received with the data acquisition system.

[0048] In another aspect, the disclosure is directed to a method of evaluating a coiled tubing strand. The method includes (a) deploying the coiled tubing strand from a reel positioned on an offshore vessel, (b) receiving the coiled tubing strand with a guide arch positioned on the offshore vessel and conveying the coiled tubing strand into a body of water below the offshore vessel, (c) measuring a weight of the coiled tubing strand with at least one weight detector disposed on the offshore vessel, thereby generating one or more weight measurement signals, (d) receiving the one or more weight measurement signals with a data acquisition system communicably coupled to the at least one weight detector, (e) processing the one or more weight measurement signals with the data acquisition system to determine an elastic strain imparted to the coiled tubing strand, and (f) generating an output signal with the data acquisition system indicative of real-time bending fatigue of the coiled tubing strand based on the elastic strain determined from the one or more weight measurement signals.

[0049] In one or more example embodiments, measuring the weight of the coiled tubing strand further includes measuring the weight of the coiled tubing strand with a plurality of weight detectors disposed at distinct fixed locations with respect to a deck of the offshore vessel. Processing the one or more weight measurement signals may further include determining a directionality of the elastic strain imparted to the coiled tubing strand with weight measurement signals received from the plurality of weight detectors.

[0050] In some embodiments, the method further includes measuring a real-time elastic strain assumed by the coiled tubing strand with one or more bend sensors, thereby generating one or more bend sensor signals. Generating the output signal may further include generating the output signal based on both the one or more weight measurement signals and the elastic strain measured by the one or more bend sensors.

[0051] The method, in some embodiments, further includes detecting heave and movement of the offshore vessel and allowing for motion effects of the offshore vessel in at least one of the weight measurement signals, and accelerometer signal and a reference sensor signal received with the data acquisition system. The heave and movement of the offshore vessel may be detected with the at least one weight detector, and/or with a reference sensor. The method may further include determining a remaining operational life of the coiled tubing strand, and may include removing the coiled tubing strand from operation if the remaining operational life of the coiled tubing strand is below a predetermined threshold.

[0052] In another aspect, the disclosure is directed to a coiled tubing deployment system. The system includes a reel positioned on a surface reference location and coiled tubing strand wound on the reel. A guide arch is positioned on the surface reference location to receive the coiled tubing from the reel and to direct the coiled tubing strand into a deployed location. At least one weight detector is positioned between the guide arch and the surface reference location. The at least one weight detector is operable to measure one or more characteristic values indicative of a surface weight of the coiled tubing strand and operable to generate one or more weight measurement signals. A data acquisition system is communicably coupled to the at least one weight detector to receive and process the one or more weight measurement signals to determine an elastic strain imparted to the coiled tubing strand. The data acquisition system is further operable to generate an output signal indicative of real-time bending fatigue of the coiled tubing strand based on the elastic strain determined from the one or more weight measurement signals.

[0053] In one or more example embodiments, the at least one weight detector includes a plurality of weight detectors disposed at distinct fixed locations with respect to the surface reference location. The system may further include an injector coupled between the guide arch and surface reference location, and weight detectors of the plurality of weight detectors are disposed in array beneath the injector. In some embodiments, the surface reference location is the deck of an offshore vessel and the deployed location is a body of water on to which the offshore vessel is deployed. The system may further include a wellhead disposed within the body of water, and the coiled tubing strand may extend directly through the body of water between the wellhead and the offshore vessel without a riser.

[0054] In another aspect, the disclosure is directed to a coiled tubing deployment system. The system includes an offshore vessel having a reel positioned thereon and coiled tubing strand wound on the reel. The offshore vessel is deployable on a body of water. A guide arch is positioned on the offshore vessel to receive the coiled tubing from the reel and to direct the coiled tubing strand through a deck of the offshore vessel and into the body of water. The system also includes at least one weight detector positioned between the guide arch and the deck of the offshore vessel; the at least one weight detector operable to measure a surface weight of the coiled tubing strand and operable to generate one or more weight measurement signals. A data acquisition system is communicably coupled to the at least one weight detector to receive and process the one or more weight measurement signals to determine an elastic strain imparted to the coiled tubing strand. The data acquisition system is further operable to generate an output signal indicative of real-time bending fatigue of the coiled tubing strand based on the elastic strain determined from the one or more weight measurement signals.

[0055] In one or more exemplary embodiments, the at least one weight detector includes a plurality of weight detectors disposed at distinct fixed locations with respect to a deck of the offshore vessel. The system may optionally include an injector coupled between the guide arch and the deck of the offshore vessel, wherein the plurality of weight detectors are disposed in array beneath the injector. In some embodiments, the system further includes at least one bend sensor operable to measure a strain in the coiled tubing strand and to generate a bend sensor signal indicative of the elastic strain imparted to the coiled tubing strand. The data acquisition system may be operable to determine a real-time bending fatigue of the coiled tubing strand based on both a plastic strain calculated at least in part based on the geometries of the reel and guide arch and the elastic strain determined by the data acquisition system based on at least one of the at least one weight measurement signal and the strain measured by the at least one bend sensor.

[0056] In some embodiments the system further includes a wellhead disposed within the body of water. The coiled tubing strand may extend directly through the body of water in a riser-less manner between the wellhead and the offshore vessel.

[0057] In other aspects of the disclosure is directed to a method of evaluating a remaining operational life of a coiled tubing strand. The method includes (a) deploying the coiled tubing strand from a reel positioned on a surface reference location, (b) measuring at least one characteristic value indicative of a surface weight of the coiled tubing strand with at least one weight detector, (c) determining an elastic strain imparted to the coiled tubing strand based on the surface weight of the coiled tubing strand, and (d) estimating the remaining operational life of the coiled tubing strand based on the elastic strain imparted to the coiled tubing strand.

[0058] In some embodiments, the method further includes measuring the at least one characteristic value at a plurality of fixed locations on the surface reference location with the at least one weight detector. The method may further include injecting the coiled tubing strand into a body of water with an injector disposed on an offshore vessel, and the plurality of fixed locations may be disposed between the injector and a deck of the offshore vessel.

[0059] In other aspects, the disclosure is directed to a method of evaluating a remaining operational life of a coiled tubing strand. The method includes (a) deploying the coiled tubing strand from a reel positioned on an offshore vessel, (b) measuring a surface weight of the coiled tubing strand with at least one weight detector disposed on the offshore vessel, (c) determining an elastic strain imparted to the coiled tubing strand based on the surface weight of the coiled tubing strand, and (d) estimating the remaining operational life of the coiled tubing strand based on the elastic strain imparted to the coiled tubing strand.

[0060] In some exemplary embodiments, the method further includes measuring the surface weight of the coiled tubing strand at a plurality of fixed locations on the offshore vessel with the at least one weight detector. The method may further include injecting the coiled tubing strand into the body of water with an injector, and the plurality of fixed locations may be disposed between the injector and a deck of the offshore vessel.

[0061] The method, in some embodiments, further includes determining a plastic strain imparted to the coiled tubing strand. Estimating the remaining operational life of the coiled tubing strand may further include estimating the remaining operational life of the coiled tubing strand based on both the plastic strain and the elastic strain imparted to the coiled tubing strand. In some exemplary embodiments, the method may further include measuring an elastic strain imparted to the coiled tubing strand, and estimating the remaining operational life of the coiled tubing strand further comprises estimating the remaining operational life of the coiled tubing strand based on both the elastic strain measured and the elastic strain determined based on the surface weight of the coiled tubing strand. Measuring the elastic strain imparted to the coiled tubing strand may include measuring a stain on the coiled tubing strand with at least one bend sensor disposed on a tubing guide extending below a deck of the offshore vessel.

[0062] The Abstract of the disclosure is solely for providing the United States Patent and Trademark Office and the public at large with a way by which to determine quickly from a cursory reading the nature and gist of technical disclosure, and it represents solely one or more examples.

[0063] While various examples have been illustrated in detail, the disclosure is not limited to the examples shown. Modifications and adaptations of the above examples may occur to those skilled in the art. Such modifications and adaptations are in the scope of the disclosure.

What is claimed is:

1. A method of evaluating a coiled tubing strand, the method comprising:

deploying the coiled tubing strand from a reel positioned on a surface reference location;

receiving the coiled tubing strand with a guide arch positioned on the surface reference location and conveying the coiled tubing strand below the surface reference location;

measuring one or more characteristic values indicative of a weight of the coiled tubing strand carried by the guide arch with at least one weight detector disposed between the guide arch and the surface reference location, thereby generating one or more weight measurement signals;

receiving the one or more weight measurement signals with a data acquisition system communicably coupled to the at least one weight detector;

processing the one or more weight measurement signals with the data acquisition system to estimate an elastic strain imparted to the coiled tubing strand; and

generating an output signal with the data acquisition system indicative of real-time bending fatigue of the coiled tubing strand based on the elastic strain estimated from the one or more weight measurement signals.

2. The method according to claim **1**, wherein measuring the one or more characteristic values further comprises measuring the characteristic values with a plurality of weight detectors disposed at distinct fixed locations with respect to a surface reference location.

3. The method according to claim **2**, wherein processing the one or more weight measurement signals further comprises determining a directionality of the elastic strain imparted to the coiled tubing strand with weight measurement signals received from the plurality of weight detectors.

4. The method according to claim **1**, further comprising measuring a real-time elastic strain assumed by the coiled tubing strand with one or more bend sensors, thereby generating one or more bend sensor signals.

5. The method according to claim **4**, wherein generating the output signal further comprises generating the output signal based on both the one or more weight measurement signals and the elastic strain measured by the one or more bend sensors.

6. The method according to claim **1**, wherein the surface reference location comprises a deck of an offshore vessel, and wherein the method further comprises detecting heave and movement of the offshore vessel and allowing for motion effects of the offshore vessel in at least one of the weight measurement signals, an accelerometer signal and a reference sensor signal received with the data acquisition system.

7. The method according to claim **6**, wherein the heave and movement of the offshore vessel are detected with the at least one weight detector.

8. The method according to claim **1**, further comprising estimating a remaining operational life of the coiled tubing strand and removing the coiled tubing strand from operation if the remaining operational life of the coiled tubing strand is below a predetermined threshold.

9. A coiled tubing deployment system, comprising:

a reel positioned on a surface reference location and coiled tubing strand wound on the reel;

a guide arch positioned on the surface reference location to receive the coiled tubing from the reel and to direct the coiled tubing strand into a deployed location;

at least one weight detector positioned between the guide arch and the surface reference location, the at least one weight detector operable to measure one or more characteristic values indicative of a surface weight of the coiled tubing strand and operable to generate one or more weight measurement signals; and

a data acquisition system communicably coupled to the at least one weight detector to receive and process the one or more weight measurement signals to determine an elastic strain imparted to the coiled tubing strand, the data acquisition system further operable to generate an output signal indicative of real-time bending fatigue of the coiled tubing strand based on the elastic strain determined from the one or more weight measurement signals.

10. The system according to claim **9**, wherein the at least one weight detector comprises a plurality of weight detectors disposed at distinct fixed locations with respect to the surface reference location.

11. The system according to claim **10**, further comprising an injector coupled between the guide arch and surface reference location, wherein the plurality of weight detectors are disposed in array beneath the injector.

12. The system according to claim **9**, further comprising at least one bend sensor operable to measure a strain in the coiled tubing strand and to generate a bend sensor signal indicative of the elastic strain imparted to the coiled tubing strand.

13. The system according of claim **12**, wherein the data acquisition system is operable to determine a real-time bending fatigue of the coiled tubing strand based on both a plastic strain calculated at least in part based on the geometries of the reel and guide arch and the elastic strain determined by the data acquisition system based on at least one of the at least one weight measurement signal and the strain measured by the at least one bend sensor.

14. The system according to claim **9**, wherein the surface reference location comprises the deck of an offshore vessel and wherein the deployed location comprises a body of water on to which the offshore vessel is deployed, and wherein the system further comprises a wellhead disposed within the body of water, and wherein the coiled tubing strand extends directly through the body of water between the wellhead and the offshore vessel without a riser.

15. A method of evaluating a remaining operational life of a coiled tubing strand, the method comprising:

deploying the coiled tubing strand from a reel positioned on a surface reference location;

measuring at least one characteristic value indicative of a surface weight of the coiled tubing strand with at least one weight detector;

determining an elastic strain imparted to the coiled tubing strand based on the surface weight of the coiled tubing strand; and

estimating the remaining operational life of the coiled tubing strand based on the elastic strain imparted to the coiled tubing strand.

16. The method according to claim **15**, further comprising measuring the at least one characteristic value at a plurality of fixed locations on the surface reference location with the at least one weight detector.

17. The method according to claim **16**, further comprising injecting the coiled tubing strand into a body of water with an injector disposed on an offshore vessel, and wherein the plurality of fixed locations are disposed between the injector and a deck of the offshore vessel.

18. The method according to claim **15**, further comprising determining a plastic strain imparted to the coiled tubing strand, and wherein estimating the remaining operational life of the coiled tubing strand further comprises estimating the remaining operational life of the coiled tubing strand based on both the plastic strain and the elastic strain imparted to the coiled tubing strand.

19. The method according to claim **17**, further comprising measuring an elastic strain imparted to the coiled tubing strand, and wherein estimating the remaining operational life of the coiled tubing strand further comprises estimating the remaining operational life of the coiled tubing strand based on both the elastic strain measured and the elastic strain determined based on the surface weight of the coiled tubing strand.

20. The method according to claim **19**, wherein measuring the elastic strain imparted to the coiled tubing strand includes measuring a stain on the coiled tubing strand with at least one bend sensor disposed on a tubing guide extending below a deck of the offshore vessel.

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