(12) UK Patent Application (19) GB (11) 2597978 (13) A

(43) Date of A Publication 16.02.2022

(21) Application No: 2012637.1

(22) Date of Filing: 13.08.2020

(71) Applicant(s):
Aker Solutions AS
Postboks 94, Lysaker 1325, Norway

(72) Inventor(s):
Joakim Martens
Victor Grennberg
Geir Ivar Holberg
Arve Tvitekkja

(74) Agent and/or Address for Service:
ZACCO Norway AS
The Surrey Technology Centre,
The Surrey Research Park, Guildford, Surrey,
GU2 7YG, United Kingdom

(51) INT CL:
E21B 47/007 (2012.01) ***E21B 17/04*** (2006.01)

(56) Documents Cited:
EP 2954155 A2
WO 2016/023068 A1
US 20060065401 A1
WO 2016/166505 A1
US 7165612 B2

(58) Field of Search:
INT CL **E21B**

(54) Title of the Invention: **Method of monitoring the loading of a subsea production system**
Abstract Title: **Method of monitoring loading and condition in a coupling between two bodies**

(57) A method of monitoring the condition of a connector between two bodies e.g. umbilicals, jumpers or subsea workover components 100. The method comprises installing the connector 18 to join adjacent bodies 130, 140, 150 and using a connector sensor output and a numerical model to determine a measured force of one or both bodies, the degree of relative body movement or the connector condition. The numerical model is obtained by applying a known magnitude test force to a test element secured to the connector or a test connector, recording the sensor output with the test force applied for a plurality of test forces and using the obtained data to create a numerical model relating the output from the sensor assembly to the force on the test element. The sensors may be strain gauges or pressure sensors which feed a subsea storage 34a. A statistical representation of the model derived from a multivariat analysis may be used in a subsea processor 36a to provide real time failure warning and a full version of the model at the subsea processor or at a topsides processor 36b may provide a long term detailed, e.g. fatigue, analysis.

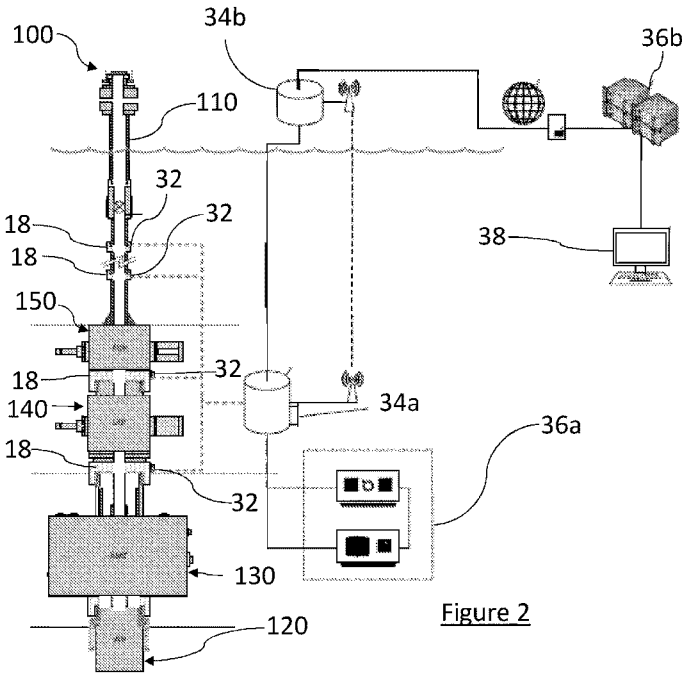


Figure 2

GB 2597978 A

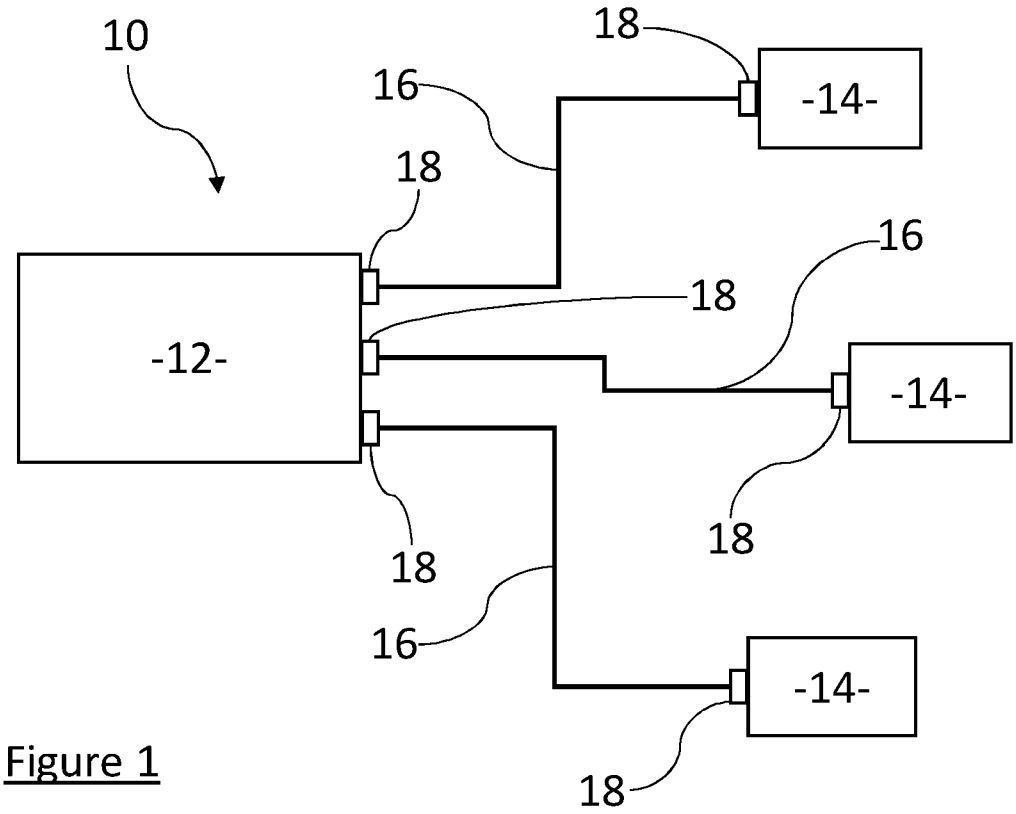


Figure 1

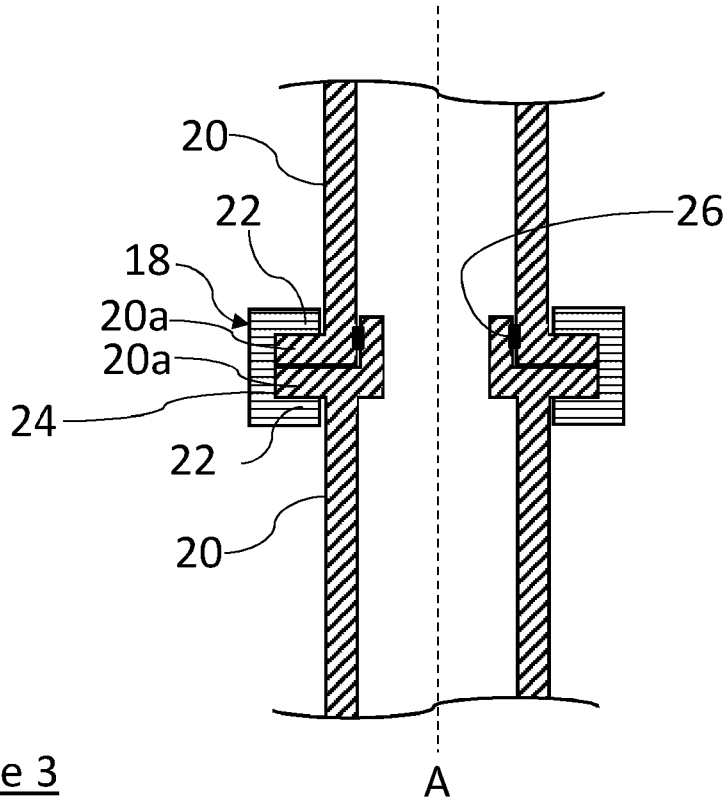


Figure 3

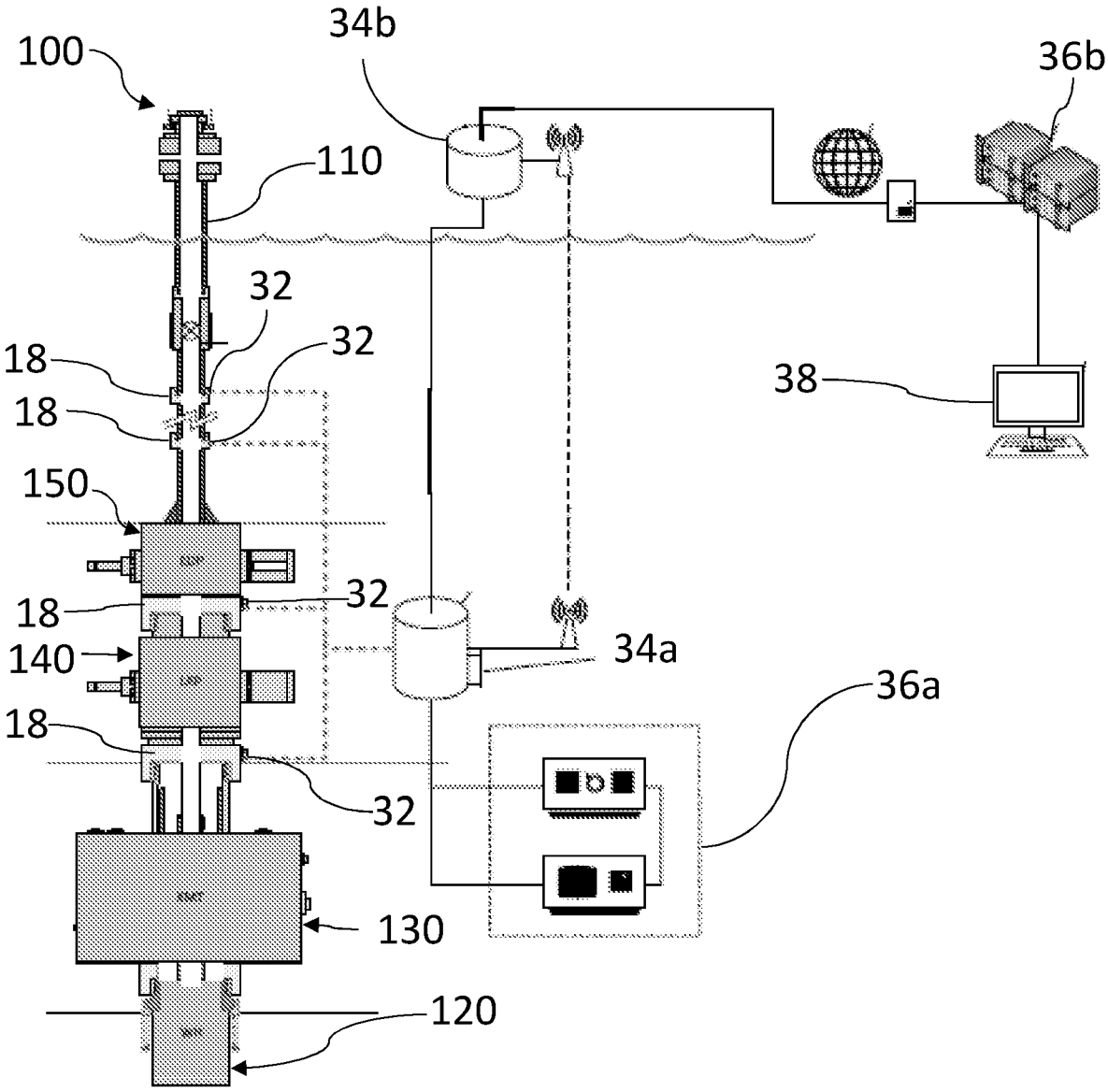


Figure 2

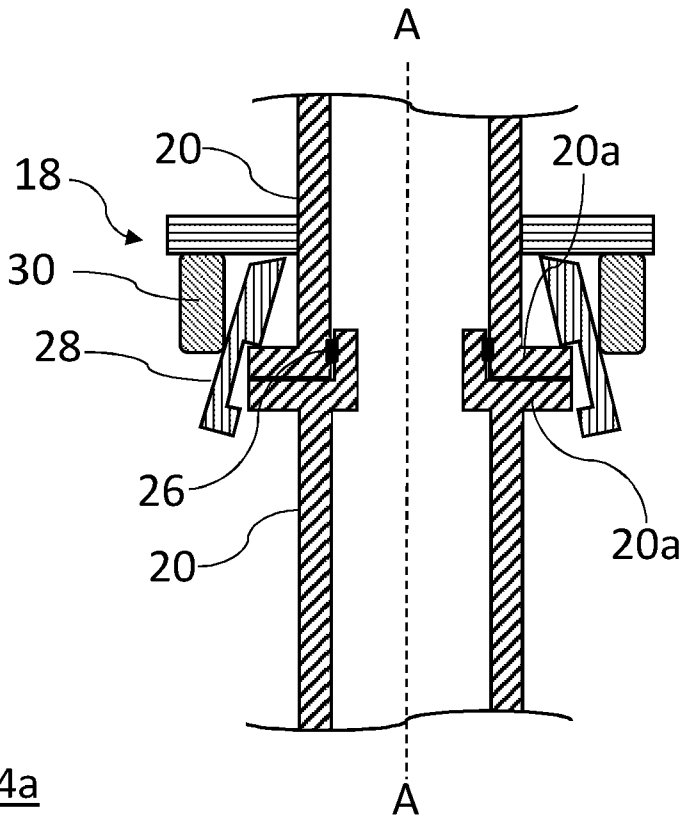


Figure 4a

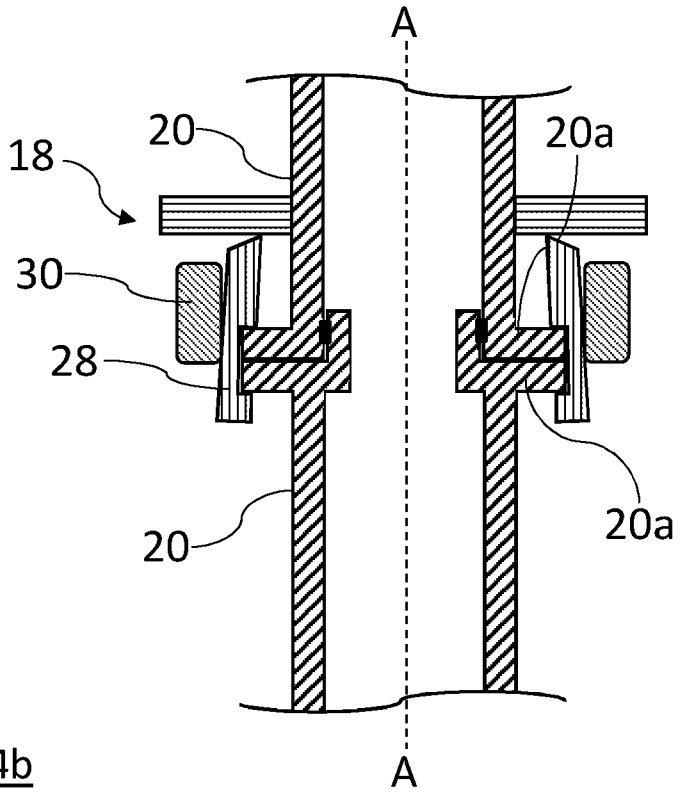


Figure 4b

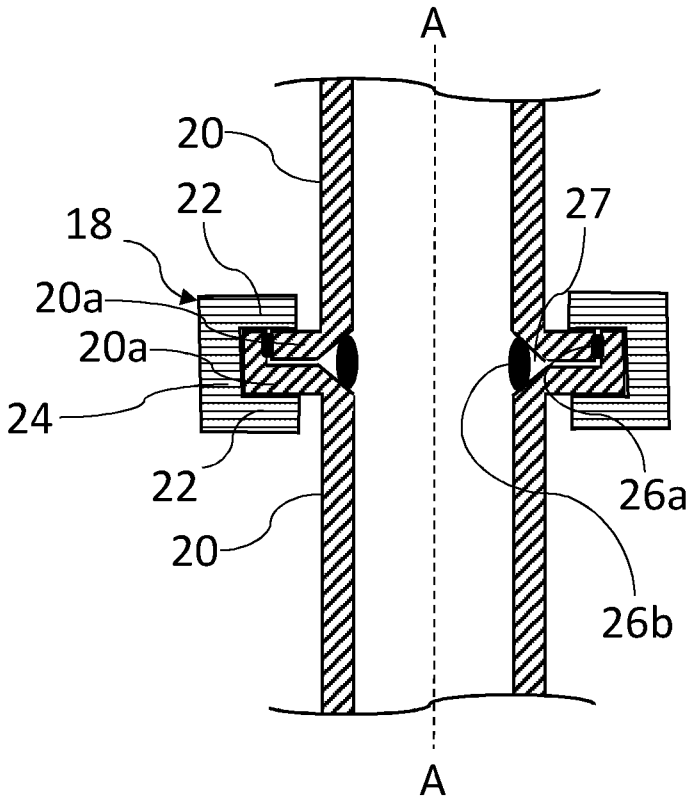


Figure 5

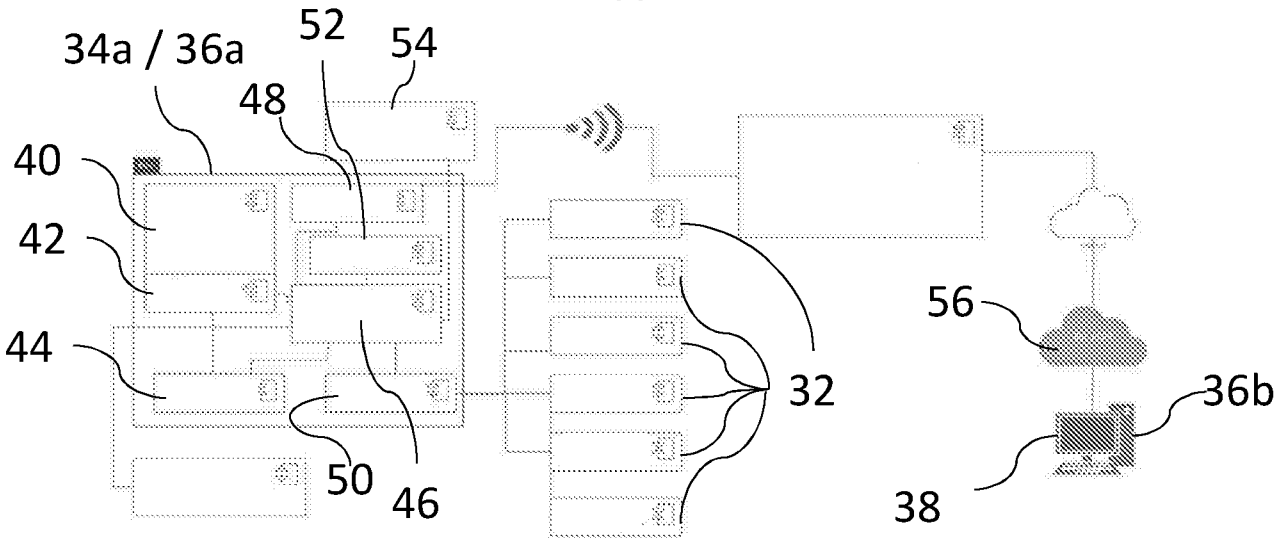


Figure 6

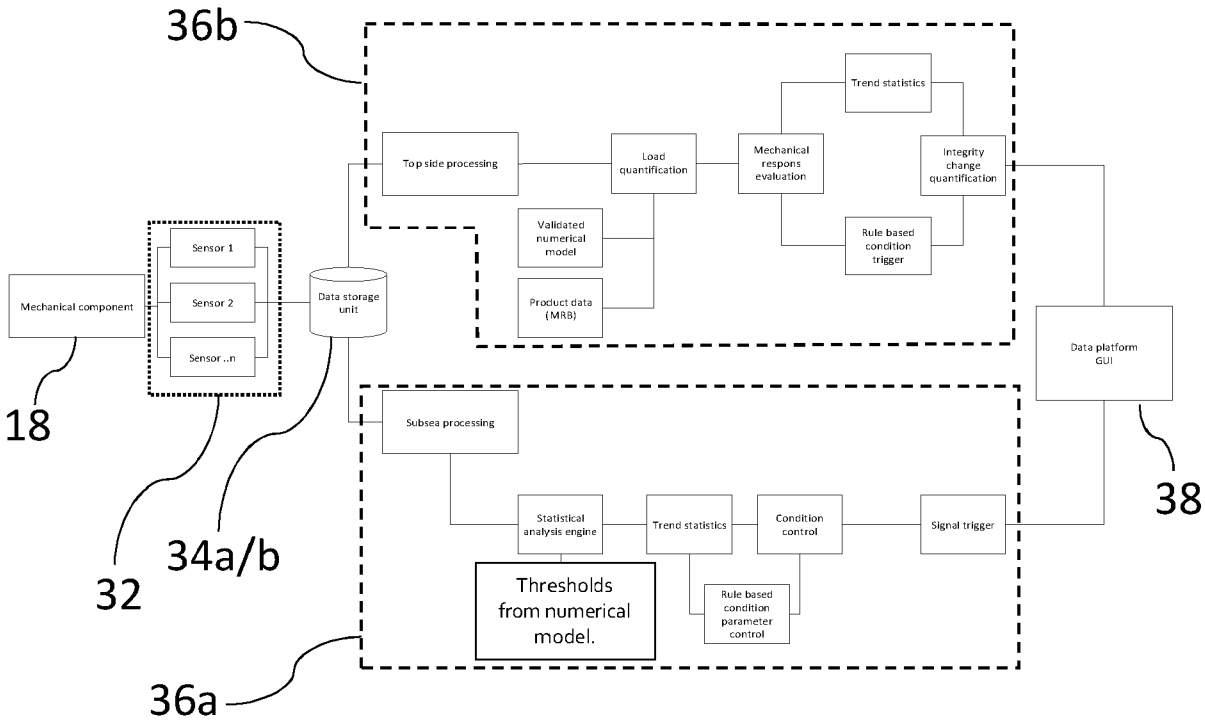

36b
Trend statistics
Top side processing
Load quantification
Mechanical respons evaluation
Integrity change quantification
Validated numerical model
Rule based condition trigger
Product data (MRB)
Sensor 1
Sensor 2
Sensor ..n
Mechanical component
Data storage unit
Data platform GUI
18
Subsea processing
Statistical analysis engine
Trend statistics
Condition control
Signal trigger
38
32
34a/b
Thresholds from numerical model.
Rule based condition parameter control
36a

Figure 7

Method of Monitoring the Loading of a Subsea Production System

The present invention relates to a method of monitoring the loading of a subsea production system or workover system including at least two modules connected together by piping.

A subsea production system, typically comprises several modules connected together with piping. For example, it might comprise a manifold module which is connected to a satellite module via a length of piping known as a flowline jumper. The satellite module could be a subsea tree, Pig launcher/receiver, pipeline end termination, pipeline end manifold, riser base, UTH, pump & control system module or a subsea storage unit. Each end of the piping is connector to its respective module using a tie-in connector. Such connectors may also be used to connect the ends of adjacent sections of piping.

Various configuration of connectors are known to be used in these applications including clamp, integral collet and non-integral collet connectors. An integral connector includes a mechanical actuation mechanism which is operable to lock the two parts to be connected together, the actuation mechanism being integral with or non-releasably secured to one of the two parts. In a non-integral connector, the actuation mechanism can be removed from both the two parts.

It is required to provide a sealing mechanism which ensures that fluid flowing along the pipeline cannot leak out at the connection to the adjacent part. The seal could be provided between the connector and the two parts which are connected together, or directly between the two parts, the connector simply serving to hold the two parts together and energise the seal.

The piping may extend between modules on the sea floor, and thus extend generally horizontally. Alternatively, in a workover system, piping may form a rigid connection between a manifold module on a rig or vessel and a subsea wellhead. In this case, the piping thus forms a generally vertical riser which provides for well access for performing completion and / or workover operations on subsea oil and gas wells.

In use, the piping may be subject to external loading, and this could affect the reliability of the system. Where the piping is connected to a module provided on a floating rig or vessel, the swell of the ocean can cause significant movement of the rig or vessel and this causes dynamic loads to be applied to the piping. Waves and sea current can also load the piping directly. The loads on the piping may also be transferred to the subsea satellite module or wellhead. In extreme cases, this loading could damage the piping itself, either as a one-off event or through fatigue damage caused by repeated loading cycles, and compromise the integrity of the connector and/or the seal between the piping and the part to which it is connected. As such, it is advantageous to quantify the loads

experienced by piping, and to use this information in numerical modelling in order to ascertain the mean time to fail, or the operational window of the pipeline, or to establish if further testing of the system is required.

It is known to monitor the forces on a pipeline using strain gauges mounted on the pipe itself. This does not, however, provide a measure of the actual response of the mechanical assembly (non linear response), but rather an applied load from static pipe section equation.

Other prior art load monitoring systems include EP 2,954,155, which discloses a method and associated system of estimating loads on a subsea component such as a wellhead system, subsea tree, emergency disconnect package or lower riser package based on measurements performed in at least two positions / sections in the lower part of a riser connected to the subsea component. The lower part of the riser is provided with at least two sensors which measure the tension/bending moment and/or the inclination, displacement of two different parts of the lower part of the riser. A further sensor is mounted on the emergency disconnect package or lower riser package which measures the inclination or acceleration of this part of the system. The readings from these three sensors are used to analyse the loading of the riser and associated subsea component.

US2006/065401 discloses a riser monitoring assembly for use on a riser which extends between a lower marine riser package mounted on a well head, to a floating vessel. It comprises two riser measurement modules including gyroscopes and linear accelerometers which are mounted at discrete locations adjacent the top and/or bottom of the riser. The system is also provided with a wellhead measurement instrument module which is mounted on a rigid portion of the lower marine riser package to provide a measurement of the wellhead inclination, and a vessel measurement instrument module 121 which is mounted on a rigid portion of the vessel to measure the vessel angle of inclination and heading. The signals from these instrument modules are processed to determine, in real time, the relative position and orientation of the lower, upper and medial portions of the riser, and, with a riser model determiner, used to determine a model of the riser representing its real-time shape. It is also specified that this data can be used to determine the stress in and loading of sections of the riser, and hence fatigue in the riser. Measurements of the vibrations in the riser can also be used in this stress determination.

It is an object of the invention to provide an alternative method of monitoring the integrity of a system including at least two tubular elements which are connected by a connector.

According to a first aspect of the invention we provide a method of monitoring the condition of a connection between two bodies connected using a connector, there being a sensor assembly

mounted on or integrated with the connector, the sensor assembly being operable to provide an output representing the degree of movement of one or both of the bodies to which the connector is secured, wherein the method comprises the steps of

a) installing the connector and bodies in a use position in which the connector joins the two bodies,
b) comparing the output from the sensor assembly with a numerical model to determine a measured force on the one or both of the bodies, and/or the condition of the connector, the numerical model having been obtained by testing the connector or a test connector having the same configuration as the connector by applying a test force of known magnitude to a test element secured to the connector / test connector, recording the output from the sensor assembly whilst the test force is applied, repeating this process for a plurality of test forces, and using the data relating the output from the sensor assembly to the force on the test element thus obtained to create the numerical model.

The method may comprise issuing a warning if the measured force exceeds a predetermined threshold level.

The sensor assembly may provide an output representing one or both of the strain of the connector body and displacement of one of the bodies relative to the connector.

The method may further comprise the steps of, over time, using the measured forces determined from readings from the sensor assembly at a plurality of different times to obtain an indication of the cumulative force on the connector, and issuing a warning when the cumulative force exceeds a predetermined cumulative threshold.

The predetermined threshold level may vary in a predetermined manner depending on the cumulative force on the connector.

The sensor assembly may comprise a strain gauge mounted on the connector body.

The sensor assembly may comprise a displacement sensor which is configured to measure linear or angular displacement of one of the bodies relative to the connector body.

The bodies may be fluid flow bodies, and arranged in step a such that the connector and fluid flow bodies enclose a continuous flow passage which extends from one fluid flow body to the other.

There may be a two seals which provide a barrier to fluid flow out of the flow passage – a primary seal which provides a first barrier preventing leakage of fluid out of the flow passage at the joint

between the two fluid flow bodies, and a secondary seal which provides an additional barrier to leakage of fluid from the flow passage past the primary seal in the event that the primary seal fails, there being a seal cavity between the two seals and the two fluid flow bodies or between the two seals, one or both of the fluid flow bodies and the connector. In this case, the sensor assembly may comprise a pressure sensor which measures the pressure of fluid in the seal cavity. Alternatively, the sensor assembly may comprise a displacement sensor which is configured to measure movement of a piston in a cylinder which is fluidly connected to the seal cavity.

One of the bodies may have a longitudinal axis and the test force may be applied generally parallel to the longitudinal axis at the connection between the two bodies. Alternatively, or additionally the test force may be a bending moment applied generally perpendicular to the longitudinal axis at the connection between the two bodies.

One or both of the bodies may be a section of pipeline.

One or both of the bodies may be one of the following: a manifold, a riser, a flow spool, and emergency disconnect package, a subsea tree, a Christmas tree adapter connector, a well control package, a Pig launcher/receiver, a pipeline end termination, a pipeline end manifold, a riser base, a UTH, a pump & control system module, or a subsea storage unit.

According to a second aspect of the invention we provide a subsea system comprising a two bodies connected using a connector, the connector comprising a sensor assembly, the sensor assembly being operable to provide an output signal representing the degree of movement of one or both of the bodies to which the connector is secured, a data storage apparatus which is connected to and stores output signals from the sensor assembly, a processor which is connected to the data storage apparatus and which is configured to use an output signal from the sensor assembly and a numerical model to determine a measured force on one or both of the bodies, and/or the condition of the connector, the numerical model relating the output from the sensor assembly to the force on the test element and having been obtained by testing the connector or a test connector having the same configuration as the connector by applying a test force of known magnitude to a test element secured to the connector / test connector, recording the output from the sensor assembly whilst the test force is applied, repeating this process for a plurality of test forces, and using the data thus obtained to create the numerical model.

The processor may be configured to compare an output signal from the sensor assembly with the numerical model to determine the load on one or both of the bodies.

The processor may be configured to compare output signals from the sensor assembly at a plurality of different times with the numerical model to obtain a data set representing the loading of one of the bodies over time.

The processor may be at a topside location.

The processor may be a subsea processor and be configured to compare an output signal from the sensor assembly with a statistical representation of the numerical model to determine if the loading on one of the bodies has reached a threshold level.

The processor may be configured to transmit a warning signal to a topside location or to an ROV/AUV if the loading on one or both or the bodies has reached a threshold level.

The system may further comprise a topside processor which is configured to compare an output signal from the sensor assembly with the numerical model to determine the loading on one or both of the bodies.

Embodiments of the invention will now be described, by way of example only, with reference to the following figures, in which,

FIGURE 1 is a schematic illustration of a subsea production system suitable for use in the inventive method,

FIGURE 2 is a schematic illustration of a subsea workover system suitable for using the inventive method,

FIGURE 3 is a schematic illustration of a longitudinal cross-section through a first embodiment of connection between two adjacent sections of pipeline suitable for use in the inventive method,

FIGURE 4a and 4b are schematic illustrations of a longitudinal cross-section through a second embodiment of connection between two adjacent sections of pipeline suitable for use in the inventive method, with a) the connector in a release configuration, and b) the connector in a locking configuration,

FIGURE 5 is a schematic illustration of a longitudinal cross-section through a third embodiment of connection between two adjacent sections of pipeline suitable for use in the inventive method, and

FIGURE 6 is a schematic illustration of a processor suitable for use in the production or workover systems illustrated in Figures 1 or 2, and

FIGURE 7 is a schematic illustration of a load monitoring system suitable for in the inventive method.

Referring now to Figure 1, there is shown a schematic illustration of part of a subsea production system 10 including a manifold module 12 connected to a plurality of satellite modules 14 (three in this example), each of which is connected to the manifold module 12 by means of a pipeline 16. The satellite module could be a subsea tree, Pig launcher/receiver, pipeline end terminal, pipeline end manifold, riser base, UTH, a pump & control system module, or a subsea storage unit, for example for storage of well fluids, chemicals, pressurised hydraulic or pneumatic fluids, or electricity . The pipeline 16 may be what is known as a flowline jumper, well jumper or spool. There is a connection between each end of each pipeline 16 and its respective module 12 / 14 which is made by means of a connector 18.

Referring now to Figure 2, there is shown a schematic illustration of a subsea workover system 100, comprising a riser 110 which is connected to a wellhead 120. In this example, the riser 110 is connected to the wellhead 120 via, in ascending order, a Christmas tree 130, a lower riser package 140, and an emergency disconnect package 150. Each of these parts encloses a passage for flow of fluid, and a connection is made between each part and its adjacent parts such that the passages in the two parts are connected to provide a continuous flow path for fluid to flow from one part to the other, and provides a substantially fluid tight seal between the two parts to prevent any significant leakage of fluid out of the flow path at the interface between the two parts. To achieve this, each of these parts is connected to the adjacent part by means of a connector 18. As such, a connector 18 is provided between the wellhead 120 and the Christmas tree 130, the Christmas tree 130 and the well control package 140, and the well control package 140 and the emergency disconnect package 150. Moreover, the riser 110 is made up of a plurality of sections of pipeline, and the ends of adjacent sections of pipeline are also connected by means of a connector 18.

It will be appreciated that the systems illustrated in Figures 1 and 2 are merely examples of subsea systems in which such connectors 18 could be employed. The subsea production system 10 could include more or fewer than three satellite modules 14, and these could comprise one or more of the following: a subsea tree, Pig launcher/receiver, pipeline end termination, pipeline end manifold, riser base, UTH, pump & control system module, or subsea storage unit. Similarly, the workover system 100 may include different elements between the riser 110 and the wellhead 120, such as **a** BOP, weak link, stress joint, or inriser valve. Moreover, such connectors 18 could equally be used where a riser 110 is used in a subsea drilling system.

It will be appreciated, therefore that the invention could be used where the connector 18 is used to provide a connection to a horizontal or generally horizontal pipe system, or to a connector used to provide a connection to a vertical or generally vertical pipeline.

In all cases mentioned above, the connector 18 mechanically connects two fluid flow bodies each enclosing a passage for flow of fluid, such that the passages in the two bodies are connected to provide a continuous flow path for fluid to flow from one body to the other, and assisting in providing a substantially fluid tight seal between the two bodies to prevent any significant leakage of fluid out of the flow path at the interface between the two bodies. As such, any configuration of connector which can achieve this, could be used, and the invention is not restricted to use with any particular configuration of suitable connector. The connector 18 may be integral with one of the fluid flow bodies, or detachable from both.

For example, one or more of the connectors 18 could comprise an annular clamp connector, as illustrated schematically in Figure 3 connecting two sections of pipeline 20 together. Each section of pipeline 20 encloses a passage with a longitudinal axis A, and has radially outwardly extending flange 20a at an end thereof, and these are sandwiched between two arms 18a of the connector 18 so that, when in place, the connector 18 prevents the separation of the two sections of pipeline 20. In order to be clamped around the flanges 20a, the connector 18 may be split into two, three, or more, separable parts, which come together to form an annulus. The arms 18a extend from a main body 24 of the connector, so that each part of the connector has a generally U-shaped transverse cross-section.

Alternatively, one or more of the connectors 18 could comprise a collet connector, as illustrated schematically in Figures 4a and 4b also connecting two sections of pipeline 20 together. Again, each section of pipeline 20 has a radially outwardly extending flange 20a at an end thereof. In this example, the connector 18 comprises a set of collet fingers 28 which can be deformed by axial movement of a movable annular locking ring 30 so that the flanges 18a are clamped between two locking parts of the collet fingers 28. The connector 18 is then in a locking configuration as illustrated in Figure 4b. The axial movement of the locking ring 30 can be achieved using an external tool, or by means of a piston arrangement. The collet connector 18 is illustrated in Figure 4a in a released configuration in which the two pipeline sections 20 can be separated.

In these embodiments, one of the sections of pipeline 20 has an extension which sits with the passage enclosed by the other section of pipeline 20, and a seal 26 is provided between the radially outwardly facing surface of the extension and the radially inwardly facing surface of the section of pipeline 20 in which the extension is lodged. It will be appreciated, however, that this need not be the case, and the seal 26 could be provided in a different location – between the flanges 20a of the pipeline sections 20, for example, or in the clamp connector illustrated in Figure 3, between each of the two arms 18a of the connector 18 and the adjacent flange 20a.

Moreover, it is possible to provide two seals – a primary seal which provides the first barrier preventing leakage of fluid out of the flow passage at the joint between the two sections of pipeline 20, and a secondary seal (or back seal). The primary seal has an interior side which, in use, in contact with fluid from the flow passage, and an opposite exterior side. The back seal is located at the exterior side of the primary seal. In use, the back seal thus acts to prevent sea-water from contacting the exterior side of the primary seal, but is typically provided for testing of the primary seal, by supplying pressurised fluid into the cavity between the primary seal and the back seal..

Such an arrangement of connection is illustrated in Figure 5. This embodiment uses a clamp connector 18 as described above, but in this case, there are two seals 26a, 26b provided between the two sections of pipeline 20. A seal cavity 27 is therefore formed between the two flanges 20a and the seals 26a, 26b. It will be appreciated that one or both of the seals could equally be provided to seal between the sections of the pipeline 20 and the connector 18, in which case the seal cavity would be formed between the pipelines 20, connector 18 and two seals 26a, 26b.

It should be appreciated, however, that the invention is not restricted to use in connection with a connector which connects a rigid pipe-line, and may also be used where the connector is connected to a flexible hose or umbilical. Equally, the invention is not restricted to use in connection with a connector which connects two fluid flow bodies. It may be used to monitor the condition of any connection between non-tubular parts which is subject to cyclic loading – such as the connection between and electrical module and an electrical cable, or between two adjacent sections of electrical cable.

According to the invention, in order to monitor the condition of the connections described above, each connector 18 is provided with a sensor assembly 32 which is operable to provide an output representing the degree of movement of one or both of the parts secured to the connector 18. The sensor assembly 32 could comprise one sensor or more than one sensor, and the output from the sensor assembly 32 could be one or both of the strain experienced by the connector 18 or the displacement of one of the parts forming the connection relative to the connector 18. Examples of the sort of sensor assemblies 32 which could be used are described below.

For example, the sensor assembly 30 could comprise a displacement sensor such as a low voltage displacement sensor, which may be mounted on the connector 18 to measure the displacement of one or both of the parts joined by the connector 18 relative to the connector 18. The displacement sensor could be configured to measure longitudinal displacement of the part in question relative to the connector 18 (i.e. linear movement generally parallel to the longitudinal axis A) resulting from a force acting on the part parallel to the longitudinal axis A), and/or angular displacement, or pivoting ,

of the part in question relative to the connector 18 resulting from a force acting on the part perpendicular to the longitudinal axis A.

The movement could be elongation or compression of the connector 18, and therefore, alternatively, or additionally, one or more strain gauges could be mounted on the connector 18.

In the embodiment of connector 18 illustrated in Figure 3, a strain gauge may be mounted on the main body 24 of the connector 18, and/or one or both of the connector arms 18a. In the embodiment of the connector 18 illustrated in Figures 4a and 4b, a strain gauge could be mounted on one or more of the collet fingers 28, and or the locking ring 30.

Advantageously, the sensor assembly 32 includes sufficient sensors to measure movement of the or each flow body in three orthogonal directions. For example, it may comprise an array of three strain gauges which are configured to measure the strain on the connector along three orthogonal axes.

In embodiments in which two seals 26a, 26b, and a seal cavity 27 are present, such as the embodiment illustrated in Figure 5, the sensor assembly 32 could be connected to the seal cavity 27, and, could comprise a pressure sensor for measuring the pressure in the seal cavity 27. It will be appreciated that any movement of one or both of the sections of pipe-line 20 would cause the volume of the seal cavity 27 to change. Where the seal cavity 27 is closed, this will result in a change in the pressure of fluid in the seal cavity 27. Alternatively, the connector could comprise a cylinder and floating piston arrangement, the floating piston dividing the volume enclosed by the cylinder into two volumes, a first one of which is vented to atmosphere, and a second one of which is connected to the seal cavity 27. Any change in volume of the seal cavity 27, would cause the piston to move in the cylinder to change the relative sizes of the first and second volumes. In this case, the sensor assembly 32 could comprise a displacement sensor which is configured to measure the linear displacement of the piston relative to the cylinder.

The sensor assembly 32 may comprise a combination of two or more of the above types of sensor.

Prior to use of the connector 18 or connectors 18, or a test connector, which has the same configuration as the connector 18 to be used in the system in question is calibrated, by connecting it to a test element in the same way as the connector 18 will be connected in use, applying a range of pre-determined test forces to the test element, and recording the output from the sensor assembly 32 during each applied test force. The output from the sensor assembly 32 is also advantageously recorded after the test force is released, as, if the test force is sufficiently high, it might cause permanent changes to the condition or state of the connector 18 which could result in the output

from the sensor assembly 32 when no force is applied to the test element (the zero output) changing from before the test force was applied to after.

The test forces can vary in both magnitude and direction, and will be chosen depending on the forces likely to be applied to the parts secured to the connector 18 in use.

In this way, a numerical model linking the output from the sensor assembly 32 to the force acting on the test element is created.

It will be appreciated that repeated loading of one or both of the bodies connected to the connector 18 could cause permanent changes to the condition or state of the connector 18 which result in changes in the zero output and/or the output of the sensor assembly 32 when loaded. This could mean that, for example, the very first application of a force to one of the bodies connector to the connector 18 may result in sensor assembly output α, β, γ, but after repeated and prolonged loading, the same sensor assembly output may be generated when a different force is applied that body. This could result in significant inaccuracies in converting the sensor assembly output to a force over time.

To account for this, in addition to applying test forces of varying magnitude and direction, the same test force can applied repeatedly, and the output of the sensors recorded during and after each application of the test force. In this way, it can be determined if the repeated application of the same test force causes permanent changes to the condition or state of the connector 18 which result in changes in the zero output and/or the output from the sensor assembly 32 during the application of the test force depending on the number of applications of the test force. By doing this, the effect of the historical / cumulative loading of the connector 18 on the current output of the sensor assembly 32 is taken into account by the numerical model.

In order to produce the complete numerical model, it may be necessary to carry out this process using more than one test connector. For example, a first test connector could be used to map the sensor assembly outputs for a range of magnitudes of applied longitudinal forces, a second test connector used to map the sensor assembly outputs for a range of magnitudes of applied bending moments, a third test connector used to map the outputs of the sensor assembly 32 after the repeated application of a test force etc etc.

When the connector 18 or connectors 18 is/are ready for use , as illustrated in Figures 1 or 2, each sensor assembly 32 is connected to a subsea data storage apparatus 34a, either wirelessly, or using a wired connection, and all signals from the sensor assembly 32 are stored in the subsea data storage apparatus 34a. In this embodiment, the subsea data storage apparatus 34a is also connected to a

topside data storage apparatus 34b, either by wired or wireless connection, or both. The topside data storage apparatus 34b could be cloud storage. A subsea data processor 36a is connected to the subsea data storage apparatus 34a, and a topside data processor 36b is connected to the topside data storage apparatus 34b. A topside display unit 38 is connected to the topside data processor 36b

Figure 6 is a schematic illustration of a subsea processor system which could be used for implementing the present invention. In this case, the sensors 32 provided for each connector 18 are strain gauges, and these are connected to a combined subsea storage apparatus and data processor 34a/36a. This comprises a battery 40, power controller 42, memory 44, a central processing unit (CPU) and microcontroller (MCU) 46 and a communications LAN 48. The strain gauges are connected to the CPU/MCU 46 via an amplifier 50, and the CPU/MCU is, in turn, connected to the memory for storage of the signals from the sensors 32. An accelerometer 52, and other environmental sensors 54, such as temperature and pressure sensors are also connected to the CPU / MCU 46. The PCU / MCU 46 is also connected to the communications LAN 48 which is connected to cloud storage 56 and the topside processor 36b and GUI 38 via a wireless internet connection.

The data storage apparatus 34 could be connected to each sensor assembly via a wired or wireless connection, or through subsea data transfer via ROV/AUV. The data storage apparatus could equally be a topside unit, again connected to the data storage apparatus 34 either via a wired or wireless connection.

Figure 7 illustrates an example of the processing which could be carried out for monitoring the condition of the connectors 18. This shows one connector 18 and its associated sensor assembly 32.

In this embodiment, the data storage apparatus 34 is connected to both a subsea processor 36a and a topside processor 36b, either by a wired or wireless connection.

The subsea processor 36a has access to a statistical representation of the numerical model and which it uses to derive the applied force and is enabled with a warning signal that is sent topside or live signal sent topside for live tracking of applied forces and current condition level of assembly.

Analysis of the signals from the sensors 32 using the numerical model by the subsea processor 36a might be too time-consuming to yield results in real-time. This is why, in this embodiment, the subsea processor 36a has access to a statistical model which is derived by carrying out a multivariat analysis of the numerical model to obtain a range of threshold limits for the sensor outputs which when reached, indicate that the loading of at least one of the bodies has reached a threshold level. The statistical analysis engine of the subsea processor 36a is programmed use this statistical

representation of the numerical model to determine when one of the bodies to connected to the connector 18 is exposed to loads above an acceptable level or the condition of each connector 18 is below an acceptable level due to the effect of external loads applied to the bodies connected to the connector 18.

In other words, the subsea processor 36a is programmed to compare output from each sensor assembly 32 with the statistical model to determine is the force on any of the bodies has exceeded a predetermined failure threshold level. The failure threshold level may represent a force limit above which there is likely to be catastrophic failure (e.g. breakage) of the body or the connector 18, but, where the connector 18 connects two fluid flow bodies, it could more usefully represent a force limit above which the applied force compromises the integrity of the seal between the two fluid flow bodies, and allows leakage of fluid out of the flow path at the interface between the two bodies. For example, in the embodiment of connector 18 illustrated in Figure 3, the application of a sufficiently large bending moment (i.e. a force generally perpendicular to the longitudinal axis A) to one of the sections of pipeline 20 could cause the seal 26 to separate from one of the surfaces it is supposed to seal against. Similarly, if the seal were provided between the two flanges 20a as described above, the same could happen if a sufficiently large force were applied to one of the sections of pipeline 20 generally parallel to the longitudinal axis A pulling it away from the other section of pipeline 20.

The subsea processor 36b may also be programmed to use the statistical model, and the historic output from the sensor assemblies 32 to determine if loading of the bodies has been such that the condition of any of the connectors 18 has deteriorated to a critical level as a result of the forces applied to it over time.

In other words, the subsea processor 36a is also programmed to use the statistical model to determine if a running total of the outputs from each sensor assembly 32, means that the forces on the bodies over time (the total cumulative force) exceeds a predetermined cumulative threshold level. Repeated application of forces to the fluid flow bodies could result in fatigue failure of a structural part of the connector 18, or could result in deformation of the connector 18, which, over time, causes the separation of one of the seal 26 from one of the surfaces it is supposed to seal against.

The failure threshold level may also be affected by the cumulative total force. For example, repeated applications of forces which were not sufficiently high to cause the immediate failure of the connector 18 could cause deformation of the connector 18 so that the force required to cause separation of the seal 26 from a sealing surface is lower than it was before the deformation of the

connector 18 occurred. In this case, the failure threshold level would decrease as the cumulative total force increases. The statistical model may be set up to take this into consideration.

The failure threshold level, cumulative threshold level, and the relationship between the failure threshold level and the total cumulative force, is determined empirically through testing of the test connector. It will be appreciated that, as failure of the connector 18 whilst in use is to be avoided, the failure threshold level and cumulative threshold level should be set such to be below the likely failure level, so that the alert can be issued, and the operator has the opportunity to replace or repair the connector 18 before it or the seal 26 fails.

When the subsea processor 36a determines that either the failure threshold level or the cumulative threshold level have been exceeded, it may be programmed to send an alert to the topside, which may be an audible alert, or a visual alert displayed on the display apparatus 38.

The subsea processor 36a may also use the load data from the statistical analysis engine to note any trends in the loading of the bodies. The resulting trend statistics may be compared with a set of rules derived from the expected behaviour of the system under the applied starting conditions and operating envelope. The subsea processor 36a may be programmed to issue a warning signal if the trend statistics show any deviation or significant deviation from what was expected. An operator may thus respond to this warning and make appropriate changes to the operating envelope.

The full numerical model (rather than the statistical representation of the numerical model) can be used in analysing the signals from the sensor assemblies 32 topside, to provide a more detailed or accurate analysis of the loading on the bodies. It will be appreciated, however, that it may not be possible to provide real-time loading information in this way. For example, the data gathered from sensor assemblies 32 can be processed (after being transferred to the topside data storage apparatus 34b) by comparing each output with the numerical model to determine the force on the part or parts secured to each connector 18 at any given time, and create an accurate representation of the condition of each connector 18, and its remaining capacity (ie. leakage or structural). Based upon this data the need for change of parts or future maintenance can be determined.

The topside processor 36b can also use the load data to determine trend statistics, and, just as in the subsea processing, the resulting trend statistics may be compared with a set of rules derived from the expected behaviour of the system under the applied starting conditions and operating envelope. If the trend statistics show any deviation or significant deviation from what was expected, an operator or the system controller in an automated system may respond to any such deviation and make appropriate changes to the operating envelope.

In a workover situation, for example using the system illustrated in Figure 2, the live outputs from the sensor assemblies 32 can be used to track the applied load vs vessel offset, and to use this to determine the acceptable offset window to maintain the forces on the riser 110 at acceptable levels. Once the acceptable offset window is known, an operator, or an automated system controller can then take steps to maintain the vessel within this acceptable offset window.

Additionally or alternatively, the force over time data derived by comparing the signals from the sensor assemblies 32 to the numerical model, can be examined purely to learn more about the performance of the system, and make informed decisions on how to operate that or an equivalent system in the future. For example, if the forces on one or both of the bodies connected to the connector 18 have caused the connector 18 to degrade at an unacceptable speed, the operating parameters of a similar system could be limited in the future, in order to avoid such degradation.

Claims

1. A method of monitoring the condition of a connection between two bodies connected using a connector, the connector comprising a sensor assembly, the sensor assembly being operable to provide an output representing the degree of movement of one or both of the bodies to which the connector is secured, wherein the method comprises the steps of
    a) installing the connector and bodies in a use position in which the connector joins the two bodies,
    b) using the output from the sensor assembly and a numerical model to determine a measured force one or both of the bodies, or the condition of the connector,

    the numerical model having been obtained by testing the connector or a test connector having the same configuration as the connector by applying a test force of known magnitude to a test element secured to the connector / test connector, recording the output from the sensor assembly whilst the test force is applied, repeating this process for a plurality of test forces, and using the data thus obtained to create a numerical model relating the output from the sensor assembly to the force on the test element.

2. A method according to claim 1 further comprising the step of

issuing a warning if the measured force exceeds a predetermined threshold level.

3. A method according to any preceding claim wherein the sensor assembly provides an output representing one or both of the strain of the connector body and displacement of one of the bodies relative to the connector.

4. A method according to any preceding claim wherein the method further comprises the steps of, over time, using the measured forces determined from readings from the sensor assembly at a plurality of different times to obtain an indication of the cumulative force on the connector, and issuing a warning when the cumulative force exceeds a predetermined cumulative threshold.

5. A method according to any preceding claim wherein the predetermined threshold level varies in a predetermined manner depending on the cumulative force on the connector.

6. A method according to any preceding claim wherein the sensor assembly comprises a strain gauge mounted on the connector.

7. A method according to any preceding claim wherein the sensor assembly comprises a displacement sensor which is configured to measure linear or angular displacement of one of the bodies relative to the connector.

8. A method according to any preceding claim wherein the bodies are fluid flow bodies, and are arranged in step a such that the connector and fluid flow bodies enclose a continuous flow passage which extends from one fluid flow body to the other.

9. A method according to claim 8 wherein there are two seals which provide a barrier to fluid flow out of the flow passage – a primary seal which provides a first barrier preventing leakage of fluid out of the flow passage at the joint between the two fluid flow bodies, and a secondary seal which is located at the exterior side of the primary seal, there being a seal cavity between the two seals and the two fluid flow bodies or between the two seals, one or both of the fluid flow bodies and the connector.

10. A method according to claim 9 wherein the sensor assembly comprises a pressure sensor which measures the pressure of fluid in the seal cavity.

11. A method according to claim 9 wherein the sensor assembly comprises a displacement sensor which is configured to measure movement of a piston in a cylinder which is fluidly connected to the seal cavity.

12. A method according to any preceding claim wherein one of the bodies has a longitudinal axis, and the test force is applied generally parallel to the longitudinal axis at the connection between the two bodies.

13. A method according to any preceding claim wherein one of the bodies has a longitudinal axis and the test force is a bending moment applied generally perpendicular to the longitudinal axis at the connection between the two bodies.

14. A method according to any preceding claim wherein one of the bodies has a longitudinal axis and the test force is torsion applied to rotate the body about its longitudinal axis.

15. A method according to any preceding claim wherein one or both of the bodies is a section of pipeline.

16. A method according to any preceding claim wherein one or both of the bodies is one of the following: a manifold, a riser, a flow spool, and emergency disconnect package, a subsea tree, a Christmas tree adapter connector, a well control package, a Pig launcher/receiver, a pipeline end

termination, a pipeline end manifold, a riser base, a UTH, a pump & control system module or a subsea storage unit.

17. A subsea system comprising a two bodies connected using a connector, the connector comprising a sensor assembly, the sensor assembly being operable to provide an output signal representing the degree of movement of one or both of the bodies to which the connector is secured, a data storage apparatus which is connected to and stores output signals from the sensor assembly, a processor which is connected to the data storage apparatus and which is configured to use an output signal from the sensor assembly and a numerical model to determine a measured force on one or both of the bodies and/or the condition of the connector, the numerical model relating the output from the sensor assembly to the force on the test element and having been obtained by testing the connector or a test connector having the same configuration as the connector by applying a test force of known magnitude to a test element secured to the connector / test connector, recording the output from the sensor assembly whilst the test force is applied, repeating this process for a plurality of test forces, and using the data thus obtained to create the numerical model.

18. A subsea processing system according to claim 17 wherein the processor is configured to compare an output signal from the sensor assembly with the numerical model to determine the load on one or both of the bodies.

19. A subsea processing system according to claim 18 wherein the processor is configured compare output signals from the sensor assembly at a plurality of different times with the numerical model to obtain a data set representing the loading of one of the bodies over time.

20. A subsea processing system according to any one of claims 17 to 19 wherein the processor is at a topside location.

21. A subsea system according to claim 17 wherein the processor is a subsea processor and is configured to compare an output signal from the sensor assembly with a statistical representation of the numerical model to determine if the loading on one of the bodies has reached a threshold level.

22. A subsea system according to claim 21 wherein the processor is configured to transmit a warning signal to a topside location or to an ROV/AUV if the loading on one or both or the bodies has reached a threshold level.

23. A subsea system according to claim 21 or 22 wherein the system further comprises a topside processor which is configured to compare an output signal from the sensor assembly with the numerical model to determine the loading on one or both of the bodies.

Intellectual Property Office

Application No:	GB2012637.1	**Examiner:**	Contract Unit Examiner
Claims searched:	1-23	**Date of search:**	24 March 2021

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-3, 6, 7, 17, 18, 20, 23	US7165612 B2 (MCLAUGHLIN STUART) column 5, lines 35-63; figures 2-5
X	1, 17	WO2016/023068 A1 (DEEP EXPLORATION TECHNOLOGIES COOPERATIVE RES CT LTD) paragraphs [0071], [0118]; figures 5a, 5b
A	-	WO2016/166505 A1 (EXPRO NORTH SEA LTD) the whole document
A	-	EP2954155 A2 (FMC KONGSBERG SUBSEA AS)
A	-	US2006/065401 A1 (ALLEN JOHN ET AL)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

E21B

The following online and other databases have been used in the preparation of this search report

Intellectual Property Office

International Classification:

Subclass	Subgroup	Valid From
E21B	0047/007	01/01/2012
E21B	0017/04	01/01/2006