(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 March 2017 (30.03.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/052383 A1

(51) International Patent Classification:
F04D 13/08 (2006.01) *F04B 23/00* (2006.01)
E21B 43/12 (2006.01) *F04B 47/06* (2006.01)

(21) International Application Number:
PCT/NO2016/050193

(22) International Filing Date:
22 September 2016 (22.09.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/222,297 23 September 2015 (23.09.2015) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

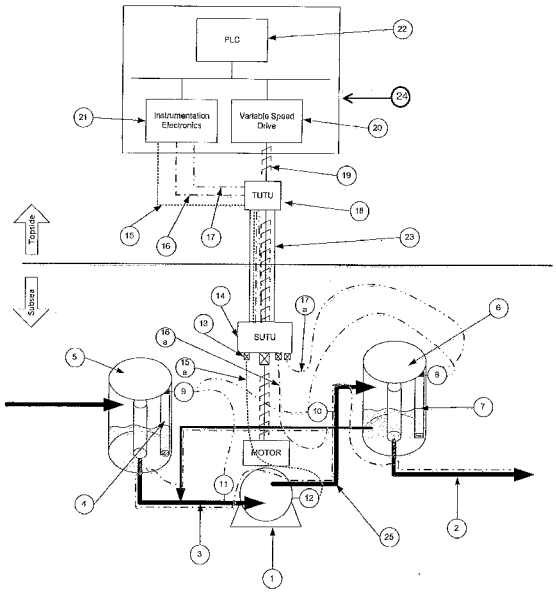
Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

[Continued on next page]

(54) Title: SUBSEA PUMP SYSTEM

Fig. 1



(57) Abstract: The invention provides a subsea pump system, comprising a subsea pump, a fluid conditioner tank, a liquid conservation tank, a line arranged for liquid recirculation from the liquid conservation tank to upstream the subsea pump, and an umbilical for power, monitoring and control, wherein the fluid conditioner tank is arranged upstream to the subsea pump which is arranged upstream to the liquid conservation tank. The subsea pump system is distinctive by that it further comprises: a first buoyancy element suspended in the fluid conditioner tank, a second buoyancy element suspended in the liquid conservation tank, optical fiber sensors, at least arranged to a suspension of the buoyancy element in the fluid conditioner tank and to a suspension of the buoyancy element in the liquid conservation tank, and electronics, wherein all subsea sensors consist of optical fiber sensors and all electronics for monitoring and control consist of electronics arranged topsides. The invention also provides a subsea pressure booster, comprising at least one optical fiber sensor arranged in the motor compartment for monitoring a lubricant flow rate.

WO 2017/052383 A1

Published:

— *with international search report (Art. 21(3))*

SUBSEA PUMP SYSTEM

Field of the invention

The present invention relates to subsea pumps for the petroleum industry, instrumentation, control, reliability and cost thereof.

Background of the invention and prior art

Reliability is a key issue for subsea equipment.

A subsea pump system, that is a pump system arranged on or at the seabed for pumping multiphase fluid or one phase fluid, typically comprises electronic instrumentation and electronic control modules arranged subsea. Subsea electronics can be a limitation with respect to reliability, since a large number of components and connections are included. Even though each component has very high reliability, the reliability of each component typically must be multiplied with the reliability of other components. With sometimes thousands of components, the resulting reliability can be a limitation to uptime of the equipment.

Smart Fibres Ltd of UK has suggested a subsea pump with a condition monitoring system with fiber optical sensors, published by the url: http://smartfibres.com/docs/Subsea_Rotating_Machine_Condition_Monitoring_System.pdf

According to Smart Fibres, optical Fiber Bragg Grating (FBG) technology is used for condition monitoring of a subsea pump and motor, by arranging optical fibers with FBG sensors to the subsea motor and pump. All optical sensors are suggested subsea, with electronic instrumentation at surface, connected via optical fibers in an umbilical. Only FBG sensors are suggested and only as arranged to the subsea pump and motor.

For a downhole pump, a so-called electric submersible pump (ESP), distributed fiber optic sensing devices for monitoring the health of an ESP downhole is

described and illustrated in the patent publication US 2015/0110439 A1. The method and system described in said publication relate to determining a parameter of at least one component of an artificial lift system located in a subterranean formation. It is not explicitly described where processors and electronic modules are arranged; topsides or downhole. From said publication, is not clear whether components or parameters in addition to the at least one parameter and component are monitored with electronic sensors or optical fiber sensors, downhole or topsides, or where electronics are arranged.

A demand exists for improved reliability and reduced cost for subsea pumps and subsea pump systems.

Summary of the invention

The invention meets the demand by providing a subsea pump system, comprising

a subsea pump,

a fluid conditioner tank,

a liquid conservation tank,

a line arranged for liquid recirculation from the liquid conservation tank to upstream the subsea pump, and

an umbilical for power, monitoring and control,

wherein the fluid conditioner tank is arranged upstream to the subsea pump which is arranged upstream to the liquid conservation tank.

The subsea pump system is distinctive by that it further comprises:

a first buoyancy element suspended in the fluid conditioner tank,

a second buoyancy element suspended in the liquid conservation tank,

optical fiber sensors, at least arranged to a suspension of the buoyancy element in the fluid conditioner tank and to a suspension of the buoyancy element in the liquid conservation tank, and

electronics,

preferably all subsea sensors consist of optical fiber sensors and all electronics for monitoring and control consist of electronics arranged topsides.

In the most preferred embodiments, all subsea sensors consist of optical fiber

sensors and all electronics for monitoring and control consist of electronics arranged topsides. Topsides means above the water, on a platform or vessel or onshore. Preferably, no electronics is arranged subsea, especially no electronics for monitoring and control. A possible exception, not for monitoring and control however, and definitely not in contact with process fluids or subsea pump motor compartment fluids, is a possible subsea electronics module, conveniently arranged at the subsea umbilical termination, for analog to digital conversion of optical signals, for allowing longer distance transmission. Such subsea electronics module, if present, is however not for monitoring and control, only for conversion of one type of optical signals to another type of optical signals for better transmission of the optical signals. Accordingly, no electronics is operatively coupled to the process equipment for monitoring and control in the most preferred embodiments.

The subsea pump system preferably comprises a single wet mate connector, connecting the umbilical to the subsea pump and the optical fiber sensors of the subsea pump, the fluid conditioner tank and the liquid conservation tank. Preferably, all other connections are by dry mate connectors or pre-installed fusion splices made before the subsea pump system installation.

In a preferable embodiment, the subsea pump system comprises fiber optical sensors in the umbilical for measuring both temperature and strain of dynamic loading of the umbilical.

In a preferable embodiment, the subsea pump system comprises at least one Fabry Perot optical fiber pressure and temperature sensor.

In a further preferable embodiment, the subsea pump system comprises fiber optic sensors for liquid level monitoring using differential pressure, in the fluid conditioner tank and the liquid conservation tank. In a further preferable embodiment, the subsea pump system comprises fiber optic Bragg grating sensor arrays attached to the suspension of the buoyancy element in the fluid conditioner tank and to the suspension of the buoyancy element in the liquid conservation tank. The buoyance elements used in the system of the invention

may have positive or negative buoyancy as submerged in liquid, however, said elements must have known weight and volume or the measured values must be calibrated to values of at least one of the parameters: level, flow rate and fluid composition.

The subsea pump system preferably comprises one or more of fiber optic Bragg grating or Distributed Acoustic Sensing, as optical fibers operatively arranged to the subsea equipment structure or subsea rotating equipment. Preferably, the pump system of the invention also comprises fiber optical Distributed Temperature Sensing (DTS), particularly as arranged in the process fluid flow path or volumes and downstream a bypass choke, which is particularly useful for detecting risk of hydrate formation during shut-in or bypass choking. In addition, the subsea pump system preferably comprises fiber optic current sensors using Faraday Effect to modulate polarization in the presence of a magnetic field, wherein said sensors are arranged outside conducting elements or inside conducting elements, including the umbilical.

As mentioned, the advantages of the subsea pump system of the invention mainly relates to cost and reliability. For each sensor or each parameter to be measured at a specific location subsea, a rough estimate is that 0.1 to 1 million USD will be saved in capital cost, before installation. The subsea pump system of the invention preferably comprises several optical fiber sensors in each fiber, preferably comprises at least three optical fiber sensors operatively arranged through the umbilical and to equipment subsea, and preferably at least one redundant fiber or sensor for each parameter and location. The result is a very significant improvement in reliability. In addition, since the installation subsea involves only one, optionally no, subsea wet connector matings, since all sensors are presinstalled and fusion spliced, a large simplification for installation will also be achieved. Faster and simpler installation means significant reduction in cost. Furthermore, the fiber optical sensors have advantage by not being affected by electromagnetism, allowing measurements

at locations where electronic sensors may not function.

Figures

Figure 1 illustrates an embodiment of a subsea pump system of the invention.
Figure 2 illustrates details of said system.

Detailed description

Reference is made to Figure 1. A subsea pump (1) is connected to topside power and communication (24) system via an umbilical (23) containing power transmission cable (19) and optical fiber (15, 16, 17). The umbilical is terminated at a topside umbilical termination unit (18) and subsea umbilical termination unit (14). The subsea umbilical termination unit (14) includes wet mateable connectors (13) for power cables and optical fibers. Subsea optical fibers (15a, 16a, 17a) forming the subsea instrumentation are connected to the subsea umbilical termination through one or more wet mate connectors (13). In this embodiment: a first fiber (15a) may be measuring vibration, for example using distributed acoustic sensing; a second fiber (16a) represents a fiber coupled to the pump station flow lines for distributed temperature measurement; a third fiber (17a) is a fiber with one or more Fabry Perot sensors for pressure measurements (10,11) with the same fiber extended to measure strain or pressure (8,9) for tank fluid density. More specifically, the system includes a fluid conditioning tank (5) which separates liquid and gas phases from a subsea well and provides an averaged gas volume fluid fraction at the pump input (3), achieved by having a perforated outlet pipe extending up into the tank volume. At the outlet of the pump (25) is a liquid conservation tank (6) which ensures a percentage of liquid is circulated back to the inlet of the pump, via a separate line from a liquid filled part of said tank to upstream the pump. The fluid level in both tanks can be estimated by the use of a test cylinder, also termed a buoyancy element, of known density (4, 7), which is located inside the tanks with either an optical strain or optical pressure gauge (8, 9) mechanically attached to load bearing suspension structure between test cylinders (4,7) and tanks (5,6), respectively. As the fluid level increases, the weight of the test cylinder (4, 7) will decrease due to the buoyancy from displacing fluid. This displacement is measured through gauges (8, 9). A benefit of this approach is

that it provides a measurement of net fluid density in the tank from which level may be inferred by calculation. The net density measurement is also a useful input to the pump control algorithm as it is related to the density of fluid at the pump inlet.

Measurements such as those mentioned above may be included on the same fiber or additional fibers. In each case the fiber used for measurement is extended through the umbilical (23) and measurement taken topside without the need for subsea electronics.

The subsea pump system and subsea pressure booster of the invention may include every feature or step as here described or illustrated, in any operative combination, which operative combinations are embodiment of the invention.

The invention also provides a subsea pressure booster, comprising a pump compartment or compressor compartment with impellers and diffusers and a motor compartment with a motor operatively coupled to rotate the impellers, and a lubrication arrangement for lubrication of the motor compartment bearings, seals and coil windings, distinctive in that the subsea pressure booster comprises at least one optical fiber sensor arranged in the motor compartment or in a lubricant circuit part arranged from and to said motor compartment, for monitoring a lubricant flow rate, and preferably all subsea sensors consist of optical fiber sensors and all electronics for monitoring and control consist of electronics arranged topsides. The flow rate of the lubricant, typically an oil or a water-glycol mixture, is a vital parameter for monitoring a subsea pressure booster, giving a direct monitored parameter providing early warning if the lubricant flow rate drops or increases outside a due operation window, which parameter is not mentioned or implicit by the teaching of Smart Fibres or the patent publication US 2015/0110439 A1. Preferably, the lubricant flow rate is measured at the lubricant inlet to and lubricant outlet from a bearing or other component, by using Fabry-Perot optical fiber pressure sensors, relating the lubricant pressure drop over the component to a lubricant flow rate and a motor speed. More specifically, a lubricant impeller or pump is driven directly by or is operatively coupled, typically with a 1 to1 coupling, to the motor, meaning that the lubricant flow rate is directly related to motor speed. For a known or

measured motor speed, the lubricant pressure drop over a component is then directly related to the lubricant flow rate. Alternatively, Fabry-Perot optical fiber sensors are arranged to measure strain or stress to a restriction in a lubricant inlet or outlet or both inlet and outlet, the measured strain or stress relates to lubricant flow rate. FBG vortex flow meters can be used but are less feasible for measuring lubricant flow rate due to limitations with respect to vibrations, high lubricant viscosity at start up and too small dimensions at the locations for measurements. The lubricant flow rate is preferably measured for each bearing of a motor shaft. Fabry-Perot optical fiber pressure or differential pressure sensors, and other fiber optical sensors or arrangements, are arranged in a single optical fiber or in several optical fibers. In addition, pressure and temperature are preferably also measured, as well as vibration and other parameters, preferably with only optical fiber sensors subsea and electronics merely topsides.

CLAIMS

1.

Subsea pump system, comprising

a subsea pump (1),

a fluid conditioner tank (5),

a liquid conservation tank (6),

a line arranged for liquid recirculation from the liquid conservation tank to upstream the subsea pump, and

an umbilical (23) for power, monitoring and control,

wherein the fluid conditioner tank is arranged upstream to the subsea pump which is arranged upstream to the liquid conservation tank,

c h a r a c t e r i s e d i n that the system further comprises:

a first buoyancy element (4) suspended in the fluid conditioner tank,

a second buoyancy element (7) suspended in the liquid conservation tank,

optical fiber sensors (16), at least arranged to a suspension of the buoyancy element in the fluid conditioner tank and to a suspension of the buoyancy element in the liquid conservation tank, and

electronics (20, 21,22),

preferably all subsea sensors consist of optical fiber sensors and all electronics for monitoring and control consist of electronics arranged topsides.

2.

Subsea pump system according to claim 1, comprising a single wet mate connector (13) connecting the umbilical to the subsea pump and the optical fiber sensors of the subsea pump, the fluid conditioner tank and the liquid conservation tank.

3.

Subsea pump system according to claim 1 or 2, comprising fiber optical sensors in the umbilical for measuring both temperature and strain of dynamic loading of

the umbilical.

4.
Subsea pump system according to claim 1, 2 or 3, comprising one or more Fabry Perot optical fiber pressure and temperature sensors.

5.
Subsea pump system according to any one of claim 1-4, comprising fiber optic sensors for liquid level monitoring using differential pressure, in the fluid conditioner tank and the liquid conservation tank.

6.
Subsea pump system according to any one of claim 1-5, comprising fiber optic Bragg grating sensor arrays attached to the suspension of the buoyancy element in the fluid conditioner tank and to the suspension of the buoyancy element in the liquid conservation tank.

7.
Subsea pump system according to any one of claim 1-6, comprising fiber optic Bragg grating or Distributed Acoustic Sensing, as optical fibers operatively arranged to the subsea equipment structure or subsea rotating equipment.

8.
Subsea pump system according to any one of claim 1-7, comprising fiber optic current sensors using Faraday Effect to modulate polarization in the presence of a magnetic field, wherein said sensors are arranged outside conducting elements or inside conducting elements.

9.
Subsea pressure booster, comprising a pump compartment or compressor compartment with impellers and diffusers and a motor compartment with a motor operatively coupled to rotate the impellers, and a lubrication arrangement for lubrication of the motor compartment bearings, seals and coil windings, c h a r a c t e r i s e d i n that the subsea pressure booster comprises at least

one optical fiber sensor arranged in the motor compartment or in a lubricant circuit part arranged from and to said motor compartment, for monitoring a lubricant flow rate, and preferably all subsea sensors consist of optical fiber sensors and all electronics for monitoring and control consist of electronics arranged topsides.

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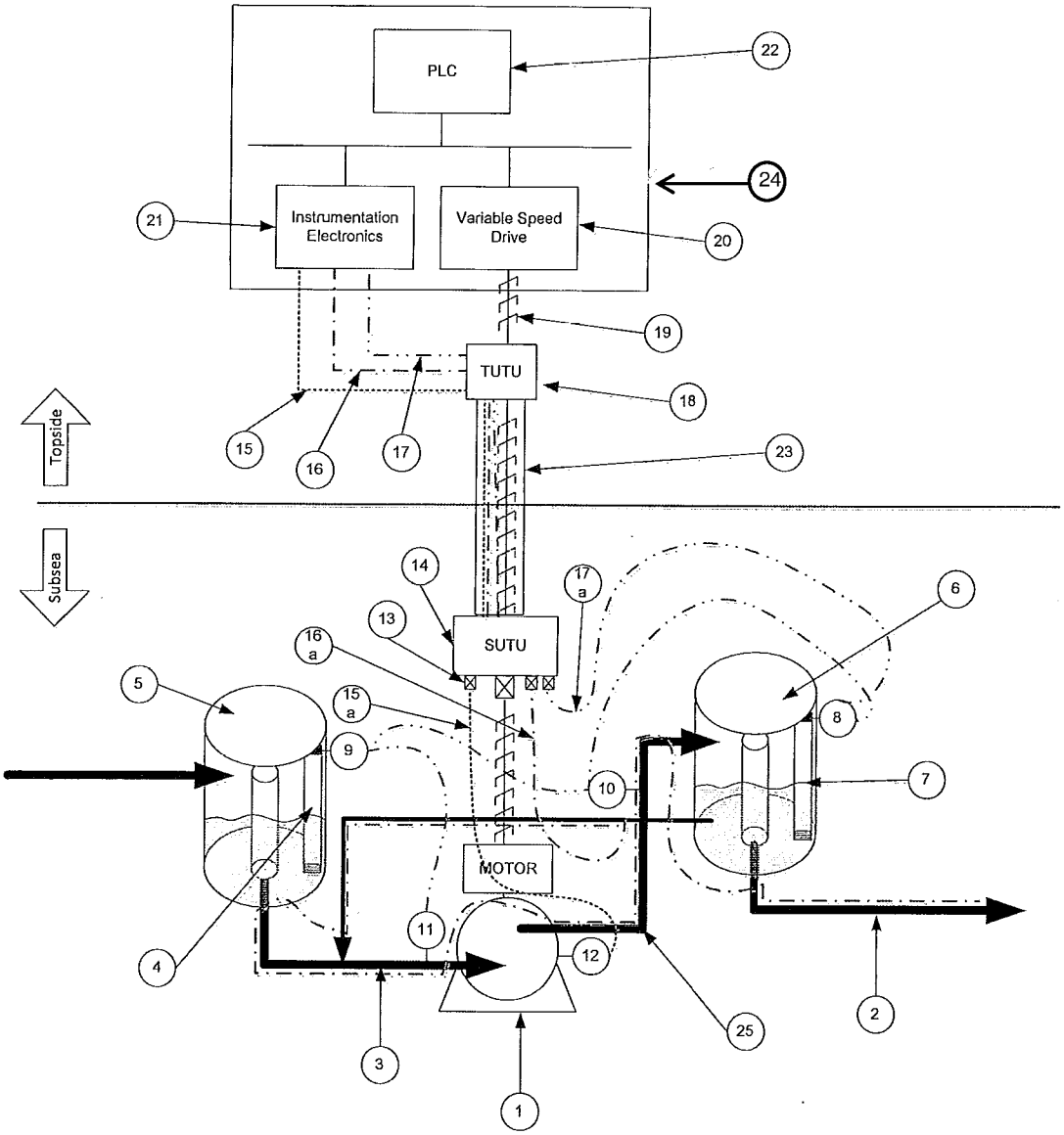
Fig. 1


PLC
22
24
21
Instrumentation Electronics
Variable Speed Drive
20
19
TUTU
18
Topside
15
16
17
23
Subsea
14
17 a
6
13
SUTU
16 a
5
15 a
8
9
10
7
MOTOR
11
12
4
2
25
3
1

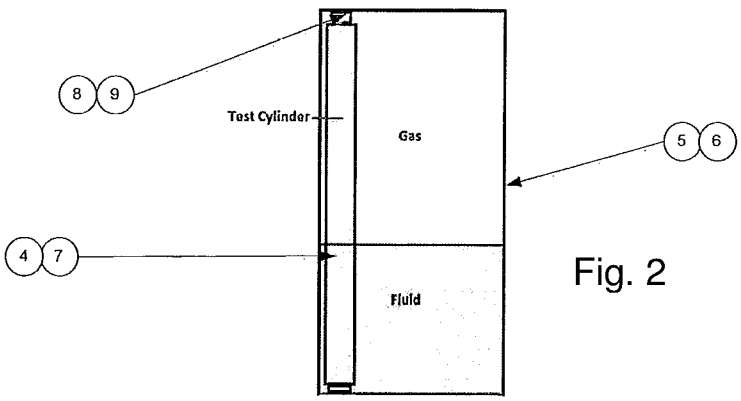

8 9
Test Cylinder
Gas
5 6
4 7
Fluid

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO2016/050193

A. CLASSIFICATION OF SUBJECT MATTER

F04D 13/08 (2006.01), E21B 43/12 (2006.01), F04B 23/00 (2006.01), F04B 47/06 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04D, F04B, E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

DK, NO, SE, FI: Classes as above.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, FULLTEKST: ENGLISH, GERMAN, FRENCH

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015/0110439 A1 (FRIPP, M. L. et al.) 2015.04.23, The whole document	1-8
A	US 2002/066309 A1 (TUBEL, P. et al.) 2002.06.06, The whole document	1-8
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05/12/2016	07/12/2016
Name and mailing address of the ISA Nordic Patent Institute Helgeshøj Allé 81 DK - 2630 Taastrup, Denmark. Facsimile No. + 45 43 50 80 08	Authorized officer John André Wilhelmsen Hodneland Telephone No. +47 22 38 75 46

Box No. IV **Text of the abstract (Continuation of item 5 of the first sheet)**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO2016/050193

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-8, which essentially define a subsea pump system.

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99/40553 A1 (KIM, W. T. et al.), 1999.08.12, The whole document	1-8
A	US 5164605 A (KIDWELL, J. J.), 1992.11.17, The whole document	1-8

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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Continuation of: Box No. III, Observations where unity of invention is lacking:

This application is deemed to comprise two inventions, therefore it does not meet the requirements for unity of invention, as set forth in Rule 13.1 PCT. Invention 1 is described in claims 1-8, and invention 2 is described in independent claim 9, and they are considered to be:

1. Claims 1-8 essentially define a subsea pump system comprising:

a) a subsea pump, a fluid conditioner tank, a liquid conservation tank.

b) the fluid conditioner tank is arranged upstream to the subsea pump, which is arranged upstream to the liquid conservation tank.

c) a first buoyancy element suspended in the fluid conditioner tank, a second buoyancy element suspended in the liquid conservation tank.

d) optical fiber sensors, at least arranged to a suspension of the buoyancy element in the fluid conditioner tank and to a suspension of the buoyancy element in the liquid conservation tank.

2. Independent claim 9 essentially define a subsea pressure booster, comprising a pump compartment or compressor compartment with impellers and diffusers and a motor compartment with a motor operatively coupled to rotate the impellers, and a lubrication arrangement for lubrication of the motor compartment bearings, seals and coil windings comprising:

a) at least one optical fiber sensor arranged in the motor compartment or in a lubricant circuit part arranged from and to said motor compartment.

The features of claims 1-8 addresses the technical problem to monitor and control buoyancy elements in the fluid conditioner tank and in the liquid conservation tank.

The features of claim 9 addresses the objective technical problem of monitoring a motor compartment in a subsea pressure booster.

The only technical feature common to the claims 1-8 and claim 9 is, at most, to arrange an optical fiber sensor in different subsea equipment. Such arranging of optical fiber sensors for monitoring and controlling subsea equipment, is considers well known for a skilled person in the art.

The requirement of unity is not fulfilled, according to Rule 13.2 PCT, because there are no common special technical features in claims 1-8 and independent claim 9.