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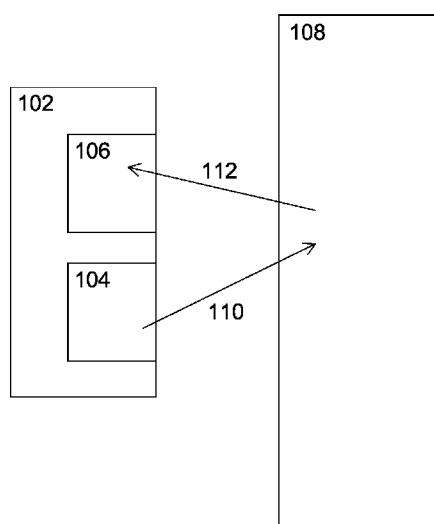


Fig. 1

(57) Abstract: A down hole scanner comprising a cathode comprising a plurality of carbon nanotubes attached to a substrate, an anode arranged to receive electrons emitted from the cathode and arranged to emit electromagnetic radiation for open hole diagnostics, wherein said cathode and anode are provided within a vacuum chamber and a detector arranged to detect electromagnetic radiation.

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X-RAY BASED DIAGNOSTICS TOOL AND METHOD

Field of the invention

- 5 This invention relates to diagnostics tools, and more specifically to X-ray based diagnostics tools adapted for use in pipeline, open hole or flow measurements.

Background

- 10 Various diagnostic tools are available for applications related to pipeline, open hole and flow measurements. Some of these tools are based on radio-active sources, which pose a high risk to users and are preferably avoided.

Statement of invention

- 15 According to a first aspect of the invention, there is provided a down hole scanner comprising: a cathode comprising a plurality of carbon nanotubes attached to a substrate; an anode arranged to receive electrons emitted from the cathode and arranged to emit electromagnetic radiation for open hole diagnostics; wherein said
20 cathode and anode are provided within a vacuum chamber; and a detector arranged to detect electromagnetic radiation.

- The emitted electromagnetic radiation may be X-ray electromagnetic radiation. The down hole scanner may further comprise a processor arranged to process the detected
25 electromagnetic radiation to determine one or more of: sourceless density, bulk density, azimuthal bulk density, photoelectric factor, azimuthal photoelectric factor, calliper measurements and a Z number.

- According to a second aspect of the invention, there is provided a flow meter for
30 detecting the flow of one or more fluids or solids within a conduit, the flow meter comprising: a cathode comprising a plurality of carbon nanotubes attached to a substrate; an anode arranged to receive electrons emitted from the cathode and arranged to emit electromagnetic radiation for pipeline diagnostics; wherein said cathode and anode are provided within a vacuum chamber; one or more detectors
35 arranged outside the conduit to detect electromagnetic radiation.

The emitted electromagnetic radiation may be X-ray electromagnetic radiation.

5 According to a third aspect of the invention, there is provided a method of detecting a flow, comprising emitting X-ray electromagnetic radiation into a conduit, detecting X-ray electromagnetic radiation emitted from the conduit, and analysing the detected X-ray electromagnetic radiation to determine the flow.

10 The method according to the third aspect may further comprise one or more of: measurement of the attenuation of the signal; displaying the through transmission; Radon image reconstructions on line integral for through transmission; backscatter detection and attenuation; inverse Radon transform image reconstruction for carrying out tomography; image convolution on pairs for same pairs for through transmission and backscatter; deconvolution of a backscatter image from through transmission
15 image; pattern recognition on the convolution image with space reference through triangulation of the error slump; pattern recognition on the de-convoluted image with space reference or through triangulation on the error slump; depth / distance position discrimination of error slump in through transmission image; time lapse the results along the detection interval with plurality of results; combine time lapse results with
20 standard flow meter results

According to a fourth aspect of the invention, there is provided a pipeline diagnostics assembly, comprising: a cathode comprising a plurality of carbon nanotubes attached to a substrate; an anode arranged to receive electrons emitted from the cathode and
25 arranged to emit electromagnetic radiation for pipeline diagnostics; wherein said cathode and anode are provided within a vacuum chamber; a detector arranged to detect electromagnetic radiation.

30 The emitted electromagnetic radiation may be X-ray electromagnetic radiation.

The vacuum chamber may be provided within a pipeline and the detector is provided outside the pipeline. The vacuum chamber may be attached to a pipeline pig and the detector may be arranged to detect the location of said pig within the pipeline. A controller may further be provided which is arranged to generate an electric signal for
35 the anode and the cathode in order to generate a corresponding X-ray signal.

Circuitry may further be provided for connecting the controller to detection tools provided at the pig to transmit signals generated at the detection tool. The vacuum chamber and detector are optionally both provided within a pipeline.

5

The detector may be arranged to detect electromagnetic radiation reflected or emitted from one or more of: deposits attached to the interior of the pipeline, materials provided behind deposits within a pipeline, a liner, a cement layer, or a formation of a wellbore.

10 The vacuum chamber and said detector may both be provided outside a pipeline. The detector may be arranged to detect electromagnetic radiation transmitted or scattered from a pipeline or from a layer provided around the pipeline. The detector may further be arranged to detect electromagnetic radiation transmitted through or scattered from fluids flowing through the pipeline.

15

According to a fifth aspect of the invention, there is provided a flow meter for detecting the flow of one or more fluids or solids within a conduit, the flow meter comprising: a cathode comprising a plurality of carbon nanotubes attached to a substrate; an anode arranged to receive electrons emitted from the cathode and arranged to emit
20 electromagnetic radiation for pipeline diagnostics; wherein said cathode and anode are provided within a vacuum chamber; one or more detectors arranged outside the conduit to detect electromagnetic radiation, wherein the emitted electromagnetic radiation may be X-ray electromagnetic radiation.

25 According to a sixth aspect of the invention, there is provided a method of detecting a flow, comprising emitting X-ray electromagnetic radiation into a conduit, detecting X-ray electromagnetic radiation emitted from the conduit, and analysing the detected X-ray electromagnetic radiation to determine the flow. The method according to the sixth aspect may further comprise one or more of: measurement of the attenuation of the
30 signal; displaying the through transmission; Radon image reconstructions on line integral for through transmission; backscatter detection and attenuation; inverse Radon transform image reconstruction for carrying out tomography; image convolution on pairs for same pairs for through transmission and backscatter; deconvolution of a backscatter image from through transmission image; pattern recognition on the
35 convolution image with space reference through triangulation of the error slump;

pattern recognition on the de-convoluted image with space reference or through triangulation on the error slump; depth / distance position discrimination of error slump in through transmission image; time lapse the results along the detection interval with plurality of results; combine time lapse results with standard flow meter results

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Drawings

Some embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

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Fig. 1 illustrates a detection method;

Fig. 2 illustrates a tunable CNT-based irradiator;

Fig. 3 is a schematic drawing of a pipeline and diagnostics system;

Fig. 4 is a schematic drawing of a pipeline and diagnostics system;

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Fig. 5 is a schematic drawing of a pipeline and diagnostics system;

Fig. 6 is a schematic drawing of a pipeline and diagnostics system;

Fig. 7 is a schematic drawing of a pipeline and diagnostics system;

Fig. 8 is a schematic drawing of a pipeline and diagnostics system;

Fig. 9 is a schematic drawing of a pipeline and diagnostics system;

20

Fig. 10 is a schematic drawing of a pipeline and diagnostics system;

Fig. 11 is a schematic drawing of a pipeline and diagnostics system; and

Fig. 12 is a schematic drawing of a pipeline and diagnostics system.

Specific description

25

Herein disclosed is a pipeline diagnostics assembly. The assembly includes a cathode comprising a plurality of carbon nanotubes attached to a substrate and an anode arranged to receive electrons emitted from the cathode and arranged to emit electromagnetic radiation for pipeline diagnostics. The cathode and anode are both provided within a vacuum chamber. A detector is provided outside the vacuum chamber and is arranged to detect non-ionizing radiation or electromagnetic radiation, in particular X-ray radiation emitted from the anode and scattered by a pipeline or materials associated with a pipeline. Alternatively, the detector is arranged to detect X-rays which are transmitted through a medium associated with the pipeline.

35

In embodiments described herein, irradiators that include carbon nanotube (CNT)-based field emitters are implemented; such 'CNT-based irradiators' can be implemented in radiography. FIG. 1 schematically illustrates using a CNT-based irradiator to implement a tomographic device used to analyse a material. In particular, FIG. 1 illustrates that a tomographic device 102 includes a CNT-based irradiator 104 in conjunction with a detection device 106. The tomographic device 102 is disposed before a material 108, which may be a pipeline or a formation for example. X-rays 110 are emitted by the irradiator 104, and the X-rays are determined by a certain energy and intensity range in the direction of the material to be analysed. In accordance with principles of radiography, the interaction of the X-rays 110 with the material can produce backscatter 106. The backscatter can be detected by detection device 106 and analysed to infer information about the material.

FIG. 2 illustrates the general structure of a CNT-based irradiator. In particular, it is illustrated that the CNT-based irradiator includes a CNT-based cathode 22 and an anode 23, both of which are disposed within a vacuum chamber 21. The cathode emits a beam of electrons 24 which are received by anode 23. The anode emits X-rays 25 when the electrons are received. The vacuum chamber 21 includes a window through which the X-rays 25 can be emitted. The CNT-based irradiator includes a coating of carbon nano-tubes. The material of the anode 23 determines the wavelength of the emitted X-rays.

The inventors have appreciated that a tomographic device including a CNT-based X-ray source can have small dimensions such that it can be used in applications such as pipeline diagnostics in which conventional sources cannot be used because they are too large.

In one embodiment, the vacuum chamber is provided within a pipeline, the detector is provided outside the pipeline. The vacuum chamber is attached to a pipeline pig. The pig can be used for general pipeline pigging technologies such as internal pipeline cleaning, internal coating or inspection. The pig will travel through the pipeline, while the detector is used to detect the location of said pig within the pipeline. A plurality of detectors can be placed outside the pipeline such that the pig can be tracked while it progresses through the pipeline.

The use of the vacuum chamber within the pipeline avoids the need for a radioactive source, which represents a high safety risk. The vacuum chamber with the X-ray source emits a signal which propagates through the wall of the pipe and can be detected by the detector placed outside the pipeline. The detector is stationary and the pig with the X-ray source moves, so the detector will detect a stronger signal when the pig is in close proximity when compared to a weak signal when the pig is further away from the detector.

The signal transmitted by the X-ray source can be a signal which is stationary in time, and the strength of the signal at the detector will be an indication of the distance. Alternatively, the signal can be variable in time, such as a pulsed signal. When a plurality of pigs is used with a corresponding plurality of X-ray sources, then each source can be arranged to emit its own unique signal such that the detector can be used to identify which pig passes within the pipeline.

As a further option, the X-ray source can be controlled by a device which is coupled to diagnostics tools provided at the pig. For example, the pig may be used for inspection and the X-ray source can be used to transmit the result of this inspection to a detector located outside the pipeline. When, for example, a weakening of the pipeline is identified, or when a deposit at the wall of the pipeline is identified, then this result can be transmitted in real time to the detector located outside the pipeline.

Figure 3 illustrates schematically a pipeline with a wall 31 and an external coating 32. A pig 33 is provided within the pipeline and the pig carries an X-ray source 34 based on the CNT technology described above. A detector 35 is provided outside the pipeline and is arranged to detect a signal 36 emitted by the X-ray source 34.

In a different embodiment, the vacuum chamber with an X-ray source and the detector are both provided within a pipeline. The detector is arranged to detect electromagnetic radiation reflected or emitted from one or more of: deposits attached to the interior of the pipeline, materials provided behind deposits within a pipeline, a liner, a cement layer, or a formation of a wellbore. In particular, Compton backscatter is generated by the incident X-ray radiation and detected by the detector.

The X-ray source can be used for in-line inspection (ILI) technologies. One of the main problems of the existing ILI technologies is the fact that it is difficult to measure the corrosion features beneath the scale deposition inside the pipeline. In a production pipeline, scale is often formed and in flexible risers it is not possible to use aggressive cleaning pigs in order to remove the scale prior to in-line inspections. Therefore, the results of the inspection are not always reliable. The inventors have realised that this problem can be overcome by using the X-ray source described above.

Figure 4 illustrates a pipeline 41. Within the pipeline, a sensor carrier pig 42 carries X-Ray sources 43, and sensors 44. The sensor carrier pig 42 can be attached to a further pig 45.

Figure 5 illustrates parts of Figure 4 in more detail and corresponding elements are assigned like reference numbers. A deposit 46 is illustrated on the inside of pipeline 41, and corrosion 47 is illustrated underneath deposit 46. The X-ray signal emitted from X-ray source 43 scatters back and the backscattering is detected by sensor 44. A data storage memory 48 is provided which is arranged to store measurements collected by the detector.

Using X-RAY scanning for mapping the interior pipeline wall topography has a higher resolution than ultrasonic technology. In addition, the X-Ray can easily penetrate the wax, debris or scale deposits on the inside of the pipe, thus assessing the pipeline wall through the deposits without any problem. This new technology can be combined with the existing ILI technologies such as UT, MLF, etc. One advantage of using the technology described herein within pipeline inspection is that it is versatile, small, and does not consume too much energy. In regards to pipelines with scale and debris which are difficult to be cleaned, this technology eliminates the need of cleaning the lines, because the X-ray based detector can accurately assess the pipe wall beneath the debris

In the previous embodiment, the X-ray source is used for inspecting the wall through deposits. However, in a further embodiment the deposits themselves are measured. The wax or deposit on the pipe wall can be characterised with high accuracy. The resolution of the measurements can be in the order of nanometres due to the short wavelength of the X-rays. Information can be obtained about various chemical and

physical properties of debris, such as: composition, density and structure. In addition to the size measurements of the deposits it can be also assessed other properties of the deposits such as: density, composition, structure, and crystallography.

- 5 Figure 6 illustrates an X-ray sensor 61 attached to one end of a carrier pig 62. The technology can also be used in a variety of environments, such as within a production line, a water injection line, lines carrying multiphase fluids, etc.

- 10 In a further embodiment, both the vacuum chamber including the X-ray source and the detector are provided outside the pipeline. In this configuration, various characteristics of the outside of the pipeline can be detected.

- 15 In a particular example of this embodiment, the corrosion of a pipeline underneath an insulating layer is detected. Fig. 7 illustrates a pipeline 71 with an insulating layer 72 and a protective layer 73. A sensor carrier 74 supports an X-ray source 75 and a detector 76, and the data collected by the detector can be stored in memory 77. A signal emitted from the source 75 scatters at a location 78 with corrosion behind the insulation layer and on the pipeline, and the scattered signal is detected by detector 76.

- 20 An advantage of the X-ray source described above is the low overall weight and energy efficiency. The X-ray source can therefore be carried on a portable device or on a drone. Long distances of pipeline can be detected in this way and pipelines which are not easily accessible can also be accessed.

- 25 In a further embodiment, the vacuum chamber with X-ray source and the detector are both provided outside a pipeline. The detected radiation can be used to analyse fluid and materials present within the pipe. In particular, the arrangement can be used as a flow meter.

- 30 Flow detection technology in general can be used to detect pressure variations of a fluid flow within a pipeline. Determining the flow properties in fluids is challenging when there are time dependent variations in chemical composition, viscoelastic parameters and grain contents. Existing technology is generally not capable of determining the volume of drill cuttings in mud, mineralogical composition of the mud, oil based mud
35 flow characterisation, properties of cement slurries.

The inventors have realised that one or more X-ray sources and detectors as described above can be used to determine these characteristics. Fig. 8 illustrates an arrangement of three X-ray sources disposed around the pipeline, shown in a cross section, and three detectors opposite each source, so nine detectors in total. A cone of X-ray emission is transmitted from each source to the three opposite detectors. The detectors will be able to detect time dependent through transmission and also backscatter. Some drill cuttings are also illustrated and these drill cuttings will provide strong scattering sources. Figure 9 illustrates a side view of the pipe and shows that the X-ray sources and detector can be distributed along the longitudinal direction of the pipe as well as around the circumferential direction. A different number of detectors and transmitters can also be used for detecting through transmission and backscatter.

The collected data for a pair of X-ray source and detectors can be processed in several ways. Some examples are: measurement of the attenuation of the signal; displaying the through transmission; Radon image reconstructions on line integral for through transmission; backscatter detection and attenuation; inverse Radon transform image reconstruction for carrying out tomography; image convolution on pairs for same pairs for through transmission and backscatter; deconvolution of a backscatter image from through transmission image; pattern recognition on the convolution image with space reference through triangulation of the error slump; pattern recognition on the deconvoluted image with space reference or through triangulation on the error slump; depth / distance position discrimination of error slump in through transmission image; time lapse the results along the detection interval with plurality of results; combine time lapse results with standard flow meter results.

Down hole use of an array of x-ray sources and detectors spaced around the sources can also be used to capture backscattering from the mud flow to capture the mud condition parameters and the content of cuttings and other particles flowing in the mud. Figure 10 illustrates a configuration of an X-ray source and an area in which detectors can be placed for detecting backscattering.

The measurement device at the topside mud return line can be made in a material suitable for x-ray transmissibility. Titanium, if suitable, can be made as a pipe with all the instrumentation attached around the pipe. A materials like GRP (Glass fiber

reinforced) and other polymer based materials, which is much used offshore, can also be used and provide a low attenuation of the x-rays between source and detectors. Hence a low energy source can be used (easier to shield) for improved HSE at the working location. Use of GRP, or similar materials, may also make it interesting to look at various x-ray picture chips for detection of the response from the flowing media. X-ray picture chips are available from various sources and can be “wrapped” around the pipe closely to detect direct photons and possibly back scattering. If the physics of this works, the next challenge is to process all the data and make them into meaningful information for the drilling process.

10

In a further embodiment, the source and detector are both provided within the pipe and are used for characterising properties of the formation.

Some existing tools for down hole use exists for fluid and formation properties logging. These tools need to be run in combinations and on several runs to provide the wanted data. The tool strings are heavy and expensive to run. The data captured are generally recorded uniformly or in one direction of the hole only. These bulk data generally average the formation properties with little around the hole resolution.

The inventors have realised that the X-ray source and detector described above can be used for downhole characterisation. Figure 11 illustrates an arrangement of an X-ray source and sensor area provided within a pipe. Figure 12 illustrate two X-ray sources and a sensor area provided within a pipe. The source can rotate and fire X-rays radially and the detectors capture the back scattering. The rotating x-ray source can be an assembly of sources on the same or on different energy levels. The X-ray source can fire very short pulses of highly focused energy giving distinct backscattering data from illuminated areas. This provides the capability to capture high resolution data from illuminated objects, fluids and the borehole formation. The X-ray energy level can be selected within a range from soft to hard, from tens to a hundred keV to suit the wanted data acquisition.

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Once the data have been collected, the data can be processed by analysing one or more of: backscatter detection and attenuation, inverse Radon transform image reconstructions, image convolution on pairs of detectors for backscatter, pattern recognition on the convolution image with space reference through triangulation of the

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error slump, time lapse the results along the detection interval with a plurality of results, combine time lapse results with standard flow meters.

Examples of further implementations of the X-ray down hole scanner include:
5 sourceless density, bulk density measurements, azimuthal bulk density measurements, photoelectric (PE) measurements, azimuthal PE measurements, measurement of the photoelectric factor (PEF), elemental capture spectroscopy, calliper measurements and measurement of the Z number (single value + quantitative image).

10 The PEF (or PE) is an specific rock matrix parameter which is defined as $(Z/10)^{3.6}$ where Z is the average atomic number of the targeted rock. The PEF depends on the energy of the excitation radiation, which in this case low energetic (or soft) Gamma radiation.

15 Although the invention has been described in terms of preferred embodiments as set forth above, it should be understood that these embodiments are illustrative only and that the claims are not limited to those embodiments. Those skilled in the art will be able to make modifications and alternatives in view of the disclosure which are contemplated as falling within the scope of the appended claims. Each feature
20 disclosed or illustrated in the present specification may be incorporated in the invention, whether alone or in any appropriate combination with any other feature disclosed or illustrated herein.

CLAIMS:

1. A down hole scanner comprising:
 - 5 a cathode comprising a plurality of carbon nanotubes attached to a substrate;
 - an anode arranged to receive electrons emitted from the cathode and arranged to emit electromagnetic radiation for open hole diagnostics;
 - wherein said cathode and anode are provided within a vacuum chamber; and
 - 10 a detector arranged to detect electromagnetic radiation.
2. The down hole scanner of claim 1, wherein said emitted electromagnetic radiation is X-ray electromagnetic radiation.
- 15 3. The down hole scanner of claim 1 or 2, further comprising a processor arranged to process the detected electromagnetic radiation to determine one or more of: sourceless density, bulk density, azimuthal bulk density, photoelectric factor, azimuthal photoelectric factor, calliper measurements and a Z number.
- 20 4. A flow meter for detecting the flow of one or more fluids or solids within a conduit, the flow meter comprising:
 - a cathode comprising a plurality of carbon nanotubes attached to a substrate;
 - an anode arranged to receive electrons emitted from the cathode and
 - 25 arranged to emit electromagnetic radiation for pipeline diagnostics;
 - wherein said cathode and anode are provided within a vacuum chamber;
 - one or more detectors arranged outside the conduit to detect electromagnetic radiation.
- 30 5. The flow meter of claim 4, wherein said emitted electromagnetic radiation is X-ray electromagnetic radiation.
6. A method of detecting a flow, comprising
- 35 emitting X-ray electromagnetic radiation into a conduit,

detecting X-ray electromagnetic radiation emitted from the conduit, and
analysing the detected X-ray electromagnetic radiation to determine the flow.

7. The method of claim 6, further comprising one or more of: measurement of the
5 attenuation of the signal; displaying the through transmission; Radon image
reconstructions on line integral for through transmission; backscatter detection and
attenuation; inverse Radon transform image reconstruction for carrying out
tomography; image convolution on pairs for same pairs for through transmission and
backscatter; deconvolution of a backscatter image from through transmission image;
10 pattern recognition on the convolution image with space reference through triangulation
of the error slump; pattern recognition on the de-convoluted image with space
reference or through triangulation on the error slump; depth / distance position
discrimination of error slump in through transmission image; time lapse the results
along the detection interval with plurality of results; combine time lapse results with
15 standard flow meter results

8. A pipeline diagnostics assembly, comprising:
a cathode comprising a plurality of carbon nanotubes attached to a
substrate;
20 an anode arranged to receive electrons emitted from the cathode and
arranged to emit electromagnetic radiation for pipeline diagnostics;
wherein said cathode and anode are provided within a vacuum
chamber;
a detector arranged to detect electromagnetic radiation.

25 9. The pipeline diagnostics assembly of claim 8, wherein said emitted
electromagnetic radiation is X-ray electromagnetic radiation.

30 10. The pipeline diagnostics assembly of any one of claim 8 to 9, wherein said
vacuum chamber is provided within a pipeline and wherein said detector is provided
outside the pipeline.

35 11. The pipeline diagnostics assembly of claim 10, wherein said vacuum chamber
is attached to a pipeline pig and wherein said detector is arranged to detect the location
of said pig within the pipeline.

12. The pipeline diagnostics assembly of claim 11, further comprising a controller arranged to generate an electric signal for the anode and the cathode in order to generate a corresponding X-ray signal.
- 5 13. The pipeline diagnostics assembly of claim 12, further comprising circuitry connecting the controller to detection tools provided at the pig to transmit signals generated at the detection tool.
- 10 14. The pipeline diagnostics assembly of claim 8 or 9, wherein said vacuum chamber and said detector are both provided within a pipeline.
- 15 15. The pipeline diagnostics assembly of claim 14 wherein said detector is arranged to detect electromagnetic radiation reflected or emitted from one or more of:
deposits attached to the interior of the pipeline,
materials provided behind deposits within a pipeline,
a liner, a cement layer, or a formation of a wellbore.
- 20 16. The pipeline diagnostics assembly of any one of claims 8 or 9, wherein said vacuum chamber and said detector are provided outside a pipeline.
- 25 17. The pipeline diagnostics assembly of claim 16, wherein said detector is arranged to detect electromagnetic radiation transmitted or scattered from a pipeline or from a layer provided around the pipeline.
- 30 18. The pipeline diagnostics assembly of claim 16, wherein said detector is arranged to detect electromagnetic radiation transmitted through or scattered from fluids flowing through the pipeline.
- 35 19. A flow meter for detecting the flow of one or more fluids or solids within a conduit, the flow meter comprising:
a cathode comprising a plurality of carbon nanotubes attached to a substrate;
an anode arranged to receive electrons emitted from the cathode and arranged to emit electromagnetic radiation for pipeline diagnostics;

wherein said cathode and anode are provided within a vacuum chamber;

one or more detectors arranged outside the conduit to detect electromagnetic radiation.

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20. The flow meter of claim 19, wherein said emitted electromagnetic radiation is X-ray electromagnetic radiation.

21. A method of detecting a flow, comprising
10 emitting X-ray electromagnetic radiation into a conduit,
detecting X-ray electromagnetic radiation emitted from the conduit, and
analysing the detected X-ray electromagnetic radiation to determine the flow.

22. The method of claim 21, further comprising one or more of: measurement of the
15 attenuation of the signal; displaying the through transmission; Radon image
reconstructions on line integral for through transmission; backscatter detection and
attenuation; inverse Radon transform image reconstruction for carrying out
tomography; image convolution on pairs for same pairs for through transmission and
backscatter; deconvolution of a backscatter image from through transmission image;
20 pattern recognition on the convolution image with space reference through triangulation
of the error slump; pattern recognition on the de-convoluted image with space
reference or through triangulation on the error slump; depth / distance position
discrimination of error slump in through transmission image; time lapse the results
along the detection interval with plurality of results; combine time lapse results with
25 standard flow meter results

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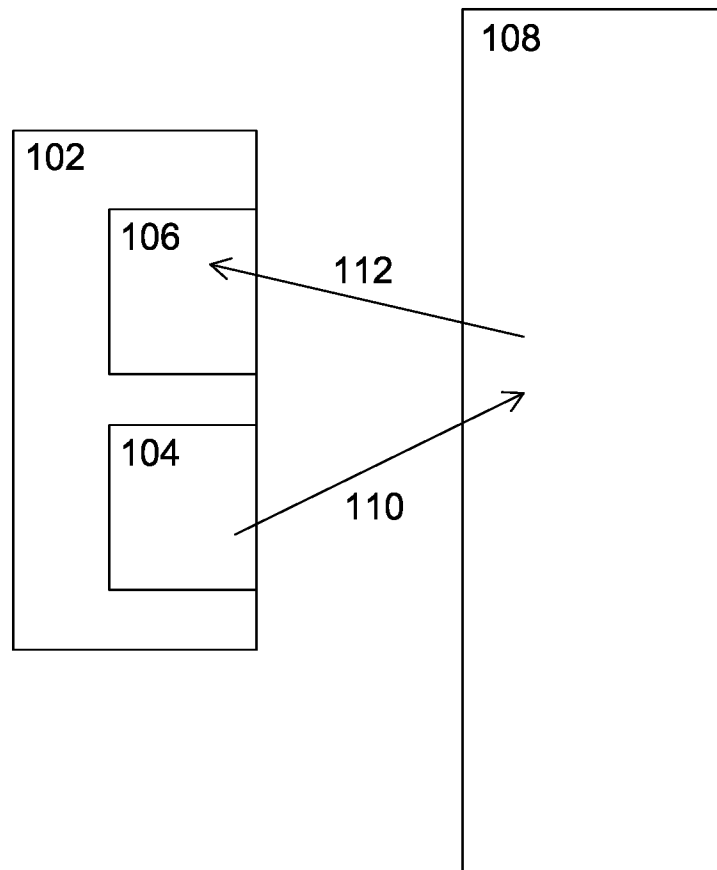


Fig. 1

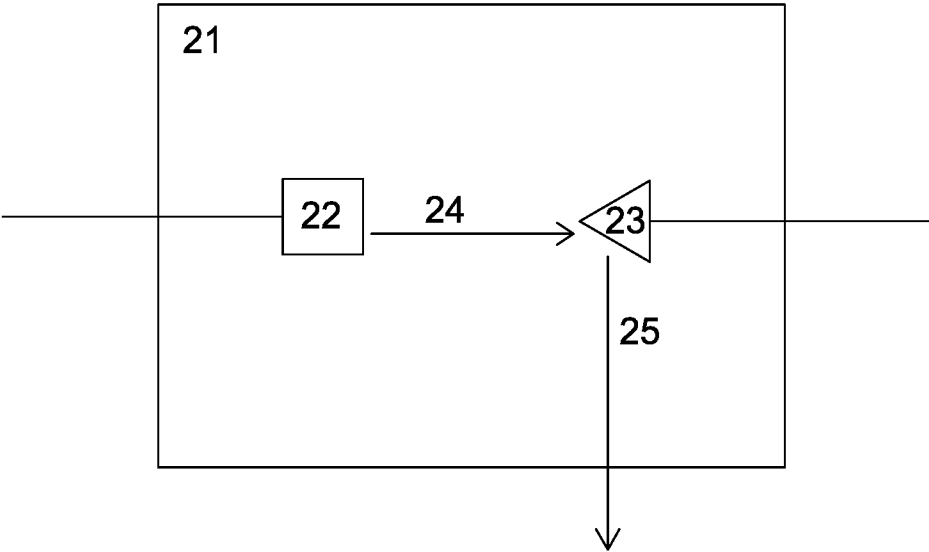


Fig. 2

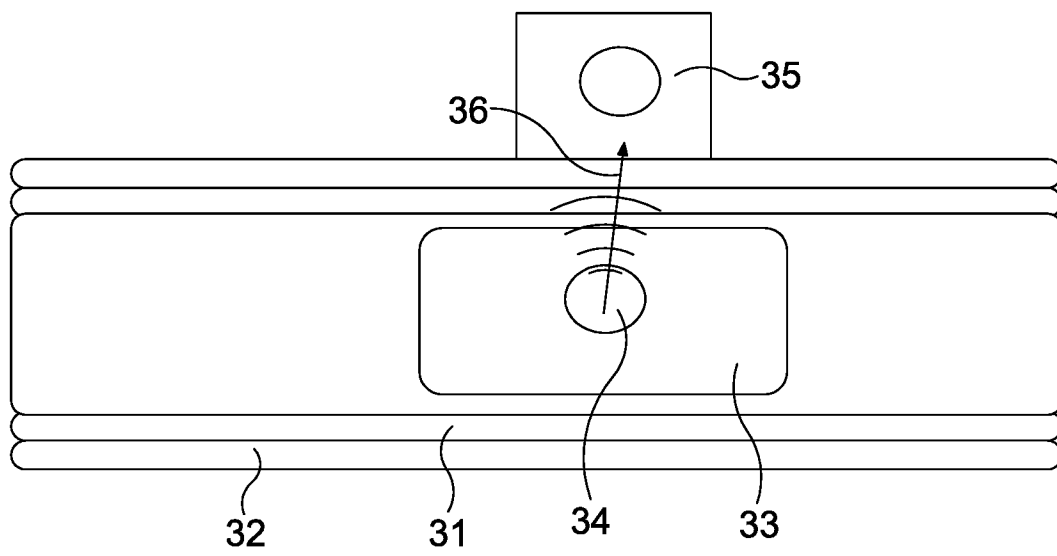


Fig. 3

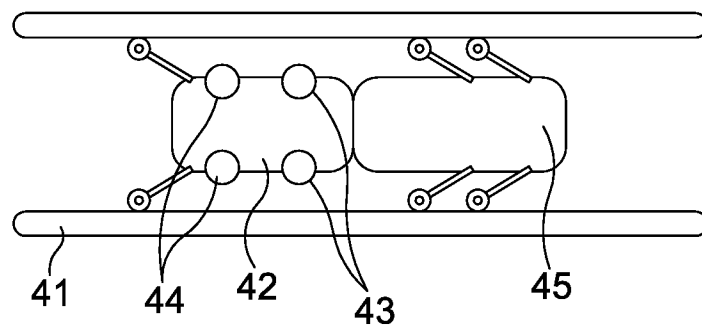


Fig. 4

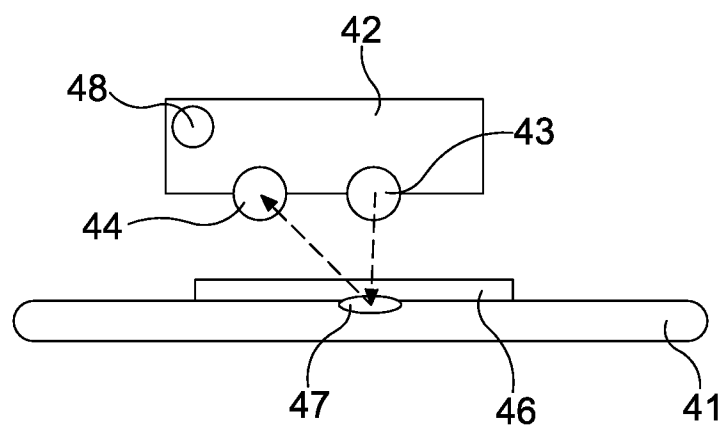


Fig. 5

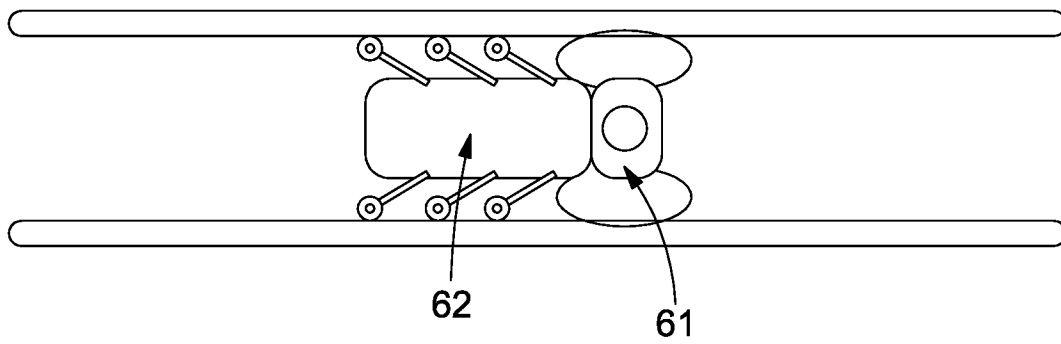


Fig. 6

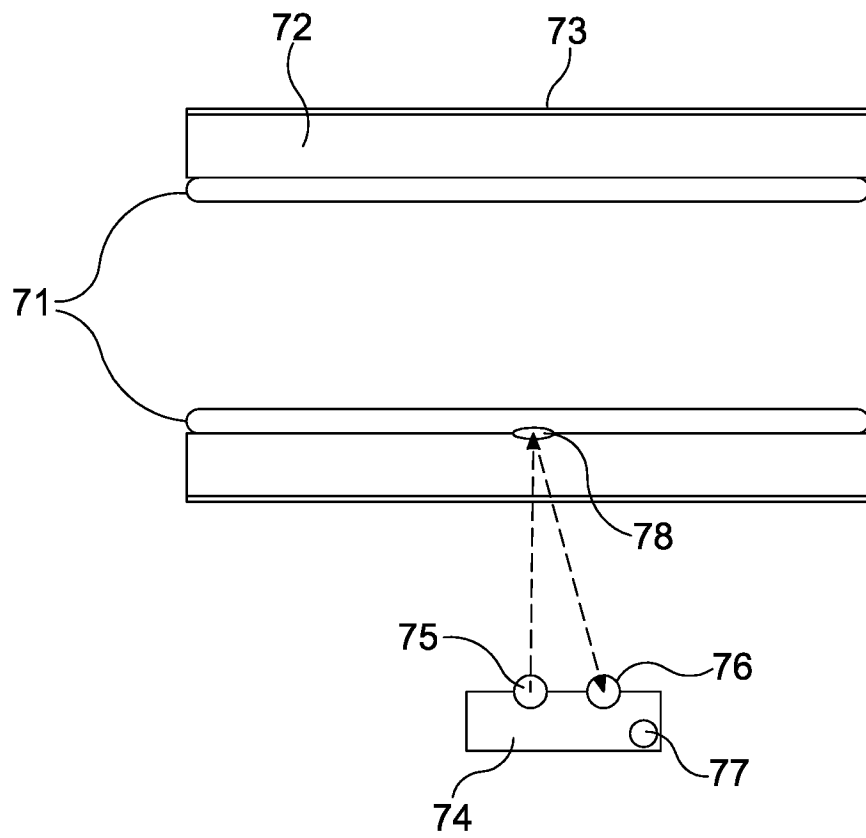


Fig. 7

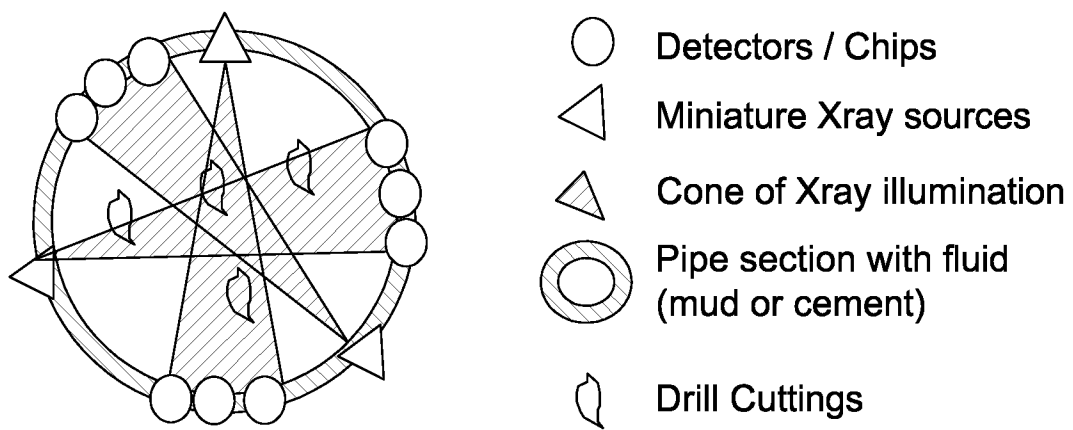


Fig. 8

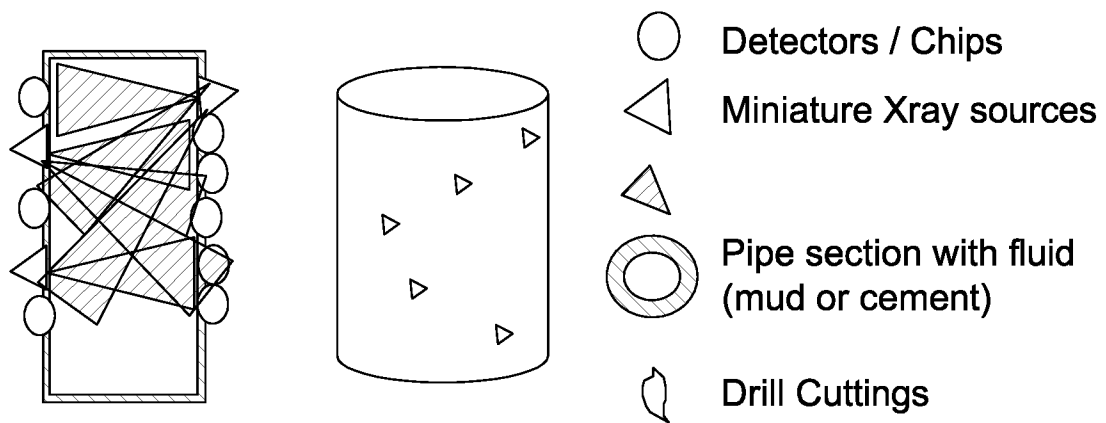


Fig. 9

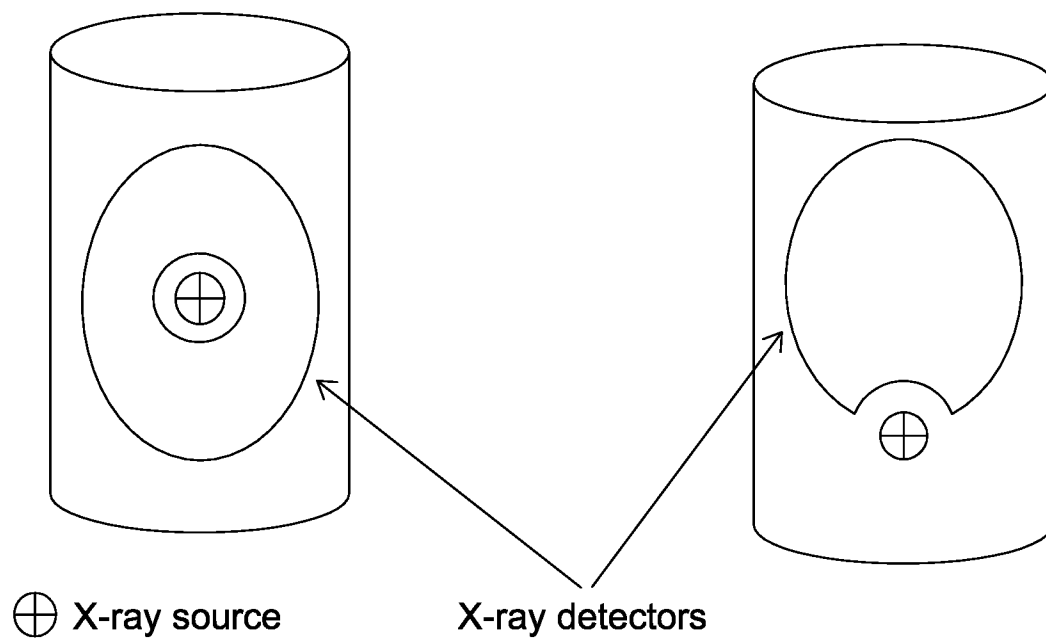


Fig. 10

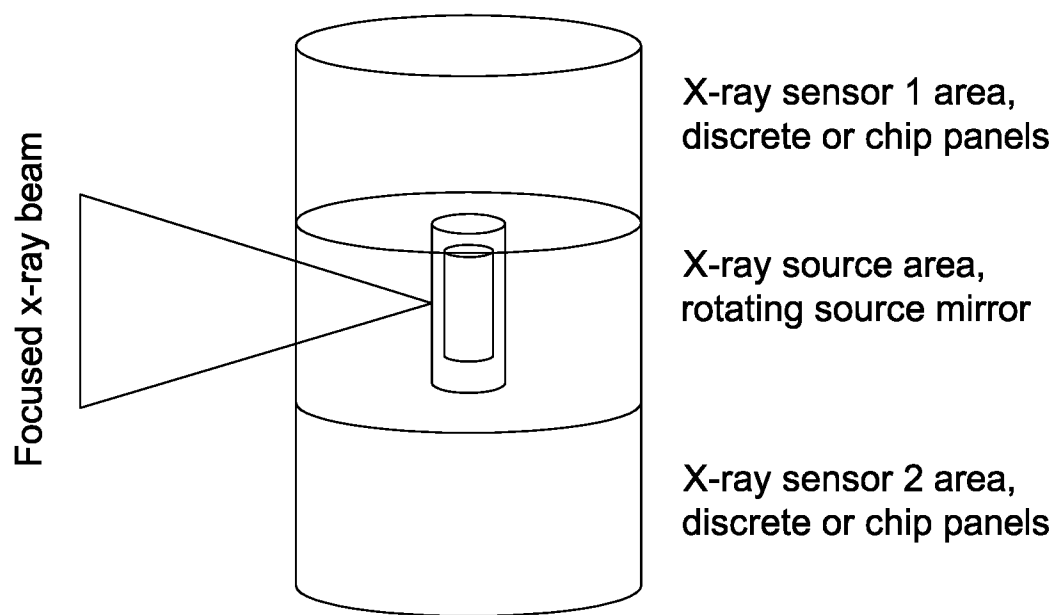


Fig. 11

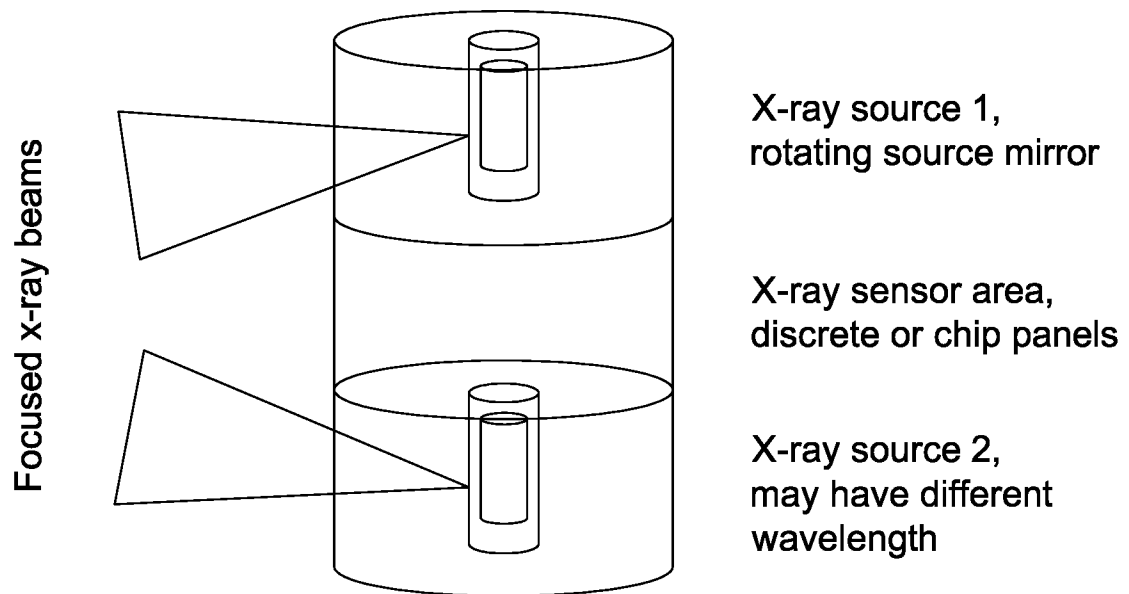


Fig. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO2017/050251

A. CLASSIFICATION OF SUBJECT MATTER G01V 5/12 (2006.01), E21B 47/00 (2012.01), G01N 23/083 (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) G01V, G01N, 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, FULL TEXT: 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.
X	US 2016/274038 A1 (D.J. BRADY et al.) 2016.09.22	1-6,8-10,16,18-21
Y	Abstract; see paragraphs [0024], [0026], [0039]; claims 1, 12; figure 1-3	11-15, 17
A	US 2015/177409 A1 (A. SOFIENKO et al.) 2015.06.25 Abstract; paragraph [0001]-[0005], [0027]-[0029].	6, 7, 21, 22
Y	US 8138471 B1 (D. SHEDLOCK and A. HAMMERSCHMIDT) 2012.03.20 Abstract; column 1, lines 7-33, column 4, line 46-column 7, line 24, column 6, line 46-column 7, line 24; figure 4, 5; claims 1-22	11-15, 17
A	US 7402796 B2 (J.B. FITZGERALD) 2008.07.22 Abstract; paragraphs [0001],[0030],[0032]; figure 1-3	1-22
A	V.B. NECULAES, et al. Multisource X-Ray and CT: Lessons Learned and Future Outlook, IEEE Access, VOL. 2, 2015.01.14, pp. 1568-1585, XP011569992, doi:10.1109/ACCESS.2014.2363949, Abstract; pp. 1572, 1576.	1-22
☐ 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 30/11/2017		Date of mailing of the international search report 30/11/2017
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 Bill Arlander Telephone No. +47 22387524

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/NO2017/050251

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