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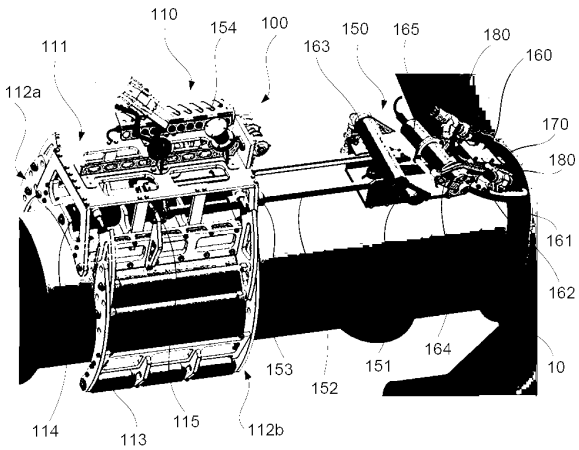
(54) Title **Portable, controllable and autonomous subsea weld inspection tool**

(57) Abstract

Portable, controllable and autonomous subsea weld inspection tool (100) for detachable attachment to a subsea structure (20), wherein it comprises an attachment assembly (110) for detachable attachment to the subsea structure (20), and an inspection probe holder assembly (150), wherein the inspection probe holder assembly (150) is arranged movable in longitudinal direction of the attachment assembly (110) and the attachment assembly (110) is arranged movable in circumferential direction of the subsea structure (20).



Portable, controllable and autonomous subsea weld inspection tool

The present invention is related to a portable, controllable and autonomous subsea weld inspection tool, according to the preamble of claim 1.

Background

It is a well-known fact that it is desired to detect fatigue fractures in offshore/subsea structures, and especially in welded joints thereof, where the load is highest.

An example where this is desired is in relation lifetime extensions where one it is desired to determine status of a structure, and especially the welded joints, which is theoretically «expired» before approval of further operation is given.

Different probes for NDT (Non-Destructive Testing) of the mentioned welded joints can be used for this purpose. Welded joints of subsea structures may be tested using NDT techniques such as ultrasonic testing, magnetic particle inspection or via eddy current technology.

Common for most of these techniques for subsea applications is that the probe used for this would have to be positioned close to the weld and follow this.

Further, there exists no suitable solutions for automated inspection with probes of this kind for subsea use.

Presently the inspection is mainly performed by use of ROV (Remotely Operated Vehicles) or divers. Divers is preferable to avoid due to HES (Health, Environment and Safety) and costs. It is further a problem that it is almost impossible to perform this operation with ROV or divers in the splash zone due to high sea forces, resulting in that it is dangerous for divers to dive there, and ROV equipment will be destroyed.

There exist some solutions where fixed guiding rails have been attached to the subsea structures for arrangement of the probes. A disadvantage with these solutions is that they require accurate arrangement by a ROV and that they would have to be designed for each joint on the subsea structure, which is both expensive and challenging to achieve. There has also been developed some

magnetic crawlers for this inspection, but the manipulation of the probe movements is very difficult for a topside pilot under these conditions.

There is accordingly a need for a portable, controllable and autonomous subsea weld inspection tool that can follow the inspection curves and in a simple manner can be arranged to and removed from a subsea structure.

There is further a need for a portable, controllable and autonomous subsea weld inspection tool that can be reused for other subsea structures.

It is further a need for a portable, controllable and autonomous subsea weld inspection tool that provides control of an inspection probe in relation to a weld of a subsea structure to be inspected.

Object

The main object of the present invention is to provide a portable, controllable and autonomous subsea weld inspection tool partly or entirely solving the above-mentioned drawbacks of prior art.

An object of the present invention is to provide a portable, controllable and autonomous subsea weld inspection tool that can easily be attached and detached from subsea structures.

It is an object of the present invention to provide a portable, controllable and autonomous subsea weld inspection tool that provides control of an inspection probe in relation to a weld of a subsea structure to be inspected.

An object of the present invention is to provide a portable, controllable and autonomous subsea weld inspection tool enabling automated inspection of a weld of a subsea structure to be inspected.

It is an object of the present invention to provide a portable, controllable and autonomous subsea weld inspection tool that is more efficient, accurate and cost-saving in relation to prior art solutions.

Further objects of the present invention will appear from the following description, claims and attached drawings.

The invention

A portable, controllable and autonomous subsea weld inspection tool according to the present invention is disclosed in claim 1. Preferable features of the portable, controllable and autonomous subsea weld inspection tool are disclosed in the remaining claims.

A portable, controllable and autonomous subsea weld inspection tool according to the present invention comprises an attachment assembly for detachable attachment to a subsea structure, and a weld inspection probe holder assembly, wherein the weld inspection probe holder assembly is arranged movable in longitudinal direction of the attachment assembly and the attachment assembly is arranged movable in circumferential direction of the subsea structure.

The inspection probe holder assembly is according to a further embodiment of the present invention arranged for rotational or pivotable movement of an inspection probe arranged to the inspection probe holder assembly about a vertical axis of the inspection probe holder assembly and thus the portable, controllable and autonomous subsea weld inspection tool.

According to a further embodiment of the present invention the inspection probe holder assembly is further arranged for tiltable movement of an inspection probe arranged to the inspection probe holder assembly in vertical direction in relation to the longitudinal direction of the portable, controllable and autonomous subsea weld inspection tool.

By the present invention is accordingly provided a solution for remote subsea weld inspection. The portable, controllable and autonomous subsea weld inspection tool according to the present invention provides controlling of an inspection probe in all 6 degrees of freedom, enabling the weld to be inspected by a pilot or inspector from topside.

Accordingly, the attachment assembly will retain the inspection probe holder assembly movably to the subsea structure and thus the inspection probe movable in relation to a weld is to be inspected.

The present invention will especially be suitable for inspection (scanning) of a weld in a joint between substructures of a main subsea structure, such as a joint between two substructures of a main subsea structure of a steel jacket of a platform used in connection with offshore oil production, offshore wind farms or fish farming structures.

According to the present invention, the controlling of the portable, controllable and autonomous subsea weld inspection tool for inspection of a subsea weld can be performed manually by means of a control unit or automatically by means of optical or laser reading of the weld by means of a vision system.

In relation to optical or laser reading of the weld, the portable, controllable and autonomous subsea weld inspection tool is provided with laser light sources or cameras for providing reference points and cameras for reading the reference points and controlling the portable, controllable and autonomous subsea weld inspection tool based on the readings. The portable, controllable and autonomous subsea weld inspection tool can then analyze the readings and automatically control the probe position at the weld and calculate the required movements, and then scan the weld configuration.

The portable, controllable and autonomous subsea weld inspection tool can according to the present invention be arranged to the subsea structure by means of rigging equipment, an splash zone access tool, or by an ROV (Remotely Operated Vehicle).

Accordingly, the portable, controllable and autonomous subsea weld inspection tool is arranged to subsea structure, whereupon it can be controlled to position the inspection probe in relation to the weld to be inspected followed by inspection (scanning or “pick and place”) by movement in relation to the weld, continuously or in sections.

Further preferable features and advantageous details of the present invention will appear from the following example description, claims and attached drawings.

Example

The present invention will below be described in further detail with references to the attached drawings, where:

Fig. 1 is a principle drawing of a portable, controllable and autonomous subsea weld inspection tool according to the present invention arranged to an access tool,

Fig. 2 is a principle drawing of an embodiment of the portable, controllable and autonomous subsea weld inspection tool according to the present invention,

Fig. 3 is a principle drawing of degrees of freedom for an inspection probe holder according to the present invention,

Fig. 4 is a principle drawing of laser tagging of a weld, and

Fig. 5 is a principle drawing of laser light for optical reading of position according to the present invention.

Reference is no mad to Figure 1 which is a principle drawing of a portable, controllable and autonomous subsea weld inspection tool 100 according to the present invention arranged to an access tool 200, *known per se*, according to prior art. In the shown example the access tool 200 is formed by a clamping device 210 for attachment to an subsea structure 20 and a controllable manipulator arm 220 arranged to the clamping device 210, which controllable manipulator arm 220 can be used to position the portable, controllable and autonomous subsea weld inspection tool 100 in vicinity of a weld 10 of a subsea structure 20 to be inspected. The access tool 200 is only one example of a system or device that can be used for positioning the portable, controllable and autonomous subsea weld inspection tool 100, and e.g. a ROV can be used for this, as well as rigging equipment, and other devices/systems which will be within the knowledge of a skilled person.

Reference is now made to Figure 2 which is a principle drawing of an embodiment of the portable, controllable and autonomous subsea weld inspection tool 100 according to the present invention, and Figure 3 which is a principle drawing of degrees of freedom for an inspection probe holder 160 according to the present invention. The portable, controllable and autonomous subsea weld inspection tool 100 according to the present invention comprises an attachment assembly 110 and an inspection probe holder assembly 150.

The attachment assembly 110 is in the shown embodiment formed by a body 111, wherein controllable clamps 112a-b are arranged to each side of the body 111 such that the body 111 and thus attachment assembly 110 can be detachably attached to a subsea structure 20 by engagement of the clamps 112a-b from each side. In the example the subsea structure 20 exhibit a tubular shape, and the body 111 preferably exhibit a mainly C-shape base adapted the curvature of the tubular subsea structure 20. The clamps 112a-b are preferably controllable by actuators and in addition spring-loaded such that the clamps 112a-b will retain the attachment assembly 110 to the subsea structure 20 with a predefined force and allowing the attachment assembly 110 to be moved in circumferential direction of the subsea structure 20. The clamps 112a-b are further preferably

provided with rolls/wheels 113 with or without magnetics for peripheral movement. In addition, also the main body 111 is preferably provided with rolls 114 at contact surface off the base with the subsea structure 20 for the same reason.

The clamps 112a-b are preferably further arranged to a controllable synchronization stay 115 for ensuring centralization in relation to the subsea structure 20 it is arranged to.

The inspection probe holder assembly 150 is formed by a main body 151, which is arranged movable in longitudinal direction of the attachment assembly 110 by at least one shaft 152 arranged movable in longitudinal direction of the body 111 by means of at least one actuator 153 driven by a motor 154, such as an electric, hydraulic or air driven motor.

The inspection probe holder assembly 150 is further provided with an inspection probe holder 160, controllably arranged to the far end of the main body 151 for arrangement of at least one inspection probe 170. The inspection probe holder 160 is arranged rotatable or pivotable about the vertical axis of the inspection probe holder assembly 150. This can e.g. be achieved by that the inspection probe holder 160 is arranged to travel on a C-shaped track 161 by means of at least one carriage 162, the C-shaped track 161 extending in transversal direction of the main body 151, in a parallel horizontal plane thereof, driven by an electric motor 163 via transmission means, such as belt and cogs.

According to the present invention, the inspection probe holder 160 is further preferably arranged tiltable in vertical direction of the main body 151. This can e.g. be achieved by that the inspection probe holder 160 is arranged to the at least one carriage 162 by a hinged connection at one side and wherein the other side is arranged to a manipulator arm 164 connected to an electric motor 165.

Accordingly, by the present invention is provided a portable, controllable and autonomous subsea weld inspection tool 100 capable of (see Figure 3):

- moving the inspection probe 170 in longitudinal direction (X-direction) of a subsea structure 20 in relation to a weld 10,
- moving the inspection probe 170 vertical direction (Z-direction) of a subsea structure 20 and in relation to a weld 10,
- moving the inspection probe 170 about the vertical axis (Y-direction) of a subsea structure and in relation to a weld 10,

- moving the inspection probe 170 about the longitudinal axis (X-direction) of a subsea structure and in relation to a weld 10,

The portable, controllable and autonomous subsea weld inspection tool 100 is accordingly controllable in all 6 degrees of freedom by pivotable, rotatable or tiltable movement about X, Y and Z-axis of the subsea structure 20, and movement in X, Y and Z-direction.

To be able to control the inspection probe 170 along a weld 10 one will be dependent to control 4 degrees of freedom at the same time. These are movement in X-direction, rotational or pivotable movement about the Y-axis, and tiltable movement about the Z-axis. The remaining two degrees of freedom will be locked according to the design of the portable, controllable and autonomous subsea weld inspection tool 100.

The portable, controllable and autonomous subsea weld inspection tool 100 can be controlled manually by a control unit based on that the portable, controllable and autonomous subsea weld inspection tool 100 is provided with a cameras 180 and light sources. This will then depend on the skills of an operator to provide a successful inspection (scan).

The portable, controllable and autonomous subsea weld inspection tool 100 can be controlled in an automated manner, which will be described below, which will remove or partly remove the need for a skilled/trained operator.

Reference is now made to Figure 4 which is a principle drawing of laser tagging of weld and Figure 5 which is a principle drawing for optical reading of position according to the present invention.

The inspection probe holder assembly 150 further will be provided with at least one camera 180, in the shown embodiment two cameras 180, preferably with integrated lights sources (not shown).

By using laser tagging or photogrammetry tagging 190 of a weld 10 at each side of the inspection probe 170 one will get reference points 1, 2 that can be read optically by means of the cameras 180. The cameras 180 will read and process the several parameters that will be dependent for controlling the portable, controllable and autonomous subsea weld inspection tool 100, and thus provide an automated movement of the inspection probe 180 along a weld 10 to be inspected.

Control of movements by means of optical reading can be summarized as follows:

- Rotation about X-axis is performed with constant velocity and controlled by rotation of the attachment assembly 110 about the surface of the subsea structure 20.

- Movement in X-direction and rotation or pivoting about Y-axis is performed by reading of the mentioned reference points 1 and 2 by laser light. The reference points 1 and 2 will define the distances A and B. These two distances A and B should always be the same and controlled by rotation or pivoting about the Y-axis. In addition, the distances A and B will have a predefined distance that will control movement in the X-direction.

- Rotation or pivoting about the Z-axis is preformed by optical reading of angle of the weld 10 in relation to the position of the inspection probe 170, ref. Figure 4.

The embodiment of the portable, controllable and autonomous subsea weld inspection tool 100 is shown attached to an access tool 200 with a controllable manipulator arm 220, which can be used to control the rotational or pivoting movement about the X-axis by controlling the manipulator arm 220 connected to the attachment assembly 110 for movement of the attachment assembly 110. The rotation or pivoting movement can also be provided by using a ROV with a manipulator arm or that the attachment assembly 110 is provided with means for rotation of the attachment assembly 110, such as rolls, wheels or belts with or without magnets or a C-ring system driven by an electrical motor or similar means which make the rotation control provided by the inspection tool 100 it selves.

The portable, controllable and autonomous subsea weld inspection tool 100 will further be provided with communication means for communication by wire or partly or entirely wireless with a control unit topside.

By the present invention is provided a portable, controllable and autonomous subsea weld inspection tool 100 that can be reused and easily moved from structure to structure without any special adaption to the structure.

By the portable, controllable and autonomous subsea weld inspection tool 100 according to the present invention one will have full control of the inspection probe at all time and the position of the inspection probe can be controlled according to the weld to be inspected, such that a scan of a sector or continuous scan of the weld can be performed with high accuracy and without any risk for personnel or equipment as the portable, controllable and autonomous subsea weld inspection tool 100 can be controlled manually or automated from topside.

Accordingly, the portable, controllable and autonomous weld inspection tool will be provided with a control unit that can read the weld and structure shape by use of sensors and from this data

calculate the movements of the probe holder in an autonomous manner or partly autonomous manner.

Even though the present invention is especially suitable for inspection of welds in joints, the present invention can be used for inspection of any weld in relation to a subsea structure or any weld configuration where an inspection probe to be guided along a weld, both above water or under water.

Modifications

The portable, controllable and autonomous subsea weld inspection tool 100 will or can further be provided with a control unit that can recognize weld shape against already modelled or read shapes (machine learning) and use this information to calculate the needed movement on the inspection scan.

Claims

1. Portable, controllable and autonomous subsea weld inspection tool (100) for detachable attachment to a subsea structure (20), **characterized in** that it comprises an attachment assembly (110) for detachable attachment to the subsea structure (20), and an inspection probe holder assembly (150), wherein the inspection probe holder assembly (150) is arranged movable in longitudinal direction of the attachment assembly (110) and the attachment assembly (110) is arranged movable in circumferential direction of the subsea structure (20).

2. Portable, controllable and autonomous subsea weld inspection tool (100) according to claim 1, **characterized in** that the inspection probe holder assembly (150) is arranged for rotatable or pivotable movement of an inspection probe (170) arranged to the inspection probe holder assembly (150) about vertical axis of the inspection probe holder assembly (150) and thus the portable, controllable and autonomous subsea weld inspection tool (10).

3. Portable, controllable and autonomous subsea weld inspection tool (100) according to claim 1, **characterized in** that the inspection probe holder assembly (150) is arranged for tiltable movement of an inspection probe (170) arranged to the inspection probe holder assembly (150) in vertical direction in relation to the longitudinal direction of the portable, controllable and autonomous subsea weld inspection tool (100).

4. Portable, controllable and autonomous subsea weld inspection tool (100) according to any one of the preceding claims, **characterized in** that it is provided with at least one camera (180) and at least one light sources, wherein the at least one light sources are arranged for providing reference points that can be optically read by the at least one cameras (180), and used for automated control of the portable, controllable and autonomous subsea weld inspection tool (100) in relation to a weld (10).

5. Portable, controllable and autonomous subsea weld inspection tool (100) according to claim 1, **characterized in** that it comprises a control unit arranged to use sensors to collect data of the weld shape, and recognizing or reading the shape in such manner that the movements can be recognized or calculated by the portable, controllable and autonomous subsea weld inspection tool (100).

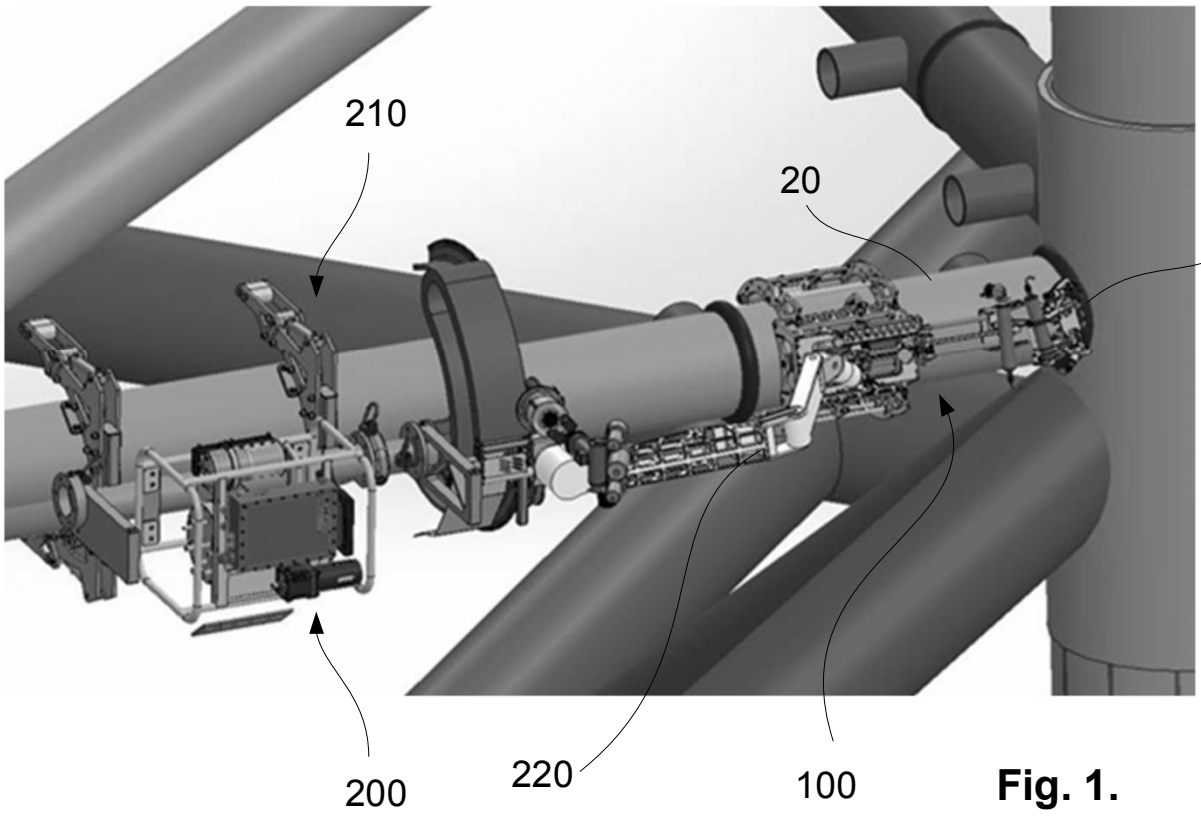
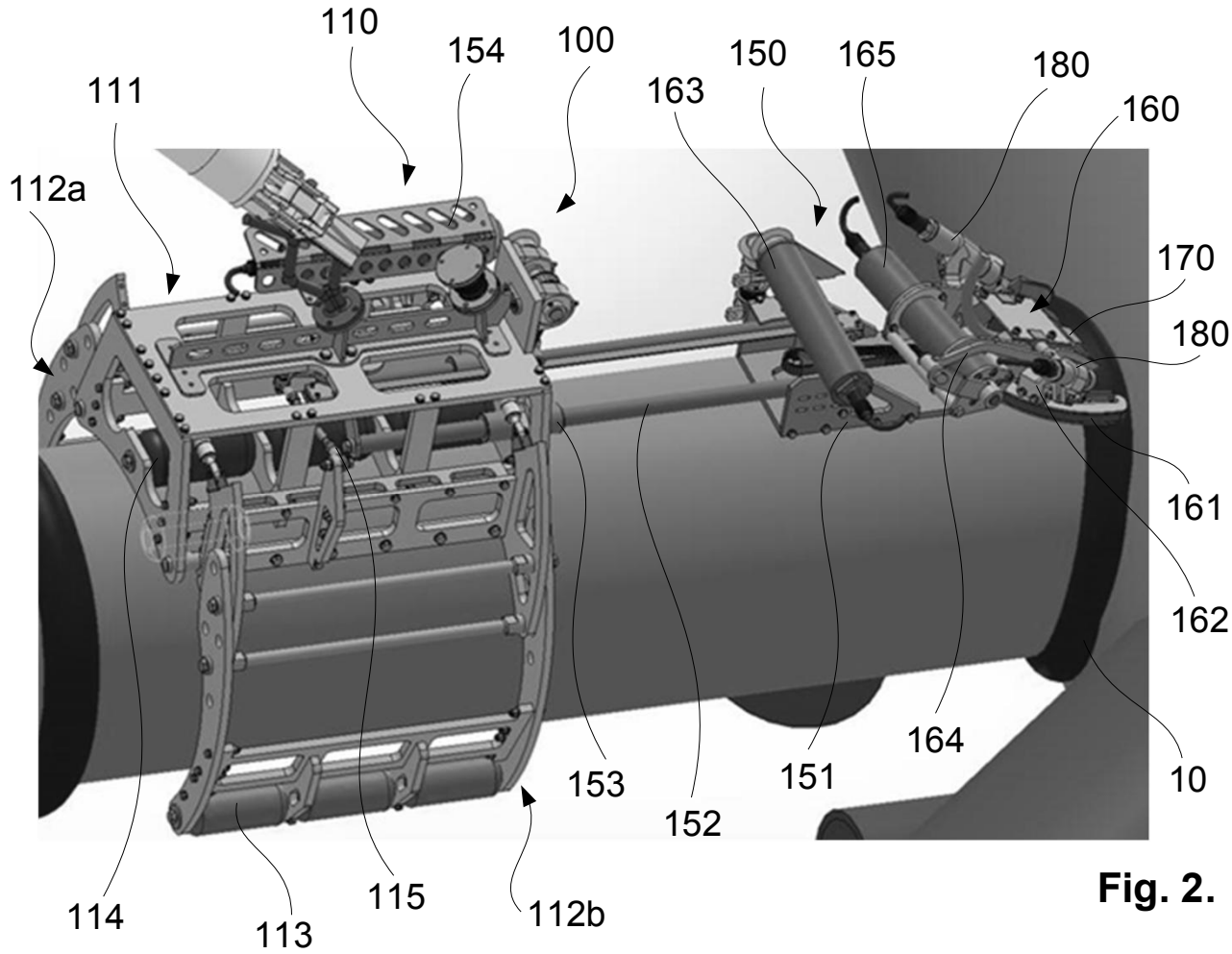

210
20
10
200
220
100

Fig. 1.


110
154
100
150
165
180
111
163
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112a
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161
162
164
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151
153
152
114
113
115
112b

Fig. 2.

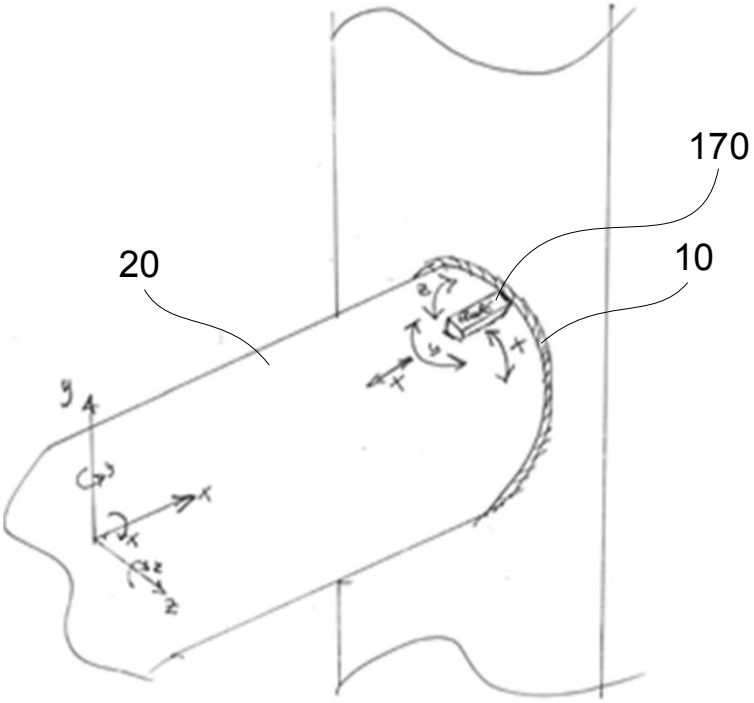

Fig. 3.

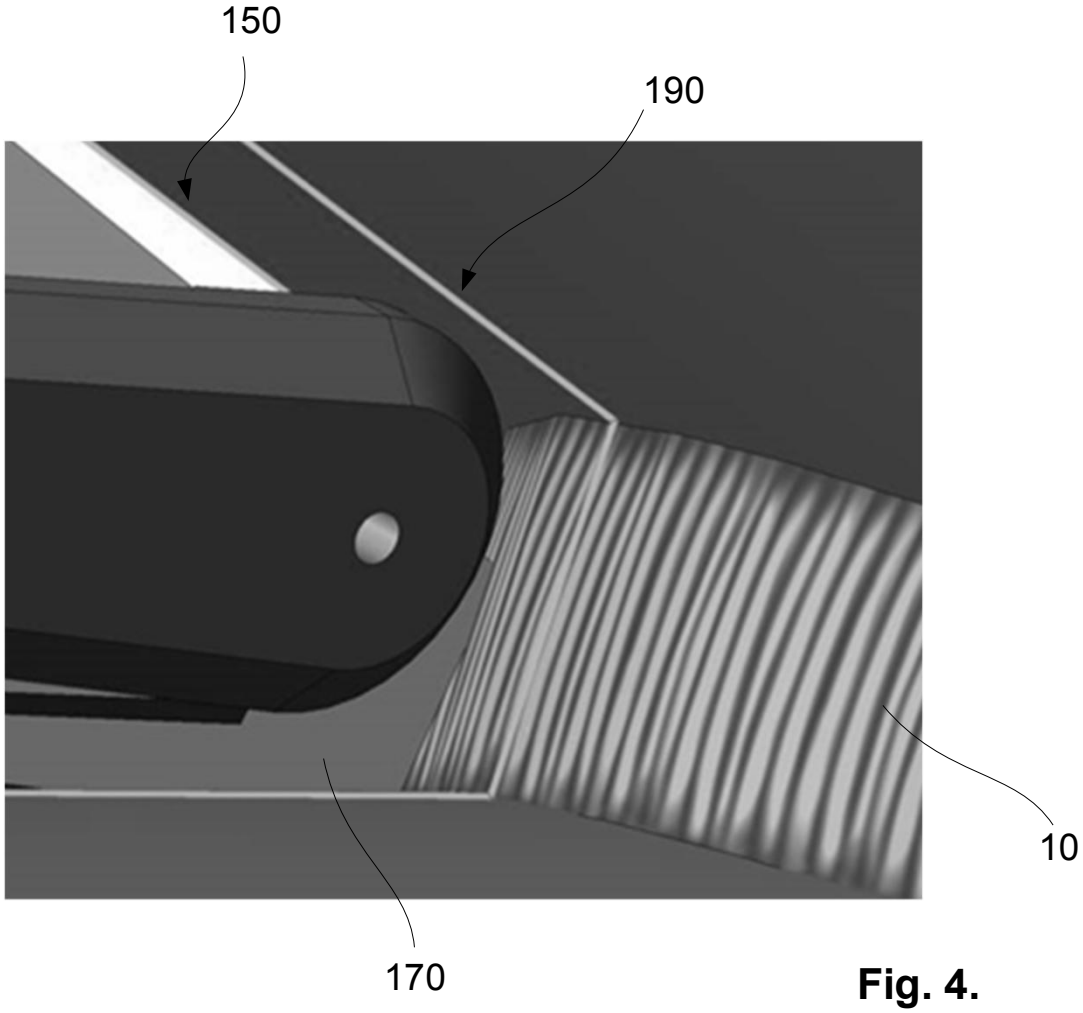

Fig. 4.

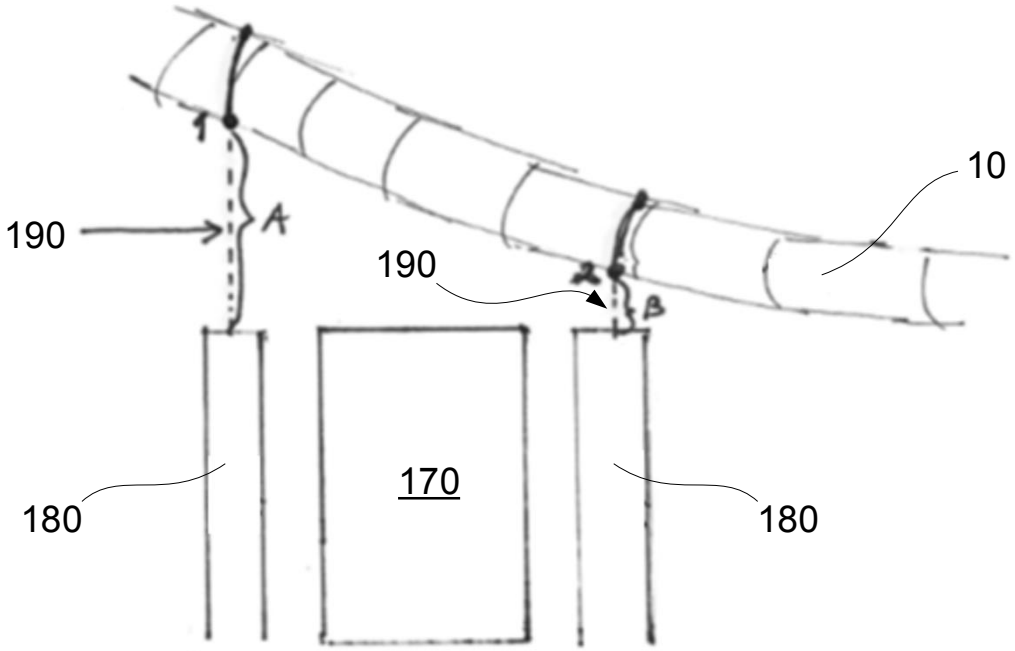

Fig. 5.