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(54) UNDERWATER, REMOTE-CONTROLLED HIGH PRESSURE CUTTING DEVICE WITH ADDITION OF ABRASIVE MATERIAL, AND CUTTING AND ABRASIVE MATERIAL FEEDING METHOD

(57) Underwater, remote-controlled high-pressure cutting device (1) with the addition of abrasive material, consisting of a nozzle guide, preferably with a chain drive (8) of modular structure, on which the cutting nozzle (4) moves, in which the cutting device has a buoyant force in water equal to its weight in the air and the centre of buoyancy (CB) is at the same point as the centre of gravity (CG), preferably at the location of the transport handle. The cutting device is attached to the structure with permanent magnets (23) and disconnection takes place by reversing the magnetic field, preferably with an induction coil or a switchable permanent magnet.

The cutting abrasive material feeding method is characterized by the puncture through the cut material (5) and the cutting speed being verified by observing the behaviour of the liquid stream ejected from the cutting nozzle with a camera and the follow-up adjustment of the nozzle feed speed based on the analysis of the stream reflected or absorbed into the cut object. It is also characterised in that in the conduit supplying the abrasive to the cutting nozzle, compressed air pressure is maintained in excess of the hydrostatic pressure at the depth at which the cutting operation is carried out, the abrasive being fed only when there is no water in the pneumatic conduit by means of a precise abrasive dispenser and after cutting from the conduit the abrasive is removed. The abrasive feeding system enables uninterrupted operation and the pressure in the abrasive feeder and the precise dispenser is equal to atmospheric pressure.

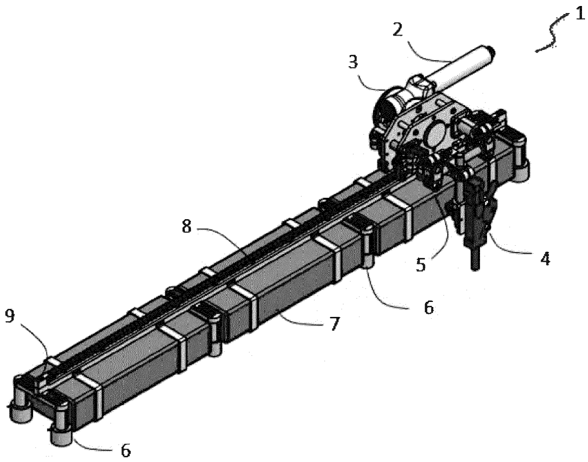

Fig. 1

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Description

[0001] The present inventions relate to an underwater, remote-controlled high pressure cutting device with addition of abrasive material and to an abrasive material feeding method as well as to a cutting method, in order to increase energy of an abrasive fluid jet affecting on a surface unit of a construction or an object, which is cut (Se - specific energy), enabling to manoeuvre with the cutting device by an underwater ROV without exerting a torsional force on the ROV resulting from the weight of the device in the water, consisting of a clamping system to a surface of an object capable to compensate the jet force generated by a high-pressure fluid jet and maintaining adhesion despite the loss of energy supply, as well as system of feeding underwater cutting nozzle with abrasive material.

[0002] Examples of structures and objects that require cutting under water can be mentioned:

- steel structures of hydrotechnical facilities, e.g. harbour facilities,
- sunken wrecks,
- remnants of military conflicts, including UXO facilities,
- offshore structures such as gas and oil platforms, offshore wind farm structures for repair or disassembly,
- underwater pipelines and tanks.

[0003] Among the most common methods of cutting underwater structures and objects there is known use of cutting torches according to the patent no. US2013196274A1 Underwater torch and others of Broco Inc., which after applying current max. 150A and compressed oxygen cause the oxygen to burn at a temperature of 5 500°C and melting of a cut material. The cutting torches require direct operation by a diver, they prevent installation on a ROV, during cutting the diver's visibility is significantly limited due to the blinding flame of the torch burner and large amounts of gas emitted, which in underwater conditions produces gas bubbles clouds. Other hazards for a diver performing thermal cutting work include the accumulation of explosive gases during cutting and electric shock.

[0004] From the patent no. US2016144439A1 Underwater Diamond Wire Saw that for cutting structures there is known use of underwater diamond saws delivered to the cutting site and fixed to a cut object by an underwater remotely operated vehicle (ROV). An object cutting is done by a powered diamond wire saw, which is taut between two arms. In order to cut the object, there is necessary a perimeter access to the object to be cut (strapping the object), wire saws allow cutting pipes, platform supports and blocks. Construction of a wire saw excludes its use for cutting objects if the arms through which the cutting rope is guided do not fully encircle the circumference of the object being cut, e.g. the access is only partial, it is also not possible to cut holes, for example, in planes.

[0005] It is known from the information available on the website https://www.saabseaeye.com/solutions/underwater-vehicles/cougar-xti the method of cutting with a circular saw ("rotary cutter") mounted on an underwater ROV manipulator. The circular saw can be hydraulically or electrically driven and powered by a ROV. The limitations of this solution are: cutting depth limited by the cutting blade radius, difficulty in stabilizing the vehicle, especially in the presence of water currents, which requires an additional manipulator for positioning the ROV to the structure, difficulty in cutting hard materials due to difficulties in exerting pressure on the surface of the blade, no possibility of arc cutting, producing vibration in the object being cut.

[0006] The use of high-pressure fluids with the addition of an abrasive agent is commonly used in land-based solutions, both in stationary cutting tables (waterjet) as well as in mobile systems. The advantages of cutting liquids (usually water) under high (up to 1700bar) or ultra-high pressure of liquids (above 1700bar) are:

- no temperature increase in the cutting zone, which allows cutting materials with a low melting point, does not cause deformations in the cut material and physical changes, e.g. hardening in the cutting zone,
- no vibration to the object being cut,
- possibility of cutting various thicknesses of materials,
- high quality of cut surfaces, which does not require additional preparation in the form of e.g. machining or grinding before subsequent operations, e.g. welding,
- can be used in potentially explosive atmospheres due to the absence of sparks with ignition energy.

[0007] There are known two types of systems for cutting with water (liquid) under pressure with the addition of abrasive material: a) abrasive water injection jets (AWIJ), b) abrasive water suspension jets (AWSJ).

[0008] The main difference is where the abrasive material is applied to the water. In the case of AWIJ, the abrasive agent is fed through a pneumatic conduit connected directly to the cutting nozzle, in which the mixing chamber is located. An abrasive agent is sucked in due to the vacuum produced by the rushing liquid and it hits a material being cut at high speed. The concentration of abrasive in relation to water is assumed to be about 10%. For land, stationary applications, AWIJ cutting is almost exclusive method. Whereas in the case of AWSJ, an abrasive agent is mixed with water under pressure in a special pressure tank and then a suspension of water with abrasive is transported to the nozzle under pressure. The concentration of the abrasive in relation to the water is, as in the case of AWIJ, 10%.

[0009] It is known from the patent No. EP2755802B1 Device for waterjet cutting with abrasive used for AWSJ underwater cutting. Disadvantages of such a solution are the high cost of the pressure vessel, the nominal pressure of which must be at least equal to the cutting pressure, small size of the pressure vessel which requires more frequent refilling with abrasive material, faster consumption of the tank's consumables such as seals, dangerous internal damage to high-pressure lines between the pressure tank and the cutting nozzle, in which the abrasive is transported (cutting through the transported material of the internal surfaces of pipes and fasteners - bends in the pipes and angular connections are particularly vulnerable to damage), destruction of the abrasive material transported in the liquid caused by mutual friction and collisions, clogging nozzle in case of breaks in cutting resulting form abrasive sedimenting in the liquid during lack of flow.

[0010] Despite the great popularity of AWIJ in land applications, the main problem in the use of AWIJ under water is the water ingress into the pneumatic conduit, which supplies the abrasive agent to the cutting nozzle. During cutting, water is supplied from a high-pressure pump or a pressure multiplier through high-pressure hoses to the cutting nozzle, in which, due to the reduction of the flow diameter, the liquid speed is increased, which creates a vacuum in the laterally connected pneumatic conduit through which the abrasive material is sucked in. Thus produced mixture of water, abrasive material and air sucked in from the pneumatic conduit is ejected at high speed towards the object or structure being cut. During cutting, when the high-pressure pump is running, there is air in the air line regardless depth at which cutting is performed. If the cutting process is interrupted, the high-pressure pump or the pressure multiplier does not pump the liquid to the high-pressure hoses, and due to the fact that there are no check or shut-off valves between the pressure generator and the nozzle, the water level in the pressure and pneumatic hoses is balanced out to the water level in the reservoir according to communicating vessels principle. If there was abrasive in the pneumatic conduit, it becomes wet and falls gravitationally towards the nozzle, which causes clogging of the nozzle and no possibility of further work. This is a well-known problem when the AWIJ cutting process is interrupted under water.

Invention essence

[0011] The underwater, remote-controlled, abrasive cutting device according to the invention is characterized by that:

a) the cutting device has a neutral buoyancy in water and the centre of gravity (CG) and centre of buoyancy (CB) are at the same point in the place of the guide handle by the manipulator installed on the ROV.

> The appropriate buoyancy force of the device in water is obtained by installing closed-chamber displacement foams with a low degree of water absorption (<5%) and a density several times lower than that of water, e.g. 200 g/dm^3. The device is trimmed by attaching light steel weights.
>
> A correctly trimmed cutting device will have a weight close to zero in the water and a centre of gravity and displacement as close as possible to each other, which will allow the device to be delivered by means of an ROV, and to manoeuvre the device by means of a manipulator arm without inducing tilting forces on the ROV. A correctly trimmed guide will be able to be delivered and attached to a structure or facility using a light ROV.

b) the adhesion of the cutting device to the cut structure or ferromagnetic object is achieved through permanent magnets, which ensures adhesion even in the event of a power failure, while the disconnection of the magnets from the ferromagnetic surface takes place by generating a magnetic field with the opposite direction of action through an induction coil or mechanically switched permanent magnets .

The force attracting the cutting device to the steel structure is greater than the recoil force generated by the cutting nozzle, e.g. for a pressure of 2500 bar and water flow through the nozzle of 10 l / min, the recoil force is 120N, and the speed of the liquid stream is 700 m / s.

[0012] The cutting method and abrasive material feeding method is characterized by that:

a) in the case of cutting a steel structure, the moment of piercing is observed in the camera and after the piercing, the cutting process is started, i.e. power is supplied to the motor driving the movement of the cutting nozzle.

Due to the fact that in order to cut a structure or an object, the first perforation of the material to be cut, e.g. sheet metal, must first occur, point the action of water under high pressure with the abrasive material until it is completely pierced by the cutting material. The moment when the stream of water breaks through the cut material is visible in the camera located e.g. on the ROV in the form of the disappearance of the reflected stream, the image is calmed down in the area of the cut, the penetration of the stream into the material being cut is visible.

b) the feeding of abrasive in the AWIJ system is carried out according to the following procedure and according to the following arrangement of devices:

- after fixing the device to the structure to be cut, water is removed from the pneumatic conduit through which the abrasive material is to be fed. A value exceeding the pressure at the depth of the cutting device is set on the pneumatic pressure regulator. The value of the hydrostatic pressure at the depth at which the guide is placed is read from the ROV depth sensor. The emptying of the pneumatic conduit is visible by the escape of air bubbles from the cutting nozzle. Compressed air is fed continuously, preferably from a compressor with a pressure reservoir or cylinder, preventing water from entering the line.
- the high-pressure pump or the pressure multiplier is started and water flows out of the cutting nozzle under high or ultra-high pressure,
- the pneumatic blow-off valve is closed and the abrasive valve is opened. A precise abrasive dispenser (e.g....) dispenses the amount of abrasive according to a given concentration (preferably 10% of abrasive per unit of water mass). The cutting nozzle injects the dosed abrasive directly into the rushing stream of water.
- in order to complete the cutting procedure, the reverse sequence of operations is carried out, i.e. closing the abrasive valve and opening the blow-off valve, and after a preset time necessary to empty the abrasive from the pneumatic conduit, the high pressure water pump is turned off.

[0013] The subject of the invention is shown in an exemplary embodiment in the drawing, where:

- Fig. 1 shows an underwater, remotely controlled high-pressure cutting device (1), which consists of a drive motor, preferably electric (2), placed in a hermetically sealed housing, preferably made of aluminium and matched to the diameter of the motor, thanks to which the heat is dissipated through the housing to the water medium, the angular gear, preferably a worm drive (3), thanks to which the drive is led at a 90-degree angle to the gear that moves along the chain, the high-pressure cutting nozzle (4), the clamp system that allows the nozzle to be positioned in space relative to the object to be cut (5), removable permanent magnets (6), displacement modules in the form of low-density closed-chamber foams (7), linear drive in the form of a chain on which a trolley with a cutting nozzle (8) moves, chain tensioner (9).

- Fig. 2 shows the selected point, in which the centre of gravity (CG) and centre of displacement (CB) are located, as well as the plotted forces Fg, the weight of the guide in the air, Fb, the weight of the displaced water. Trimming the cutting guide is done by attaching steel weights when there is positive buoyancy and removing when there is negative buoyancy. If Fg = Fb and CG and CB are at the same point, the guide has a neutral displacement equal to zero and when manipulated in an aquatic environment it does not exert any torsional force on the ROV, no torsional torque correction is required with the ROV's propellers and are not raised sediments, the cutting device can be transported under water by a light ROV. Typically, this type of work required heavy ROV Work-Class vehicles weighing several hundred kg.

- Fig. 3 shows the drive trolley (10), where the chain feed is carried out by a system of Omega type gears (15), the positioning of the nozzle in relation to the cut object is set by clamps (16) (17) (18). Due to the fact that cutting with a stream of water under high pressure with the addition of abrasive material takes place without contact with the cut object, the energy of the stream of water ejected from the nozzle decreases with the distance from the nozzle and the stream of liquid is ejected from the nozzle obtains the shape of a cone, the outlet should be the nozzle is as close as possible to the object or structure being cut. The cutting nozzle (4) has a port for connecting a high-pressure water hose (13), a port for connecting a pneumatic line through which the abrasive is supplied (11), a nozzle outlet (12) from which high-pressure water with abrasive is directed to the cut object.

- The construction of the trolley guide is shown in Fig. 4, where (19) are permanent removable magnets (19), adjustable connections (20) of the chain bar (22) with magnets, clamps for closed-chamber displacement foams (21).

[0014] In order to attach the cutting device to a steel structure or an object with a ferromagnetic coating, such as a UXO object, detachable magnets are used, the magnetic field of which is neutralized only when disconnected. The neutralization of the magnetic field takes place by applying current to a coil wound around the magnet, and the same current application generates a field opposite to the field of a permanent magnet, thanks to which the cutting device can be detached from the steel structure.

- An alternative solution according to the invention is presented in Fig. 5, where the detachable magnet (23) in the position with open levers constantly generates a magnetic field, and after sliding the levers (24) and (25) the magnetic field is reset and the magnet is detached.

- The system of permanent magnets in an exemplary embodiment is shown in Fig. 6 - Fig. 9. The magnets are placed in two layers: the upper element made of plastic (25) and the lower element made of plastic (24). The magnets are alternately oriented with the N (29) and S (28) poles. If the levers are open, the magnets in both layers have the same direction, i.e. the magnets (29) are above the magnets (29) and the magnetic field through the ferromagnetic cone (30) and the ferromagnetic steel structure that is cut is closed to the magnets (28). After rotating the layers (24) and (25) by 60 degrees in relation to each other as shown in Fig. 9, the arrangement of the magnets is changed in such a way that the magnets (29) and (28) are above each other, thanks to which they interact with opposite magnetic fields , the magnetic field is no longer directed to the object to be cut and the tool is disconnected from the ferromagnetic object.

- Fig. 10 shows a cross-section of the cutting nozzle. The subject of the invention in the field of abrasive feeding is shown in the embodiment in

- Fig. 11 contains a diagram, where cutting and feeding of abrasive in the AWIJ system is carried out according to the following procedure and according to the following arrangement of devices:

  a) after fixing the device to the structure to be cut, water is removed from the pneumatic tube (39) connected to the port of the cutting nozzle (11) through which the abrasive will be fed. The shut-off valve (37) opens, a value set on the pneumatic pressure regulator (36) exceeding the pressure at the depth of the cutting device. The value of the hydrostatic pressure at the depth at which the guide is placed is read from the ROV depth sensor. The emptying of the pneumatic conduit is visible by the escape of air bubbles from the cutting nozzle (4) through the outlet (12). Compressed air is supplied continuously, preferably from a compressor with a pressure reservoir (44) or from a cylinder, preventing water from entering the conduit.

  b) the high-pressure pump (31) or the pressure multiplier is started, the water is pumped through the high-pressure hoses (41) connected to the port (13) of the cutting nozzle (4) and escapes under high or ultra-high pressure,

  c) the pneumatic blow-off valve (37) is closed and the abrasive valve (38) is opened. The abrasive is transported from the abrasive feeder (32) via pneumatic hoses (42) to the precise abrasive dispenser (33). The quantity of the abrasive is dispensed according to the preset concentration (preferably 10% of the abrasive in a unit of mass of water), the dosing takes place through a pneumatic actuator (35) controlled by a 3/2-way valve (34). Through a pneumatic conduit (39) the abrasive is delivered is a pneumatic conduit (39) is vacuum fed to the cutting nozzle and injected directly into the rushing stream of water.

  d) in order to complete the cutting procedure, the reverse sequence of operations is carried out, i.e. closing the abrasive valve (38) and opening the blow-off valve (37) and after a preset time necessary to empty the abrasive from the pneumatic conduit (39), the pumping of water under high pressure is turned off.

Claims

1. Underwater, remote-controlled high-pressure cutting device with the addition of abrasive material, consisting of a nozzle guide, preferably with a chain drive of modular structure, on which the cutting nozzle moves, **is characterized in that**

   • the cutting device has a buoyant force in water equal to its weight in the air and the centre of buoyancy is at the same point as the centre of gravity, preferably at the location of the transport handle,
   • the cutting device is attached to the structure with permanent magnets and disconnection takes place by reversing the magnetic field, preferably with an induction coil or a switchable permanent magnet.

2. The cutting method and abrasive material feeding method **is characterized by that:**

   • puncture through the cut material and the cutting speed are verified by observing the behaviour of the liquid stream ejected from the cutting nozzle with a camera and the follow-up adjustment of the nozzle feed speed based on the analysis of the stream reflected or absorbed into the cut object
   • in the conduit supplying the abrasive to the cutting nozzle, compressed air pressure is maintained in excess of the hydrostatic pressure at the depth at which the cutting operation is carried out, the abrasive is fed only when there is no water in the pneumatic conduit by means of a precise abrasive dispenser and after cutting from the conduit the abrasive is removed. The abrasive feeding system enables uninterrupted operation and the pressure in the abrasive feeder and the precise dispenser is equal to atmospheric pressure.

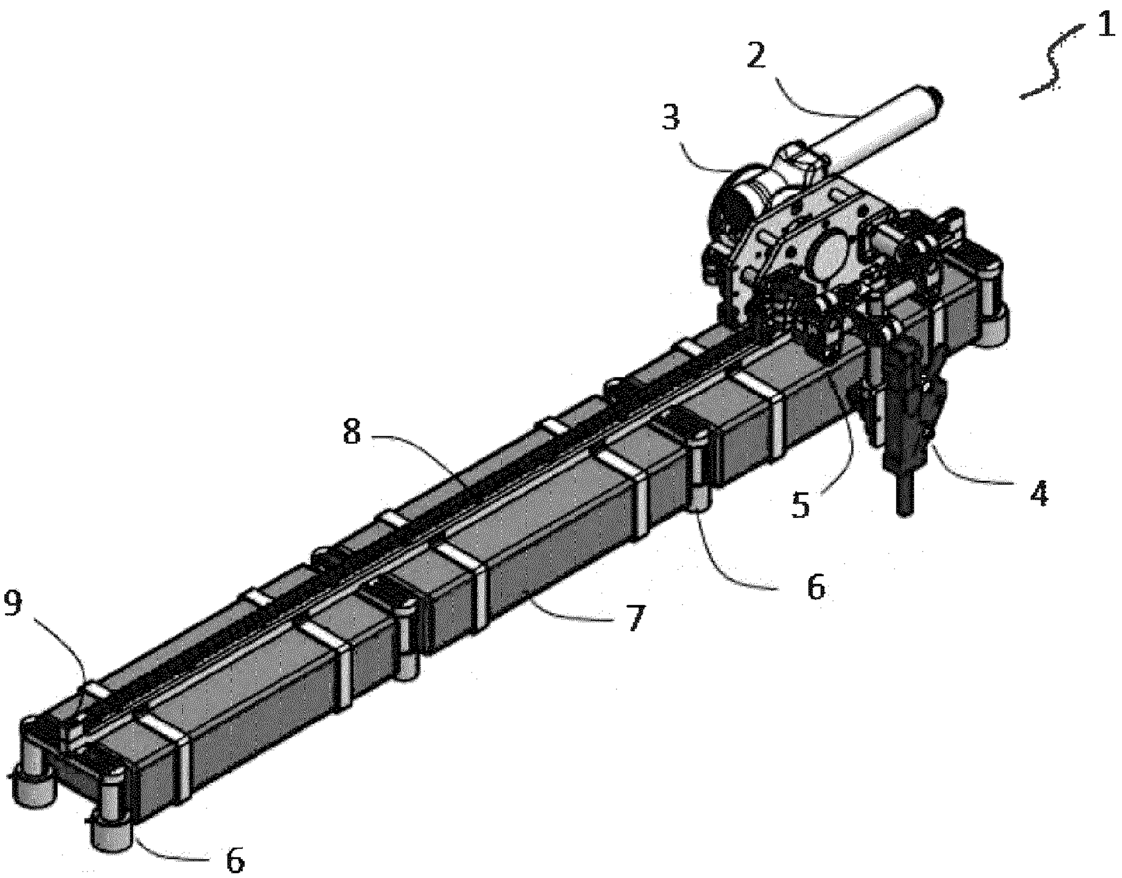

Fig. 1

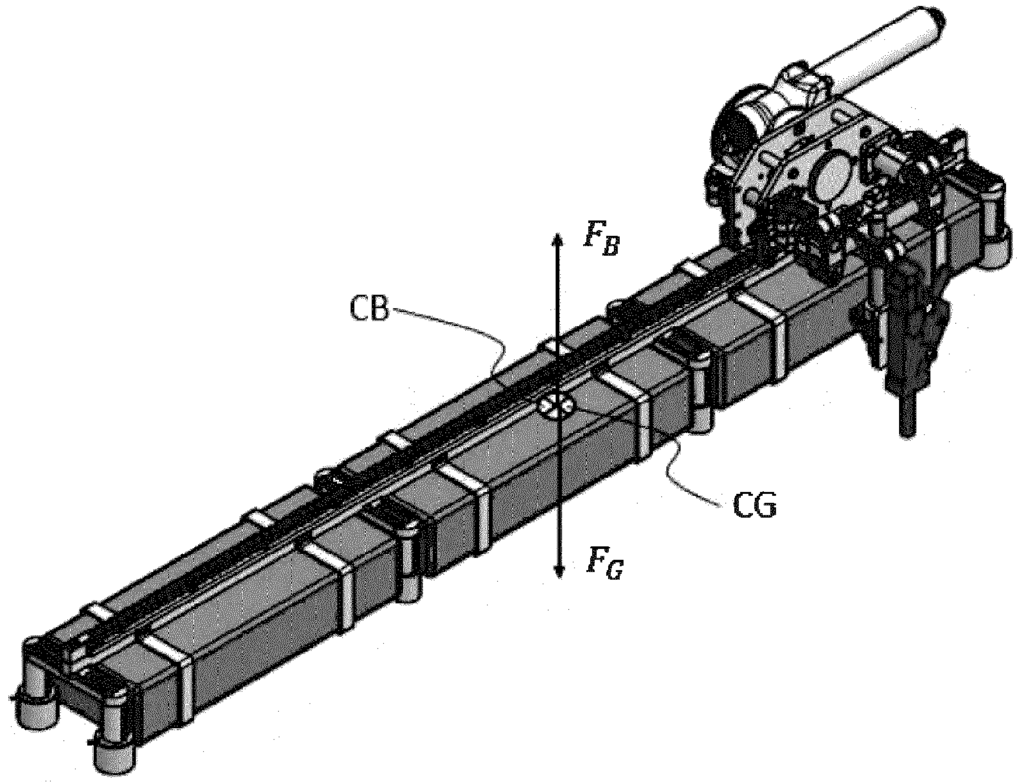

Fig.2

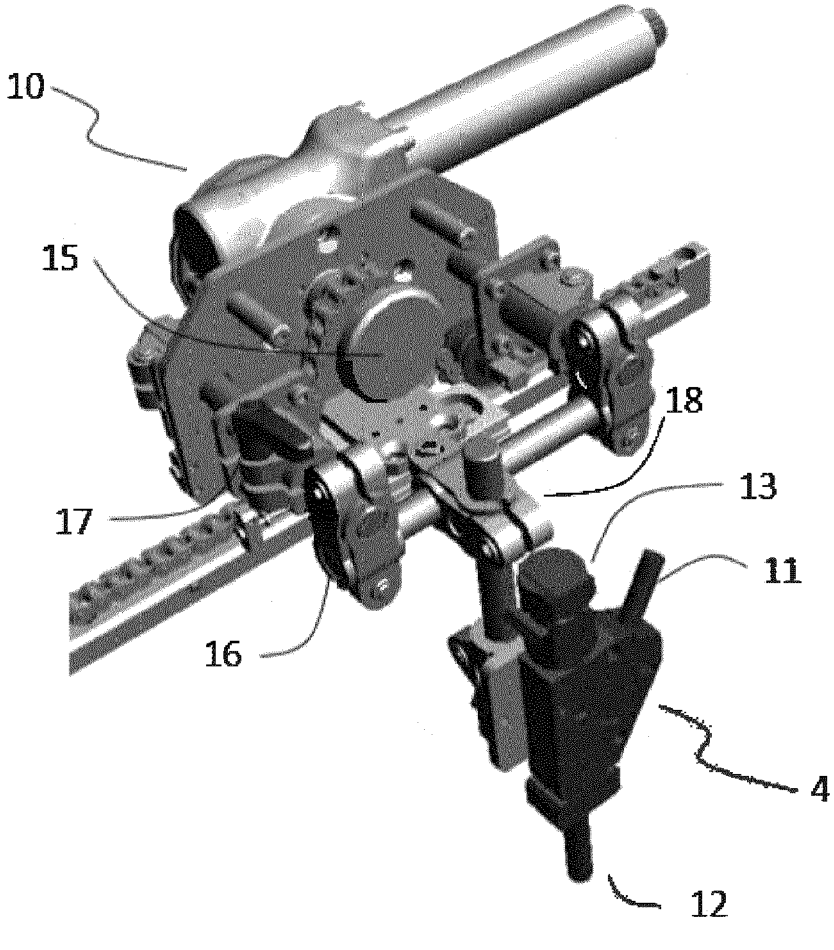

Fig. 3

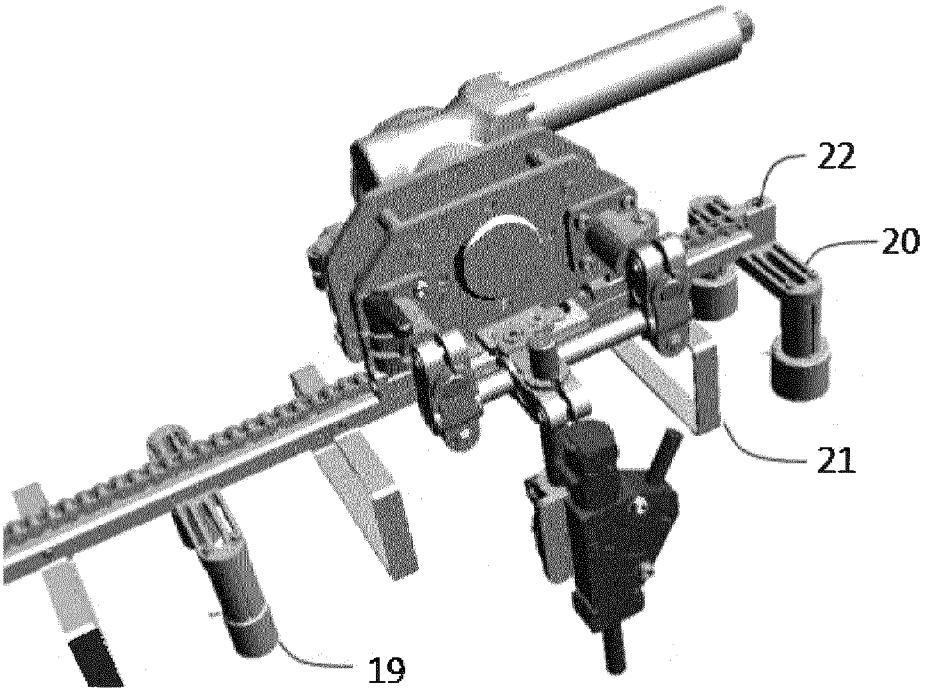

Fig. 4

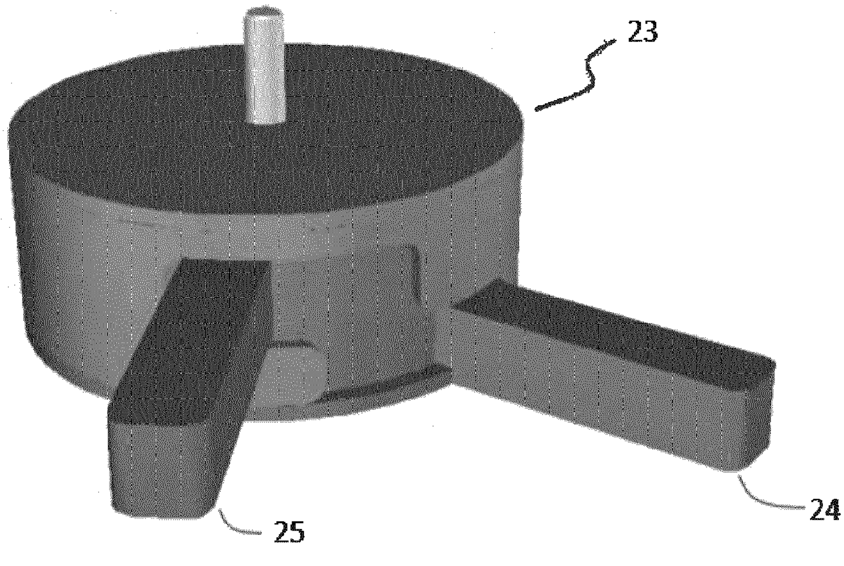

Fig. 5

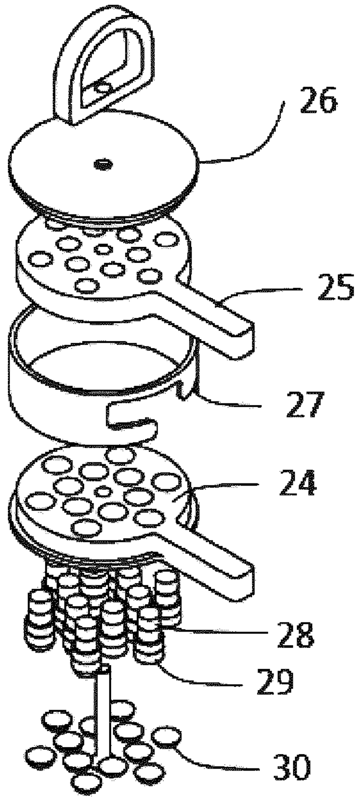

Fig. 6

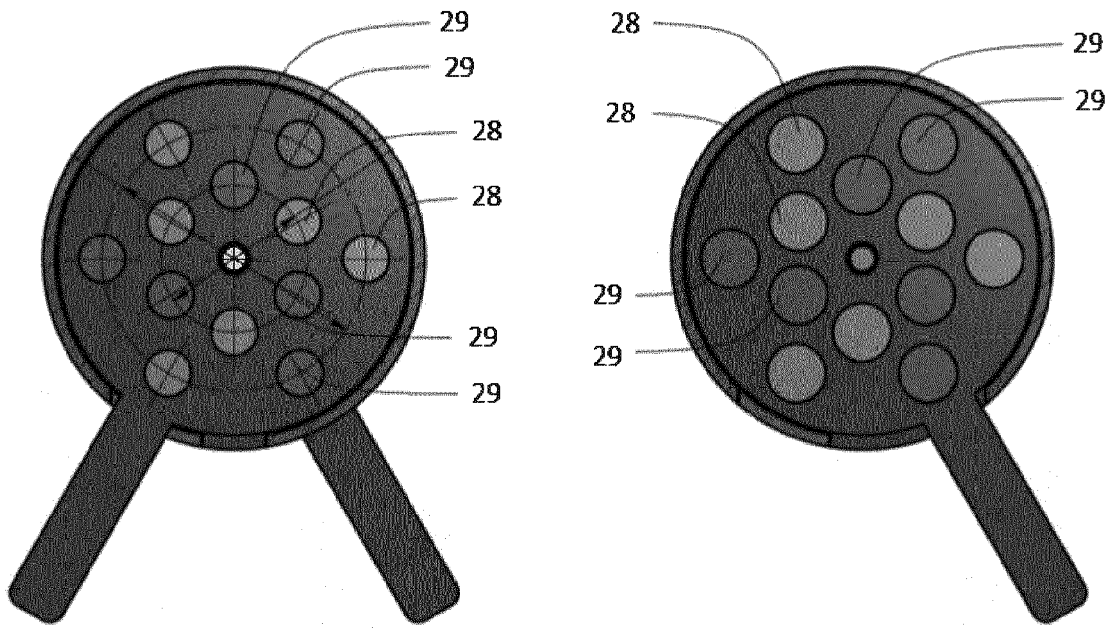

Fig. 7

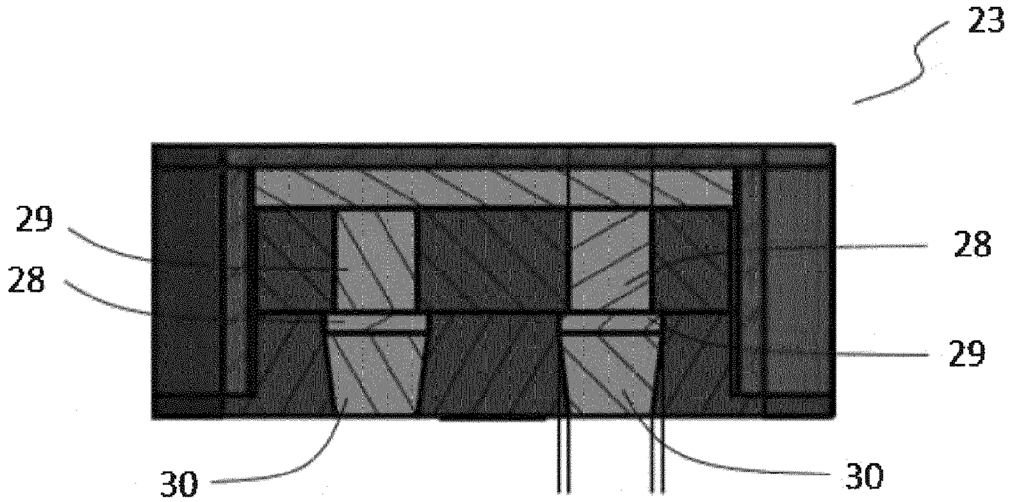

Fig. 8

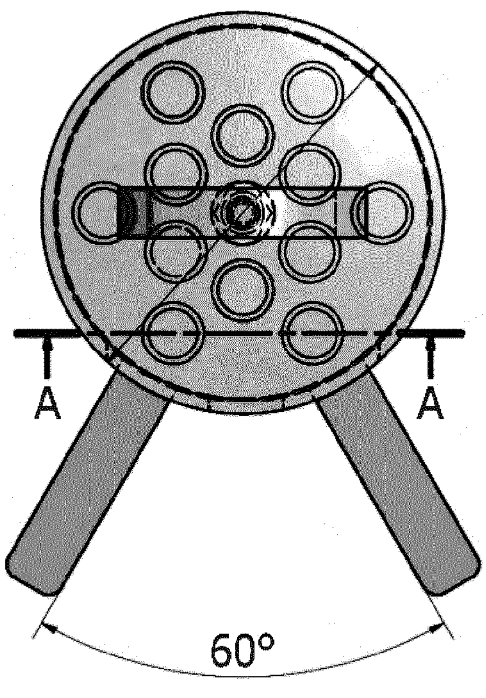

Fig. 9

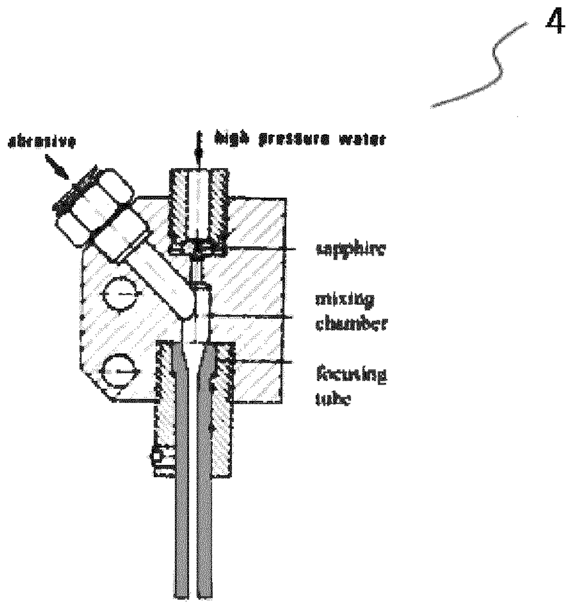
4
abrasive
high pressure water
sapphire
mixing
chamber
focusing
tube

Fig. 10

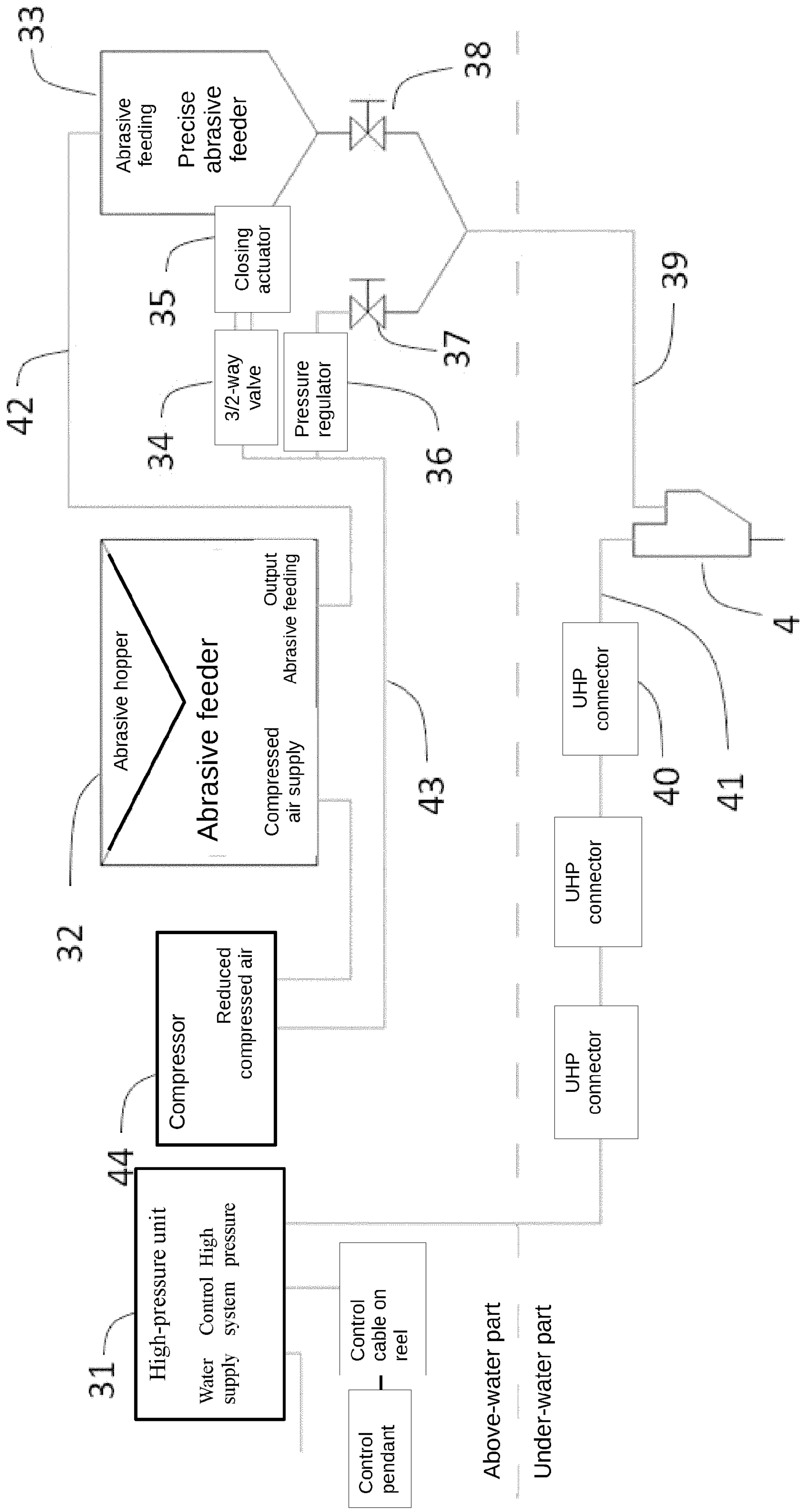
33
Abrasive feeding
Precise abrasive feeder
38
35
Closing actuator
39
42
3/2-way valve
Pressure regulator
37
34
36
Abrasive hopper
Abrasive feeder
Output Abrasive feeding
Compressed air supply
43
32
UHP connector
UHP connector
UHP connector
4
40
41
Compressor
Reduced compressed air
44
31
High-pressure unit
Water supply
Control system
High pressure
Control cable on reel
Control pendant
Above-water part
Under-water part

Fig. 11

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EUROPEAN SEARCH REPORT

Application Number
EP 21 21 8277

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	17 June 2022	Carmichael, Guy

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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17-06-2022

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