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(54) **IN-WATER SHIP HULL CLEANING MAGNETIC ROBOT WITH ADJUSTED ADHESION FORCE**

(57) An in-water ship hull cleaning magnetic robot with adjusted adhesion force in which the adhesion force is achieved by a system of five connected permanent magnets (18), preferably neodymium, specifically oriented. The adhesion force is regulated by adjusting of magnetic system through guides (10) located in the corners of the magnetic system housing and preferably one screw drive (9) with a toothed gear acting centrally on the magnetic system housing and driven preferably by an electric motor built in an underwater, hermetic housing. The mechanism for adjusting the distance of the magnetic system from the surface of the ship's hull allows for changing the adhesion force remotely without interrupting the work in the event of wheel slippage. The mechanism allows the cleaning robot to be remotely detached when the robot is above or below the water surface by increasing the air gap between the magnetic system and the ship's hull. The mechanism enables the lifting of the drive wheels without detaching the robot from the ship's hull and the replacement of wheel rims with a mixture, preferably of rubber, for rims with a different composition of the mixture realizing friction, by first extending the screw drive until the magnetic system is in full contact with the surface of the ship's hull and then further extension of the screw drive until the drive wheels are detached from the surface of the ship's hull.

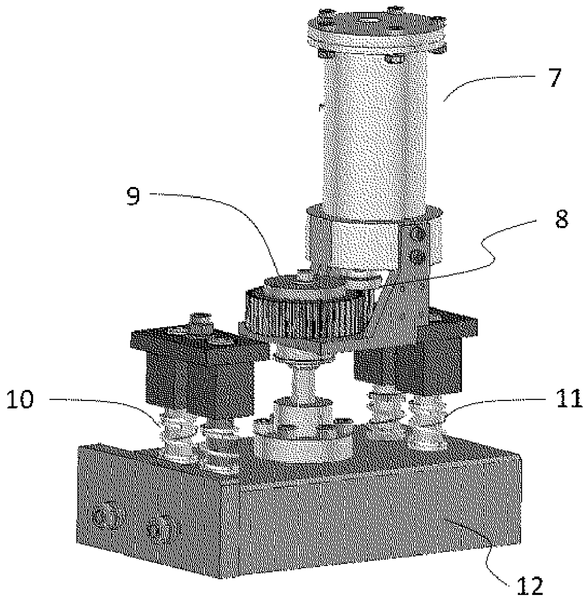

Fig. 4

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Description

[0001] The present invention relates to an in-water, remotely controlled robot exploiting set of permanent neodymium magnets with adjusted adhesion force for lichens removal from ship hulls by using high-pressure water jet.

[0002] Over time, the hulls of ships become covered with organisms such as lichens, algae and shells, which results in increased fuel consumption, reduced speed, and ecological threat by migration of invasive organisms. A way to counteract these negative phenomena is to regularly clean the hulls of ships from the so-called biofouling.

[0003] The most common methods of cleaning ships include cleaning the ship in a dry dock, i.e. after the ship is taken out of the water. It is a process that is performed no more frequently than every few years and is very expensive and time-consuming. A ship usually requires cleaning after only 6 months as the cost of increased fuel consumption outweighs the cost of cleaning the hull. For this reason, cleaning should be done on a regular basis and without taking the vessel out of the water - in-water ship hull cleaning. Due to the high costs of ship downtime, it is most desirable to clean the hull in the port during unloading and loading. Most often, the cleaning of ship hulls is carried out by scuba divers.

[0004] Due to the risk of scuba divers' health and life and the insufficient efficiency of the hull cleaning process, there are sought robotic, remotely controlled or autonomous solutions.

[0005] Solutions found on the market can be divided into two groups.

[0006] The first group consists of cleaning robots using propellers applied in the underwater ROV for motion and for ensuring adhesion.

[0007] A solution is known from the information available on the website https://www.hullwiper.co/ of a propulsion driven cleaning robot.

[0008] The propulsion-based solution has several disadvantages, including in particular the inability to work above the water surface. When a ship is unloaded or loaded in the port, its draft changes, in which case the biofouling above the water surface will be not removed. Next disadvantage is the loss of adhesion, which is obtained by the constant operation of the propulsors pushing the robot to the cleaned surface in the event of a power failure. With limited visibility in the port, the operator will find a problem returning to the place on the surface of the ship's hull where the work was interrupted.

[0009] The other group of underwater robots consists of robots achieving adhesion to the ship's hull using magnets or electromagnets.

[0010] It is known from the patent no. US 2015/0158565 'Cleaning head for cleaning a surface, device comprising such cleaning head, and method of cleaning' the use of permanent magnets in a hull cleaning robot. The permanent magnet is held above the ferromagnetic surface of the ship's hull at a preset distance, without the possibility of remote adjustment.

[0011] There are known solutions using permanent magnets in track members or on the circumferences of drive wheels.

[0012] Solutions based on permanent magnets require taking into account several important parameters such as: (a) a rapid decrease in the adhesion force with the increase of the so-called air gap between the magnets and the ferromagnetic surface, which is associated with the installation of very strong and heavy permanent magnets and (b) the coefficient of friction (COF) in the case of moving on inclined or vertical surfaces, which are ship hulls, especially in the zone above the surface of the water, which requires the right choice of mixture, usually rubber, in robot propulsion systems.

[0013] In the case of using permanent magnets and installing them without the possibility of remote adjustment of the distance from the hull surface, there are problems in detaching the robot from the ferromagnetic surface after the cleaning process is completed - this is usually done in the following ways: moving the robot onto a ramp made of non-ferromagnetic material, driving off the ferromagnetic surface (e.g. from sheet metal); the use of a lever to increase the distance of the magnets from the ferromagnetic surface and detach the robot. This is a very significant disadvantage of using permanent magnets to attract robots, especially in the event of a control or power system failure when the robot is below the water surface. In such a situation, the intervention of scuba divers is required.

[0014] It is known from patent no. WO 2007/010265 and from the project documentation under the acronym HISMAR (Hull Identification System for Marine Autonomous Robotics) a solution for robot adhesion using electromagnets. The disadvantage of the solution based on electromagnets is, as in the case of robots with a propulsor method of implementing adhesion, detaching the robot from the cleaned hull in the event of a power failure. In addition, it is required to use much larger dimensions and weights of electromagnets in order to obtain a comparable attractive force that can be obtained with neodymium magnets.

[0015] The in-water ship hull cleaning magnetic robot with adjusted adhesion force according to this invention solves disadvantages of the above-mentioned solutions unprecedentedly and non-obviously.

[0016] The in-water ship hull cleaning magnetic robot with adjusted adhesion force according to this invention characterises by that:

a) the adhesion of the magnetic robot is achieved by combining preferably five neodymium magnets in such a way that the magnetic field is directed towards the ferromagnetic surface of the ship's hull, after connecting the magnets, the attraction force is increased as a function of the distance between the magnet and the ship's hull in the adjustment section up to 15mm. In other directions, except towards the ship's hull, the magnetic field is reduced. In order to assemble the magnetic system and overcome the forces repelling the magnets, stainless steel tightening screws are used, neodymium magnets of the same size are used, but in two versions of the mounting holes.

b) the distance between the magnetic system and the ship's surface is achieved by means of a single, underwater electric screw drive and stabilizing guides, ensuring a straight line movement of the magnetic system. The electric motor together with the planetary gears is mounted in a watertight aluminium housing, then the drive is transmitted through gears. The distance adjustment is performed by changing the rotary motion caused by the electric motor into linear motion through the use of a helical gear and sliding bearings.

c) the magnets combined into a magnetic system are covered with a thin coating (thickness preferably up to 1 mm) in order to protect against the impact of aggressive sea environment on magnet coatings, e. g. nickel.

d) the robot can work both under water and remove biofouling from the surface of the ship's hull above the water level, e.g. during unloading and loading in the port.

e) the applied solution according to the claim allows for remote adjustment of the attraction force (change of the distance of the magnetic system from the ferromagnetic surface of the ship depending on changing operating conditions, e.g. thicker paint coating, various types of anti-fouling paint, corroded surface, faults occurring during driving resulting from shifting of the plating sheets during welding hulls, the occurrence of welds of different thickness, slipping of the robot on a slippery vertical surface, e.g. after driving above the water surface, change in the robot load resulting from the need to transport longer sections of high-pressure water hoses, extraction and power cables.

f) the system for adjusting the distance between the magnets and the hull surface allows the robot to be remotely detached from the hull and taken out of the water,

g) the system of adjusting the distance between the magnets and the surface of the hull allows you to change the rims of wheels with different compounds that improve friction or leave no marks on the rubber, without the need to detach the robot from the hull. The weight of the cleaning robot requires the use of lifting devices for assembly and disassembly on the hull, which is why it is important to be able to replace the wheel rims without disassembling the robot from the ship's hull. The function is performed by lowering the magnetic system until the drive unit of the magnetic robot is lifted and the drive wheels are detached. After the wheels are torn off, the robot is held on the vertical surface of the ship's hull by means of extended magnetic systems.

[0017] The subject of the invention is presented in an example of execution in the attached drawings Fig.1 - Fig.8.

[0018] Fig. 1 shows a magnetic robot (1) consisting of a cleaning unit (2), where under the housing there is a rotating cleaning unit with four arms ending with high-pressure nozzles, the rotating nozzle is preferably driven by two watertight motors, on the high-pressure rotor housing there are connections for the extraction of removed impurities and a high-pressure connection. The cleaning unit (2) is connected to the drive unit (3) by means of a joint and allows the cleaning unit to be tilted by 90 degrees for inspection and replacement of high-pressure water nozzles without having to unhook the robot from the ship's hull. The drive unit consists of 2 wheels driven independently by DC motors, built in aluminium waterproof casings, dissipating heat to the environment. The motors transmit power to the drive wheels using planetary and worm gears. In the rear part of the robot there are preferably two trailing wheels, preferably Rotacaster omni-directional. Within the drive unit (3) there are boxes with electronics and power supply.

[0019] Fig. 2 shows the location of two magnetic systems (4) with adjustable distance between the magnetic systems and the ferromagnetic surface of the ship's hull. Fig.3 shows the location of the magnetic systems in relation to the drive wheels (5) and trailing wheels (6).

[0020] The subject of the invention in the form of a system for regulating the force of attraction of the magnetic robot (1) to the ferromagnetic surface is shown in Fig.4. The system for adjusting the distance between the magnets and the surface of the hull is carried out by means of an electric motor with planetary gears located in an aluminium watertight casing (7), which transfers the rotary motion through a toothed gear (8) to the regulating screw module (9). The system of permanent magnets in the housing (12) is stabilized by preferably four sliding guides (10), which are additionally tensioned with springs (11) to prevent skewing of the magnetic module (12) during distance adjustment.

[0021] Fig. 5 shows the construction of the distance control system in the part converting rotational motion into sliding motion. The adjustment screw module (9) consists of a screw (13) and a nut (14) rigidly connected to the housing of permanent magnets (12). Fig. 5 also shows the sliding elements of the guides (15) made of self-lubricating plastics, due to the difficult environmental conditions of the device's operation, i.e. in the water environment, it is not possible to use lubricants. The system of permanent magnets, preferably neodymium (16), is screwed with two stainless screws (17).

[0022] Fig.6 shows the construction of a magnetic system consisting of five neodymium magnets. The system is made of neodymium magnets of the same dimensions with two different magnetizations. Mounting holes of magnets (18) run from poles N to S, and magnets (19) between poles S-N. The arrows indicate the orientation of the magnet (direction of the magnetic field from N to S). The presented system of combined magnets allows to obtain a magnetic field in the lower part of the system (oriented towards the surface of the ship's hull) with an attractive force 5 times higher over a section of up to 5 mm compared to a single neodymium magnet of the same type, e.g. N52, and of the same weight and dimensions as shown system. On the other hand, the magnetic field of the magnetic system (16) in other directions is several times lower than that of a single neodymium magnet, which is very important due to the presence of electronic, electrical and navigation systems in close proximity to the magnetic systems.

[0023] Fig.7 shows the principle of operation of the system for adjusting the attraction force in two projections A and B, and shows the direction of shifting the magnetic system (22) in relation to the drive wheel (20). The drive wheel (20) is connected to the worm gear (see A) and bolted to the replaceable rim (21). The attraction force adjustment system (12) allows you to change the so-called air gap depending on the slippage of the wheels of the magnetic robot. It is desirable to have a gap that is as large as possible and wheel slippage does not occur. Then the wheels will not leave marks, e.g. rubber marks during turns when the wheels have different rotational speeds, which is undesirable.

[0024] The attraction force adjustment system (12) within the scope of its adjustment allows for the replacement of drive wheel rims without the need to detach the magnetic robot from the ship's hull. By extending the magnetic system (12) as shown in Fig.7 (22) below the line of the drive wheels, the drive unit (3) will be lifted.

[0025] Fig. 8 shows the rim of the drive wheel (21), consisting of an aluminium rim (24) screwed to the drive wheel (20) and a coating increasing the friction coefficient (23), preferably made of a rubber mixture. Depending on the condition of the paint coating, surface roughness, loads that the magnetic robot transports, in addition to adjusting the attraction force using the distance between the magnets and the hull surface, it may be necessary to replace the wheel rims with ones that will allow to obtain a higher COF (coefficient of friction). The rims differ in the type of coating that increases the coefficient of friction (23), including in particular the type of rubber, polyurethane, silicone mixture, the hardness of the mixture, e.g. according to the Shore scale (soft rubber will leave larger marks on the surface during turns than e.g. polyurethane coatings).

Claims

1. The in-water ship hull cleaning magnetic robot with adjusted adhesion force characterises by that:

- the adhesion force is achieved by such a system of five connected permanent magnets, preferably neodymium, that the magnetic field is directed and multiplied towards the ship's hull and neutralized towards the components of the magnetic robot, the magnets are screwed together, preferably with two stainless screws, in the order first N-S magnet horizontally, second N-S vertical with S towards the hull, third S-N horizontally, fourth S-N vertical with N towards the hull, fifth N-S horizontally,
- the adhesion force is regulated by adjusting the distance of the magnetic system through preferably four guides located in the corners of the magnetic system housing and preferably one screw drive with a toothed gear acting centrally on the magnetic system housing and driven preferably by an electric motor built in an underwater, hermetic housing,
- the mechanism for adjusting the distance of the magnetic system from the surface of the ship's hull allows for changing the adhesion force remotely without interrupting the work in the event of wheel slippage, in particular when the magnetic robot travels over the ship's hull above the water surface, when the buoyancy force ceases to act on the magnetic robot, and in the structural elements, there are water residues that increase the value of the force of gravity pulling the robot towards the water surface,
- the mechanism for adjusting the distance of the magnetic system from the surface of the ship's hull allows the cleaning robot to be remotely detached when the robot is above or below the water surface by increasing the air gap between the magnetic system and the ship's hull,
- the mechanism for adjusting the distance between the magnetic system and the surface of the ship's hull, enabling the lifting of the drive wheels without detaching the robot from the ship's hull and the replacement of wheel rims with a mixture, preferably of rubber, for rims with a different composition of the mixture realizing friction, by first extending the screw drive until the magnetic system is in full contact with the surface of the ship's hull and then further extension of the screw drive until the drive wheels are detached from the surface of the ship's hull.

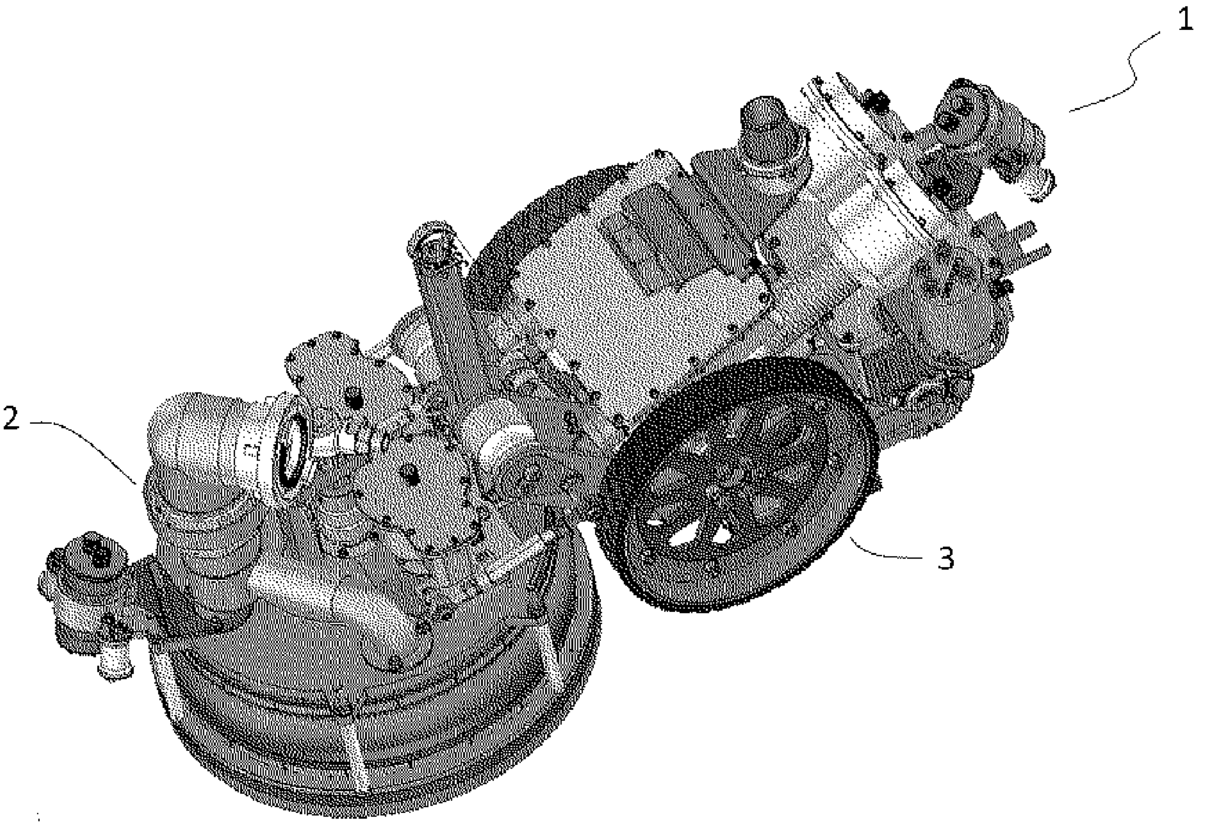

Fig. 1

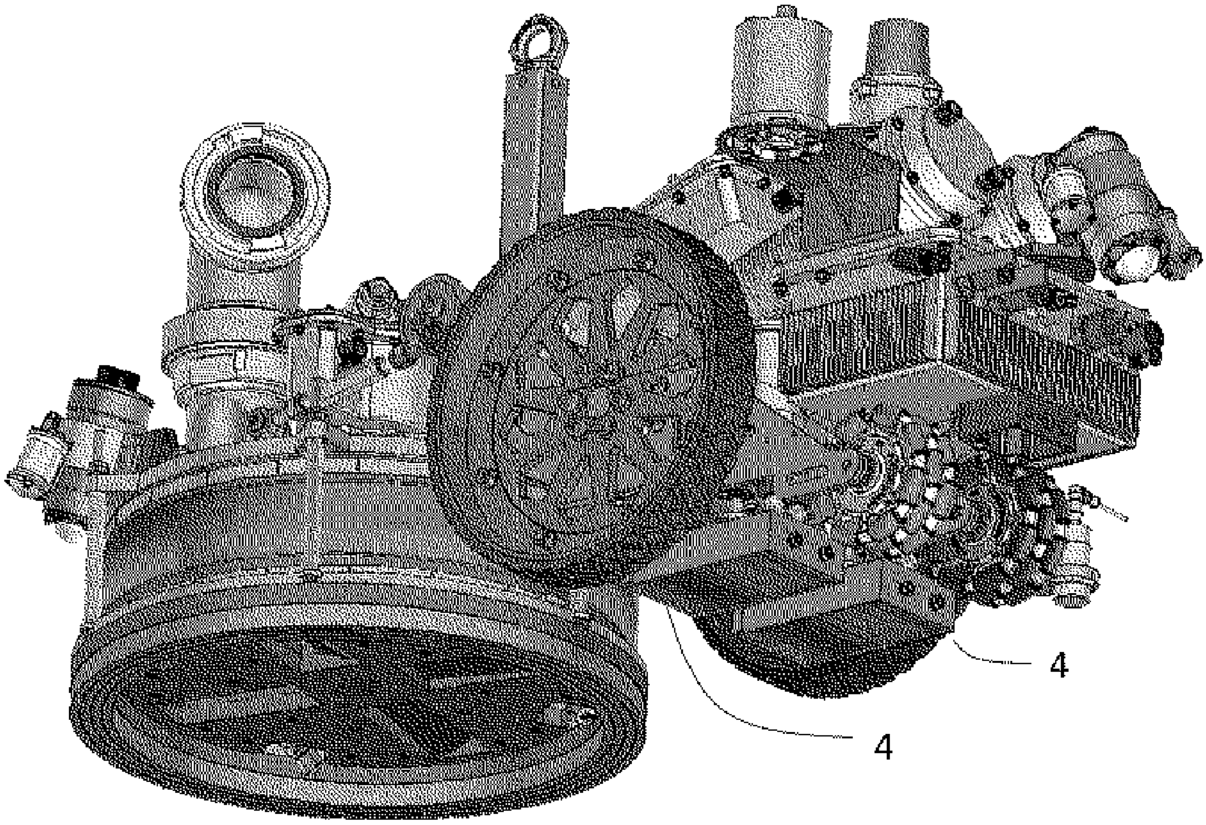

Fig. 2

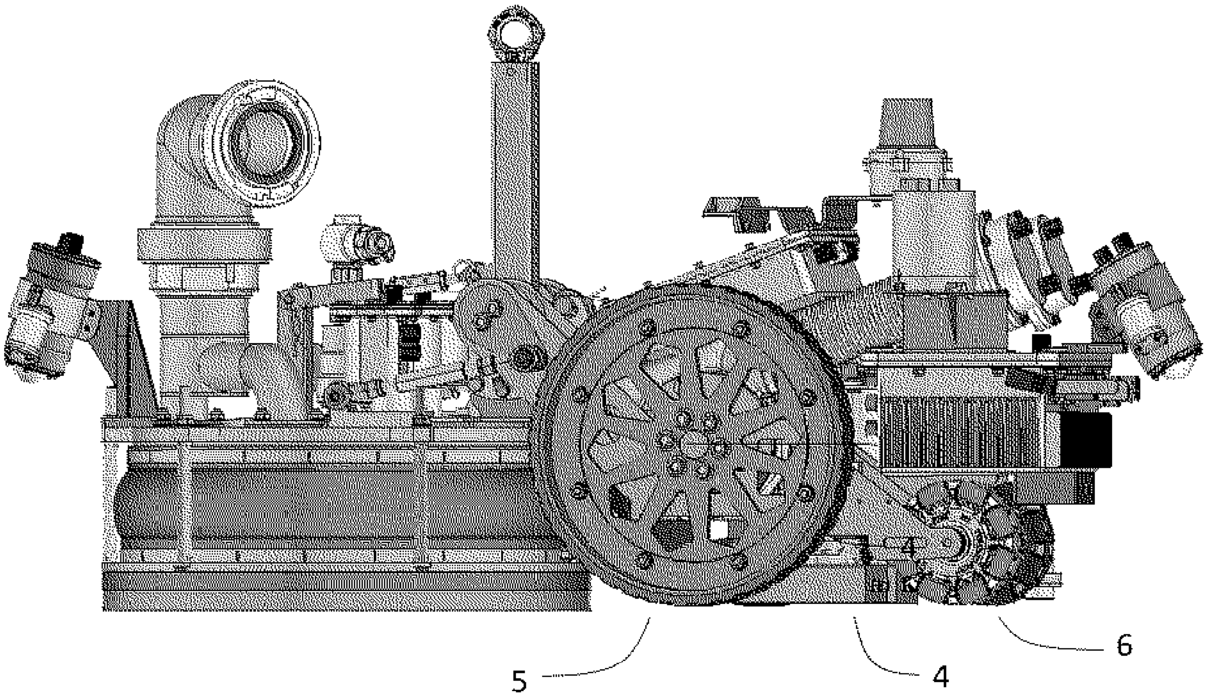

Fig. 3

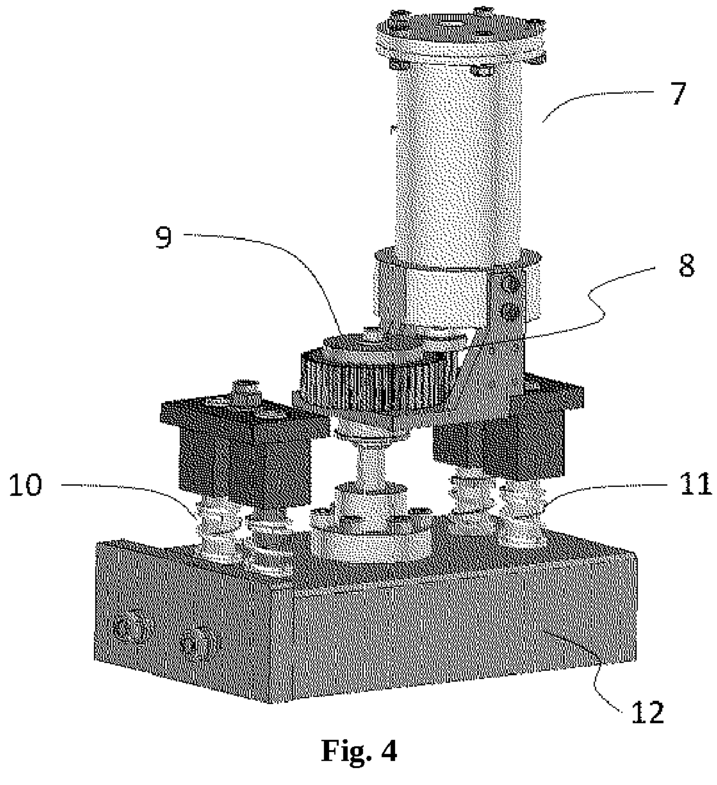

Fig. 4

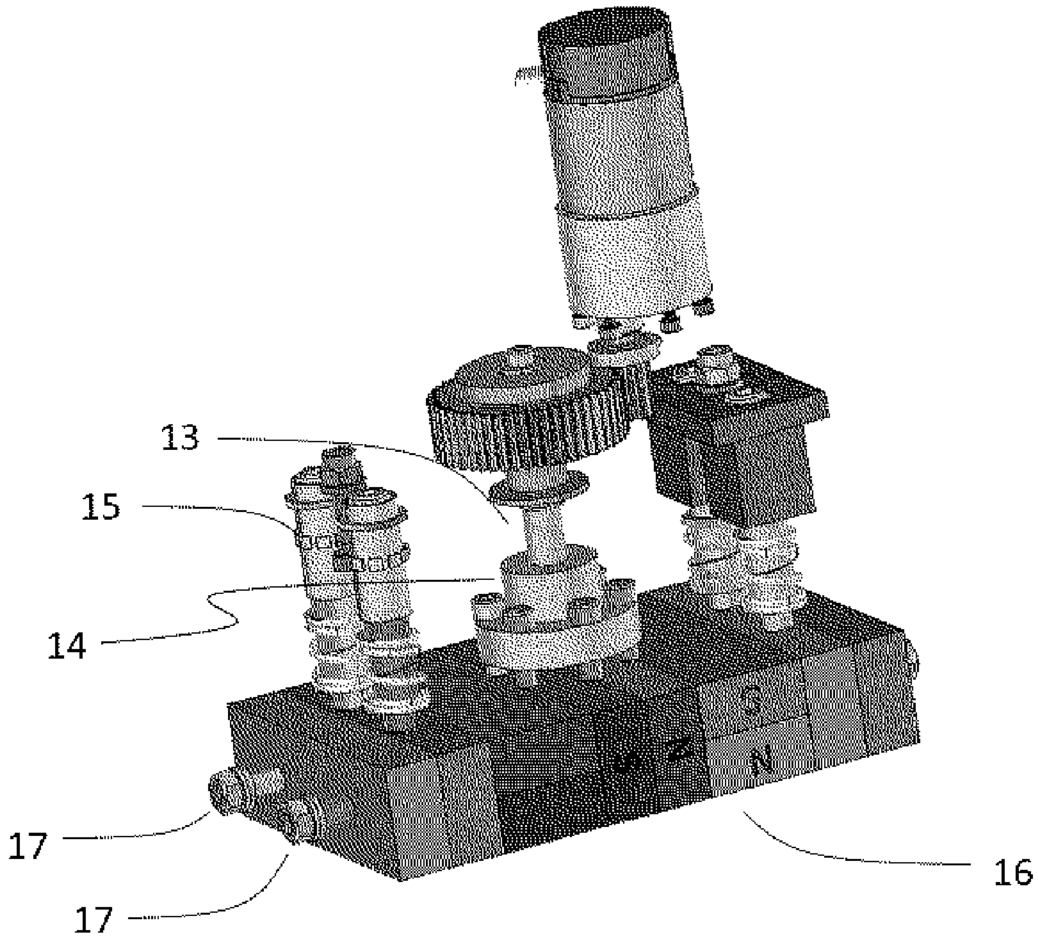

Fig. 5

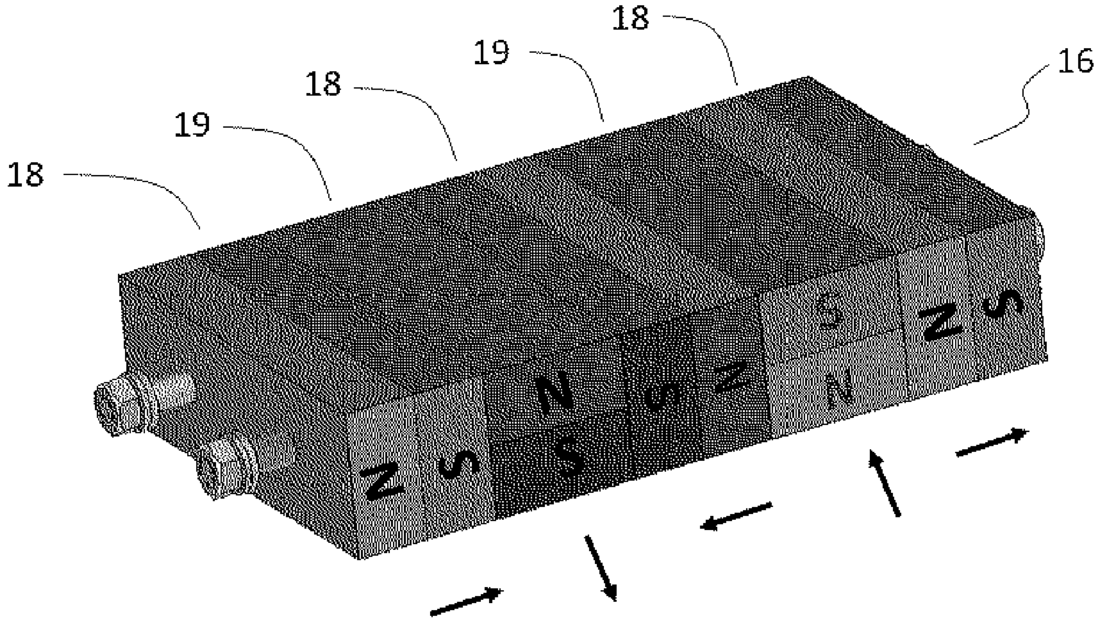

Fig. 6

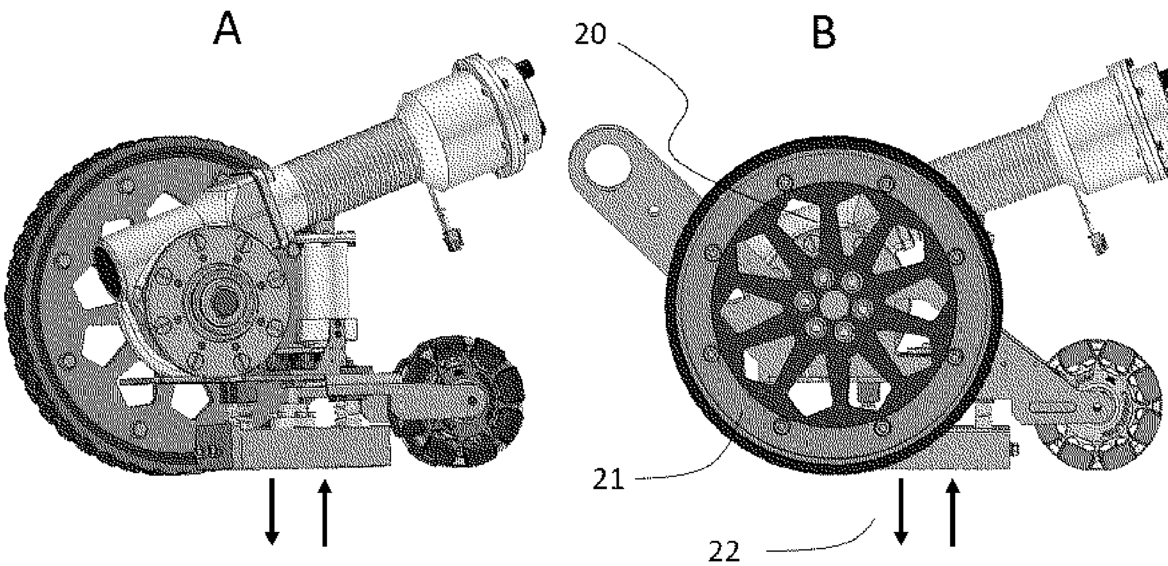

Fig. 7

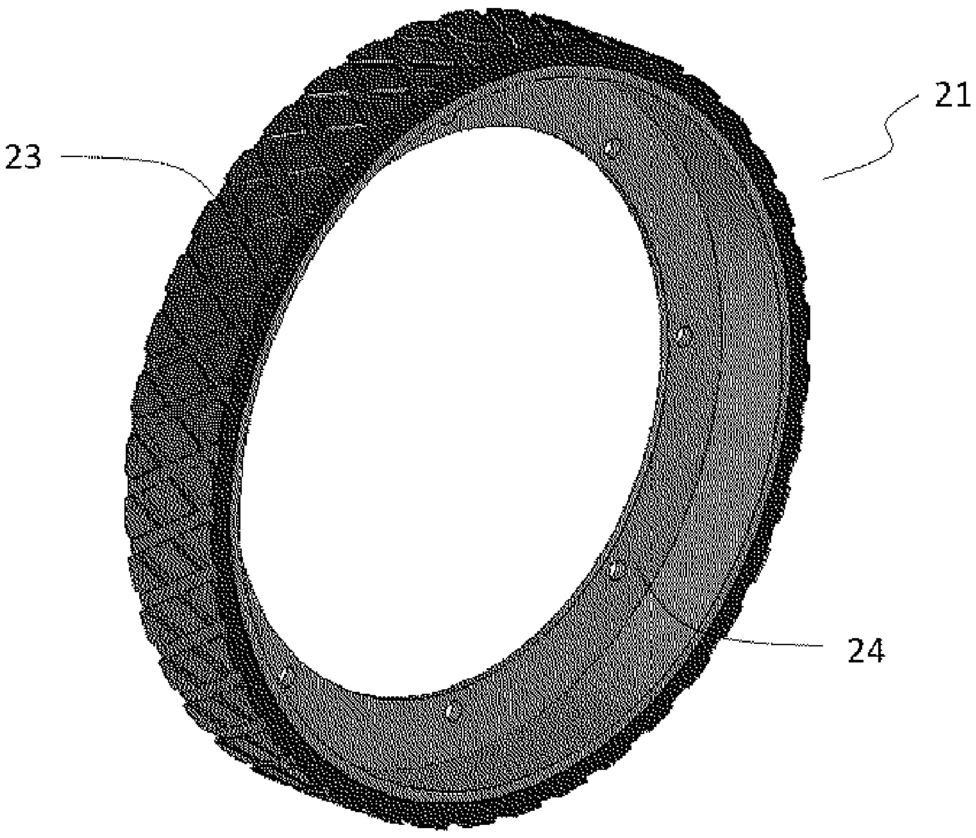

Fig. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 22 20 9766

DOCUMENTS CONSIDERED TO BE RELEVANT

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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 May 2023	Székely, Zsolt

CATEGORY OF CITED DOCUMENTS

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