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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 July 2020 (30.07.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/152502 A1

(51) International Patent Classification:
B63H 1/36 (2006.01) *F03B 17/06* (2006.01)
B63H 1/37 (2006.01)

(21) International Application Number:
PCT/IB2019/050610

(22) International Filing Date:
24 January 2019 (24.01.2019)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant: **ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE (EPFL)** [CH/CH]; EPFL-TTO, EPFL Innovation Park J, CH-1015 Lausanne (CH).

(72) Inventors: **ECKERT, Peter**; Chemin du Rossignol 1, 1110 Morges (CH). **BAYAT, Behzad**; Langfurren 32, 8057 Zürich (CH). **IJSPEERT, Auke**; Rue du Centre 55, 1025 St-Sulpice (CH).

(74) Agent: **LUMI IP GMBH**; Rodtmattstrasse 45, 3014 Bern (CH).

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

(54) Title: PROPULSION MODULE FOR GENERATING WAVE-LIKE MOTION

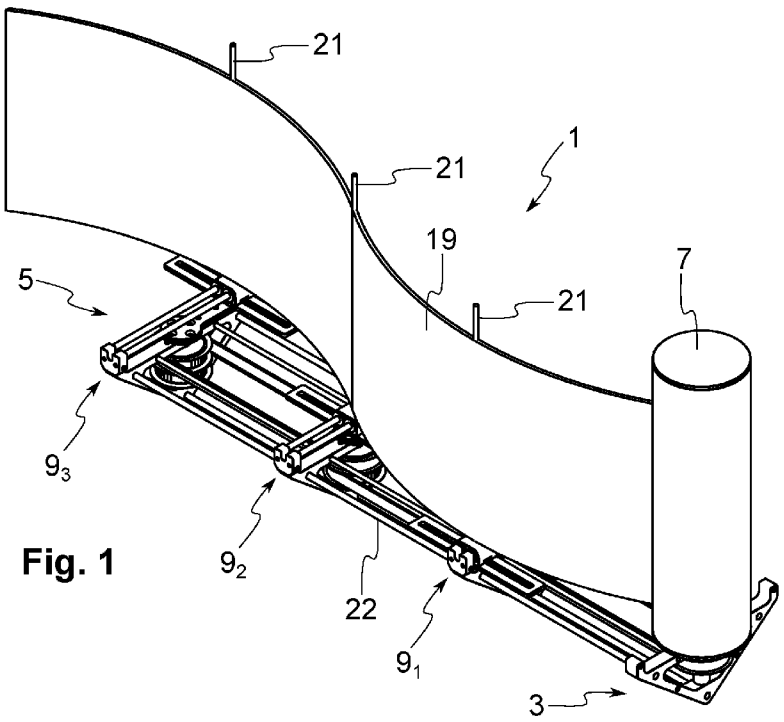


Fig. 1

(57) Abstract: The present invention relates to a propulsion module (1) for generating wave-like motion in liquid. The propulsion module (1) comprises: a motor (7) for generating rotational motion; a set of conversion devices comprising a first conversion device (9_1) and a second conversion device (9_2) each comprising a movable arm (27) for converting the rotational motion from the motor (7) into oscillatory translational motion of the respective arm (27) along a movement axis, which is angled with respect to a length axis of the propulsion module; a drive mechanism for coupling the motor (7) to the first and second conversion devices (9_1, 9_2) for transferring the rotational motion to the first and second conversion devices; and a flexible structure (19) extending along at least a portion of the length axis of the propulsion module (1), the flexible structure (19) being configured

WO 2020/152502 A1

[Continued on next page]

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

Declarations under Rule 4.17:

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

Published:

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

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

to be guided by the movable arms (27) to generate the wave-like motion of the flexible structure (19). A distance between the first and second conversion devices along the length axis, and/or a maximum range of motion of the movable arms (27) along the movement axis is/are adjustable.

PROPULSION MODULE FOR GENERATING WAVE-LIKE MOTION

TECHNICAL FIELD

The present invention relates to a propulsion module, such as an aquatic propulsion module, for generating wave-like motion. More specifically, the proposed propulsion module is configured to convert the unidirectional rotary motion of a motor to undulatory swimming patterns observed in most swimming animals.

BACKGROUND OF THE INVENTION

Movement on land, water, and air has always been a driving factor of humankind's developments in territorial expansion, trade, and discovery of the unknown. Especially the realm of robotics, emerging in the last decades, has brought change to the available propulsion methods. The present description focuses on locomotion in water or in other liquids for autonomous, semi-autonomous or non-autonomous vehicles. Swimming mechanisms can be classified in mainly two separate groups: (1) classical or non-bio-mimetic ones, such as propellers, jets, rudders or sails; and (2) bio-mimetic ones, which feature mechanisms copying kinematics and dynamics from nature or take inspiration of it by applying the resulting knowledge to construct a new way of propulsion. Most of the known propulsion vehicles use the non-bio-mimetic propulsion mechanisms, and more specifically propellers. However, the propeller-based mechanisms have the disadvantage that they are violent to the surrounding environment and they are not suitable to be operated in shallow waters. Many other known propulsion mechanisms, especially the bio-mimetic ones, are costly, inefficient, large, heavy and/or complex. There is thus a need for a more optimal propulsion mechanism to be used in aquatic vehicles for instance.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome at least some of the above problems relating to propulsion mechanisms, which are capable of generating wave-like motion.

According to a first aspect of the invention, there is provided a propulsion module for generating wave-like motion as recited in claim 1.

The proposed new solution has the advantage that the module is simple to control, yet modular. The module may be used so that it efficiently converts the unidirectional rotary motion of a motor to undulatory swimming patterns observed in most swimming animals, such as fish, eels, or lampreys. Due to its modularity and easily configurable parameters for undulatory wave generation, it can be adapted to required needs in different scenarios. The desired configuration can be achieved with minimal adjustments in the same produced mechanical mechanism. A drive mechanism, which may include a drive belt, ensures maximum power transmission, thus high efficiency of the whole propulsion system. The proposed propulsion module may be used to propel various types of vehicles forward.

According to a second aspect of the invention, there is provided an aquatic vehicle comprising the propulsion module according to the first aspect of the present invention.

Other aspects of the invention are recited in the dependent claims attached hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention will become apparent from the following description of a non-limiting example embodiment, with reference to the appended drawings, in which:

- Figure 1 is an isometric view showing a propulsion module according to an embodiment of the present invention;
- Figure 2 is a top of the propulsion module of Figure 1;
- Figure 3 is an isometric view showing the propulsion module of Figure 1 but without a flexible structure;
- Figure 4 is a side view of the propulsion module of Figure 3;
- Figure 5a is a side view showing a conversion device that can be used in the propulsion module of Figure 1;
- Figure 5b is a cross-sectional view taken along line A-A shown in Figure 5a;
- Figure 5c is a top view showing the conversion device of Figure 5a;

- Figure 6 is a side view illustrating in a connected configuration two rigidifying rods that may be used in the propulsion module of Figure 1;
- Figure 7 is a cross-sectional view taken along line B-B shown in Figure 6;
- Figure 8 is a top view of the propulsion module of Figure 1 and schematically illustrating the oscillatory movement of the flexible structure;
- Figure 9 is a top view of another propulsion module and schematically illustrating the oscillatory movement of the flexible structure;
- Figure 10 is an isometric view showing a propulsion module according to a first variant of the embodiment illustrated in Figure 1;
- Figure 11 is an isometric view showing a propulsion module according to a second variant of the embodiment illustrated in Figure 1 but without the flexible structure;
- Figure 12 is a top view of the propulsion module of Figure 11;
- Figure 13 is a front view of a hinge mechanism that may be used in the configuration of Figure 11;
- Figure 14 is a top view of the hinge mechanism of Figure 13;
- Figure 15 is a side view of the hinge mechanism of Figure 13; and
- Figure 16 is an isometric view illustrating an aquatic vehicle comprising the propulsion module of Figure 1.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

An embodiment of the present invention will now be described in detail with reference to the attached figures. The embodiment is described in the context of a propulsion module for a swimming robot in liquids, for example, but the teachings of the invention are not limited to this environment. Identical or corresponding functional and structural elements which appear in the different drawings are assigned the same reference numerals. As utilised herein, “and/or” means any one or more of the items in the list joined by “and/or”. As an example, “x and/or y” means any element of the three-element set {(x), (y), (x, y)}. In other words, “x and/or y” means “one or both of x and y.”

As another example, “x, y, and/or z” means any element of the seven-element set {(x), (y), (z), (x, y), (x, z), (y, z), (x, y, z)}. In other words, “x, y and/or z” means “one or more of x, y, and z.” Furthermore, the term “comprise” is used herein as an open-ended term. This means that the object encompasses all the elements listed, but may also include additional, unnamed elements. Thus, the word “comprise” is interpreted by the broader meaning "include", "contain" or "comprehend". An example embodiment of the invention is described next in detail.

Figure 1 illustrates a propulsion module 1 according to an example of the present invention. The propulsion module may be part of a swimming inspection and monitoring drone, destined to swim in calm to medium rough waters. The proposed propulsion module can be employed in the following fields for instance:

- aquaculture (in-land and marine);
- environmental monitoring (in rivers, lakes, ocean, artificial water reserves etc.);
- underwater inspection (harbour, close-shore, dams, off-shore structures);
- underwater manipulation/intervention operations;
- propulsion of marine vessels; and
- hydropower plants.

The propulsion module of Figure 1 forms a bionic swimming robot, which in operation forms an anguilliform swimming body. As is next explained in more detail, the propulsion module, and more specifically its propelling unit, presents several individual aspects that as a whole make up a versatile and easy to modulate propulsion module or unit. In one mode of operation, the propulsion module 1 generates a travelling wave by transforming continuous rotational motor movement into a wave, which may have a varying amplitude and/or phase shift, travelling from a first end 3 of the propulsion module, which in this case is the head, to a second, opposite end 5, which in this case is to the tail of the propulsion module. The rotational movement can be generated by a motor assembly 7, which in this example comprises a motor inside a waterproof motor housing. The motor may be an electric motor, which may be powered by a direct current (DC) source, such as a battery. The propulsion module 1 of Figure 1 comprises three conversion devices 9, namely a first conversion device 9_1, a second conversion device

9_2 and a third conversion device 9_3, each arranged to convert the rotational motion from the motor into oscillatory translational motion. In this example, the conversion devices are reciprocating motion mechanisms, and more specifically Scotch yoke mechanisms (also known as slotted link mechanisms) converting the rotational motion into linear motion of a slider. The Scotch yoke mechanism and its operation will be explained in more detail with reference to Figures 5a to 5c. The conversion devices are arranged along a length or central axis 14 of the propulsion module with an adjustable separation between any two consecutive conversion devices. It is to be noted that the length axis 14 is a straight or curved line lengthwise across the propulsion module.

The conversion devices 9_1, 9_2, 9_3 are coupled to each other and to the motor by means of a drive mechanism, which in this example comprises a set of drive belts 15 and a set of wheels 17 or pullies, and more specifically cog pullies (or cog wheels). However, it is to be noted that, instead or in addition, the wheels 17 may be considered to be part of the conversion devices. Any two consecutive wheels 17 (for operating different conversion devices) are linked to each other by a drive belt 15 which is arranged to rotate around a respective wheel at each end of the belt. The drive belt may be a toothed belt. As can be seen in Figures 1 and 2, the propulsion module 1 further comprises a flexible structure 19 or a flexible sheet-like structure, which in this example is a flexible membrane or tissue and forms, during operation of the propulsion module, an undulating surface thereby interacting with the environment. In this example, the membrane extends between the head 3 and the tail 5 such that it is connected to the conversion devices, and more specifically to their membrane fixation elements 21 (as is better seen in Figures 3 and 4), which are longitudinal elements or rods, and more specifically masts or upright posts. In this example, the membrane further extends beyond the tail. When seen from above, the membrane may comprise a set of pockets each traversing the membrane substantially parallel to the masts, and each configured to receive a respective mast such that masts are caught in the pockets during the oscillatory motion of the membrane. In other words, the membrane is configured to move around the masts back and forth towards the head and tail during the wave-like motion of the membrane. Alternatively, the masts 21 can be fixed to the side of the membrane at membrane fixing locations. During the oscillatory motion of the membrane, the membrane would simply expand and shrink in the direction of the wave-like motion of the membrane between the membrane fixing locations.

Referring to Figures 1 to 2, the elements apart from the motor assembly 7, the membrane 19 and the masts 21 form a support structure. The support structure also comprises rigidifying, longitudinal elements 22, such as support rods. These rods are arranged substantially parallel to the longitudinal axis, and in this example, they extend between the head 3 and tail 5, optionally along the entire length of the propulsion module. The length of one single rod may thus substantially equal the length of the propulsion module. Alternatively, shorter rods may be connected together at their ends to thus form a combined rod extending optionally along the entire length of the propulsion module. Two rods may be connected together by a nut, and more specifically by a longitudinal nut, which may have an inner thread such that two rods having an outer thread may be screwed into one nut (one rod from each end of the nut). Alternatively, as shown in Figures 6 and 7, the rods 22 may be connected to each other without any nuts so that one rod has an outer thread at its end, while another rod has an inner thread at its end (i.e. at least this end of the rod would be hollow). In this manner the rod with an outer thread can be screwed into the end of the rod with the inner thread. By having the capability of connecting rigidifying elements together, it is possible to adjust the length of the propulsion module and also the number of the conversion devices.

Figures 5a to 5c show one of the conversion devices 9 in more detail. All the conversion devices of the propulsion module may be substantially identical, or alternatively, different types of conversion devices may be used as long as they are configured to convert rotational motion into linear, oscillatory displacement. In this example, the conversion devices are right-angled Scotch yoke mechanisms, where the driving and driven parts (entry and exit of force) are inverted compared with conventional Scotch yoke mechanisms. As can be seen in Figures 5a to 5c, the mechanism comprises a base 23, which in this example is V-shaped, but a U-shaped base or other base shapes are equally possible. A movable arm 27, which in this example is a longitudinal element, is arranged to be supported directly or indirectly by a guide (output) runner 29, which together are arranged to move or translate along a guide element or guide rail 31. The movement of the arm thus defines a movement axis 32 (in this case a substantially straight line), which is angled (i.e. at a non-zero angle or nonparallel) with respect to the length axis of the propulsion module. In this example, the movement axis is substantially orthogonal to the length axis of the propulsion module. However, the movement axis could be angled with respect to the length axis, such that the angle between these axes could be between 45° and 90° or more

specifically between 60 and 80°. It is to be noted that the movement axes of the different arms may or may not all be placed at the same angle with respect to the length axis. The membrane 19 is thus configured to be indirectly guided by the movable arms 27 to generate the wave-like motion of the membrane.

A drive plate 33 is provided in this example underneath the movable arm 27. The drive plate 33 is arranged to be rotated by a drive shaft 36 connected to an input wheel 17_1 or a torque receiving wheel, which in turn is rotated by torque applied by the motor or by another conversion device by means of the belt 15. The drive plate is thus configured to transform rotational motion into linear motion. An output wheel 17_2 or a torque transferring wheel connected to the drive shaft 36 is arranged to output torque to a next conversion device. The propulsion module thus comprises intermediate conversion devices 9_1, 9_2 and a distal conversion device 9_3 most distant from the motor 7 of all the conversion devices. The intermediate conversion devices each comprise an input wheel for receiving the rotational motion from a preceding conversion device in the set or from the motor, and an output wheel for transferring the rotational motion to a next conversion device. In this example the distal conversion device comprises an input wheel but no output wheel. In this example, the input wheels and the output wheels are configured to rotate in the same direction. The input and output wheels are in this example coaxial or substantially coaxial, although this does not have to be the case. In this example, the rotational axis 34 of the wheels 17 is substantially parallel to the mast 21, although this does not have to be the case. The drive plate is in turn arranged to displace a transmission pin 35 along a groove or slot in the arm 27. In this manner, the pin 35 makes the arm translate back and forth along the guide rail when the motor is operating. Thus, the Scotch yoke mechanism comprises a rotational input and the linear output runner 29, which is coupled with the linear guide 31 and the transmission pin 35.

Figure 8 depicts the technical principle of the rotation to oscillation transformation for the propulsion module of Figure 1. In this example, the rotation and oscillation act in the same plane. As was mentioned earlier, the set of conversion devices are arranged to transfer the rotational drive into oscillatory back-and-forth motion. The arrow in the figure shows the propagation direction of the sinusoidal travelling wave. The thick solid line shows the position of the membrane 19 at a first time instant, i.e. at $t = 0$. At this moment, the transmission pin 35 of the first conversion device 9_1 is at its first maximum (amplitude). In other words, the membrane has its first

maximum amplitude. The transmission pin 35 of the second conversion device 9_2 is at a median position, i.e. the membrane 19 crosses the central axis of the propulsion module 1 at this moment. The transmission pin 35 of the third conversion device 9_3 is at its second, opposite maximum (amplitude). In other words, the membrane has its second maximum amplitude. The thin solid line shows the position of the membrane 19 at a second time instant, i.e. at $t = t_1$, while the dashed line shows the position of the membrane 19 at a third time instant, i.e. at $t = t_2$. The movements of the arms 27 of the different conversion devices are thus linked. For example, to generate a non-incremental, i.e. a constant or symmetrical travelling wave, the arm 27 of the first conversion device 9_1 starts to move in the first direction, while the arms of the next two conversion devices 9_2, 9_3 start to move in the second, opposite direction. Once the arm 27 of the first conversion device 9_1 reaches the median position, then the arm of the second conversion device 9_2 changes its movement direction such that it now starts to move in the first direction. The arm of the third conversion 9_3 device still moves in the second direction until the arm of the first conversion device 9_1 reaches its second, opposite maximum. Once this event has occurred, the arm of the first conversion device 9_1 starts now to move in the second direction, while the arm of the third conversion 9_3 device starts now to move in the first direction. At this moment the arm of the second conversion device 9_2 still moves in the first direction. However, it is to be noted that the oscillation amplitude does not have to be constant along the propulsion module. Indeed, the oscillation amplitude and a phase difference between conversion devices (which in the example of Figure 8 is 90° between the wheels of any consecutive conversion devices) can be chosen freely within technical boundaries and can be changed mechanically, for instance during maintenance of the propulsion module. Thus, various wave-forms (such as incremental or decremental waves) can be achieved with the same propulsion module. Combinations of different trigonometrical waves throughout the body are feasible and can be realised by pre-planned implementation of different phase lags between the conversion devices. For example, in order to minimise any disturbance to the environment close to the motor 7, the arms 27 or the transmission pins 35 may be arranged such that their maximum allowed distance from the central axis may increase towards the tail 5. In this manner an amplitude increasing travelling wave may be generated. Figure 9 illustrates the oscillation principle for a propulsion module comprising five conversion devices 9_1, 9_2, 9_3, 9_3, 9_5.

Various parameters, including the conversion device (the scotch yoke mechanism) amplitude of oscillation, the number of conversion devices in series, the

height of the undulating membrane, the length of the traveling wave, i.e. the distance along the central axis between two consecutive conversion devices, and/or the phase shift between the conversion devices (or more specifically their wheels) can be adjusted mechanically in a short amount of time, without adding complexity to the control, as only the speed and/or direction of rotation typically needs to be commanded to the motor. The phase shift may be defined as the angular position difference between cogged wheels of two consecutive conversion devices (i.e. the Scotch yoke mechanisms. It can range between -180° and +180°. A constant phase shift translates into a constant phase difference between oscillating Scotch yokes, generating thereby a travelling wave along the connected membrane 19. The number of the conversion devices can be chosen freely (only limited by the motor output torque). It is to be noted that when the conversion devices are not fixed to the rods 22, they can slide along the rods and in this manner also the distance between the conversion devices can be easily adjusted. Once a given conversion device is in a desired location, it can be locked in place by using e.g. nuts or other stopping elements on the rods 22. These elements are placed at least on the motor facing sides of the conversion devices but optionally also on the tail facing sides of the conversion devices. However, when the belts are tensioned, then the belts would prevent the conversion devices from moving towards the tail, i.e. the distal end. It is to be also noted that the distance between the conversion devices also has an impact on the belt length. In other words, if the distance between the conversion devices is adjusted, then also the length of the belt is adjusted.

Figure 10 shows a further variant of the present invention. This variant is similar to the propulsion module illustrated in Figure 1, however, with the difference that this variant comprises two support structures thus forming a double drive unit as opposed to only one drive unit. More specifically, the propulsion module 1 according to this variant comprises a first support structure, or a lower support structure, and a second support structure, or an upper support structure. This variant has the advantage that the stability of the entire structure can be increased, and the membrane can be made higher. Each one of the lower and upper support structures may be operated by its dedicated motor, both optionally located inside the same motor housing thus increasing the torque output. In this configuration, the lower and upper conversion devices operate synchronously. More specifically, when the arm of the first lower conversion device reaches its first maximum amplitude, the arm of the first upper conversion device also reaches its first maximum amplitude. When the arm of the first lower conversion device reaches its second maximum amplitude, the arm of the first

upper conversion device also reaches its second maximum amplitude. The other lower and upper conversion devices operate in a similar manner synchronously.

Figures 11 and 12 illustrate another variant of the propulsion module 1. The propulsion module according to this variant is similar to the propulsion module illustrated in Figure 1, however, with the difference that this variant comprises a steering mechanism for steering the propulsion module in the plane of the propulsion. More specifically, in this example, the steering mechanism comprises a set of hinge or pivot mechanisms, such that hinge mechanisms are distributed with a given separation along the length axis of the propulsion module. The configuration of Figures 11 and 12 comprises two hinge mechanisms 37, namely a first hinge mechanism 37_1 and a second hinge mechanism 37_2. These hinge mechanisms can be controlled by a steering cable or steering cables 39 as shown in Figures 13 to 15. For simplicity, these cables are omitted in Figures 11 and 12. These cables can be operated, i.e. pulled and/or pushed by a steering motor, such as a servo motor, which may be housed in the motor housing. It is to be noted that the motors mentioned above can be exchanged by an alternative actuation with a rotary output. The operation of the hinge mechanisms is explained next in more detail with reference to Figures 13 to 15.

Figures 13 to 15 illustrate the hinge mechanism 37 together with the steering cables 39 in more detail. The hinge mechanism comprises a base 41, which in this example is V-shaped, but a U-shaped base or other base shapes are also possible. Advantageously, the base 41 has substantially the same shape as the base 23. An adjustable hinge fixation element 43, which in this configuration is a longitudinal plate, and is connected to the base 41 by means of fastening elements, which in this example are hinge joints 45, 47. More specifically, a first hinge joint 45 is in this example fixed, while a second hinge joint 47 is pivotable and thus forms a pivotable hinge joint. A hinge pivot axis 49 is also shown in Figure 13. The steering cables 39 may pass through openings or through holes in the base 41. The other holes in the base may receive the rods 22. Thus, the bases 41 form the end pieces for the rods 22 as is shown in Figures 11 and 12. The rods 22 may be screwed into the holes or form-fit connections may be used. The steering cables may be for instance Bowden cables, which are flexible cables used to transmit mechanical force or energy by the movement of an inner cable relative to a hollow outer cable housing. The steering cables are thus connected to the hinge mechanisms by pulling the cables through the guidance holes and fixing the length of the cable with a knot directly after the hinge on the tail facing side. The steering cables

may extend from the motor to the tail end. In the configuration of Figures 13 to 15, the hinge joints 45, 47 pass through openings or through holes 53 in the fixation element forming hinge joint fixation points. However, instead of having discrete hinge fixation points, the hinge fixation element 43 may have a longitudinal slot or opening allowing the hinge joints to be fixed to the hinge fixation element at any desired location. To facilitate the steering, the fixed hinge joint 45 of a respective hinge mechanism is advantageously closer to the head than the pivotable hinge joint 47. Furthermore, the drive belts do not advantageously touch the pivotable hinge joints. It is to be noted that the number of hinge mechanisms is not limited to two but can be freely chosen according to the desired application of the propulsion module 1. Also the distance between the hinge mechanisms can be chosen freely by e.g. adapting steering cable length. Thus, the number of hinge mechanisms and their separation along the length axis are parameters that can be selected by the user.

A propulsion module for non-autonomous (e.g. boats or other cargo or passenger transportation means), semi-autonomous or autonomous vehicles, such as drones, to be used in water or in other liquids, for instance, was described above. However, it is to be noted that the proposed module can also be used on land, e.g. to advance on granular substances. The vehicle is shown in Figure 16, where the vehicle comprises the propulsion module 1 and a head module 55 for carrying a payload consisting of payload modules 56, where the head module is arranged to be propulsed by the propulsion module coupled to the head module. The payload modules may include any one of the following units: a sensor, containing e.g. environmental sensors and electronics for analytics; a battery, containing power supply for the entire vehicle; a computation unit, containing a single-board computer (SBC) and electronics for navigation and localisation; an actuation unit, containing an electronically controlled (EC) motor and power electronics for the propulsion module; and a buoyancy unit, containing a pump and fins to control the roll and/or pitch of the vehicle by changing the mass and upward/downward thrust. According to the present invention, these vehicles rely on versatile, efficient and robust propulsion methods to achieve agile and efficient movement in the water. The invention also relates to a method of operating the propulsion module.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive, the invention being not limited

to the disclosed embodiment. Other embodiments and variants are understood, and can be achieved by those skilled in the art when carrying out the claimed invention, based on a study of the drawings, the disclosure and the appended claims. For example, it is possible to combine teachings of different variants to obtain further embodiment or variants.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that different features are recited in mutually different dependent claims does not indicate that a combination of these features cannot be advantageously used. Any reference signs in the claims should not be construed as limiting the scope of the invention.

CLAIMS

1. A propulsion module (1) for generating wave-like motion, the propulsion module (1) comprising:

- a motor (7) for generating rotational motion;
- a set of conversion devices comprising a first conversion device (9_1) and a second conversion device (9_2) each comprising a movable arm (27) for converting the rotational motion from the motor (7) into oscillatory translational motion of the respective arm (27) along a movement axis (32), which is angled with respect to a length axis (14) of the propulsion module;
- a drive mechanism (15) for coupling the motor (7) to the first and second conversion devices (9_1, 9_2) for transferring the rotational motion to the first and second conversion devices; and
- a flexible structure (19) extending along at least a portion of the length axis (14) of the propulsion module (1), the flexible structure (19) being configured to be guided by the movable arms (27) to generate the wave-like motion of the flexible structure (19);

wherein a distance between the first and second conversion devices along the length axis, and/or a maximum range of motion of the movable arms (27) along the movement axis (32) is/are adjustable.

2. The propulsion module (1) according to claim 1, wherein the propulsion module (1) further comprises a support structure for linking the conversion devices to each other and to the motor (7).

3. The propulsion module (1) according to claim 2, wherein the support structure comprises rigid rods (22).

4. The propulsion module (1) according to claim 3, wherein the rods (22) are configured to be connected at their ends to each other to thereby allow adjusting the length of the propulsion module (1).

5. The propulsion module (1) according to any one of the preceding claims, wherein the drive mechanism (15) comprises a drive belt (15) for rotating a respective wheel (17) of a respective conversion device (9_1, 9_2).

6. The propulsion module (1) according to claim 5, wherein the set of conversion devices comprises intermediate conversion devices (9_1, 9_2) and a distal conversion device (9_3) most distant from the motor (7) of all the conversion devices in the set, the intermediate conversion devices each comprise a torque receiving wheel (17_1) for receiving the rotational motion from a preceding conversion device in the set or from the motor, and a torque transferring wheel (17_2) for transferring the rotational motion to a next conversion device in the set.

7. The propulsion module (1) according to claim 6, wherein the torque receiving wheel (17_1) and the torque transferring wheel (17_2) are configured to rotate in the same direction.

8. The propulsion module (1) according to claim 6 or 7, wherein the torque receiving wheel (17_1) and the torque transferring wheel (17_2) are coaxial.

9. The propulsion module (1) according to any one of the preceding claims, wherein the wave-like motion is travelling wave motion.

10. The propulsion module (1) according to any one of the preceding claims, wherein the conversion devices (9_1, 9_2) are Scotch yoke mechanisms.

11. The propulsion module (1) according to claim 10, wherein the flexible structure has a sheet-like form comprising an undulating surface during operation of the propulsion module for interacting with the environment.

12. The propulsion module (1) according to any one of the preceding claims, wherein at least one of the following parameters is adjustable:

- a phase shift defined as the angular position difference between wheels of two consecutive conversion devices;
- the height of the flexible structure (19);
- the number of conversion devices in the set;

- a speed of rotation of the motor (7); and
- a direction of rotation of the motor (7).

13. The propulsion module (1) according to any one of the preceding claims, wherein the propulsion module (1) further comprises a steering mechanism (37_1, 37_2) for steering the propulsion module in the liquid.

14. The propulsion module (1) according to claim 13, wherein the steering mechanism (37_1, 37_2) comprises a hinge mechanism (37) arranged between any two consecutive conversion devices in the set, and wherein the hinge mechanism comprises a pivot axis substantially orthogonal to a movement direction of the propulsion module (1).

15. An aquatic vehicle comprising the propulsion module (1) according to any one of the preceding claims and further comprising a head module (55) for carrying a payload, wherein the head module (55) is arranged to be propulsed by the propulsion module (1) coupled to the head module.

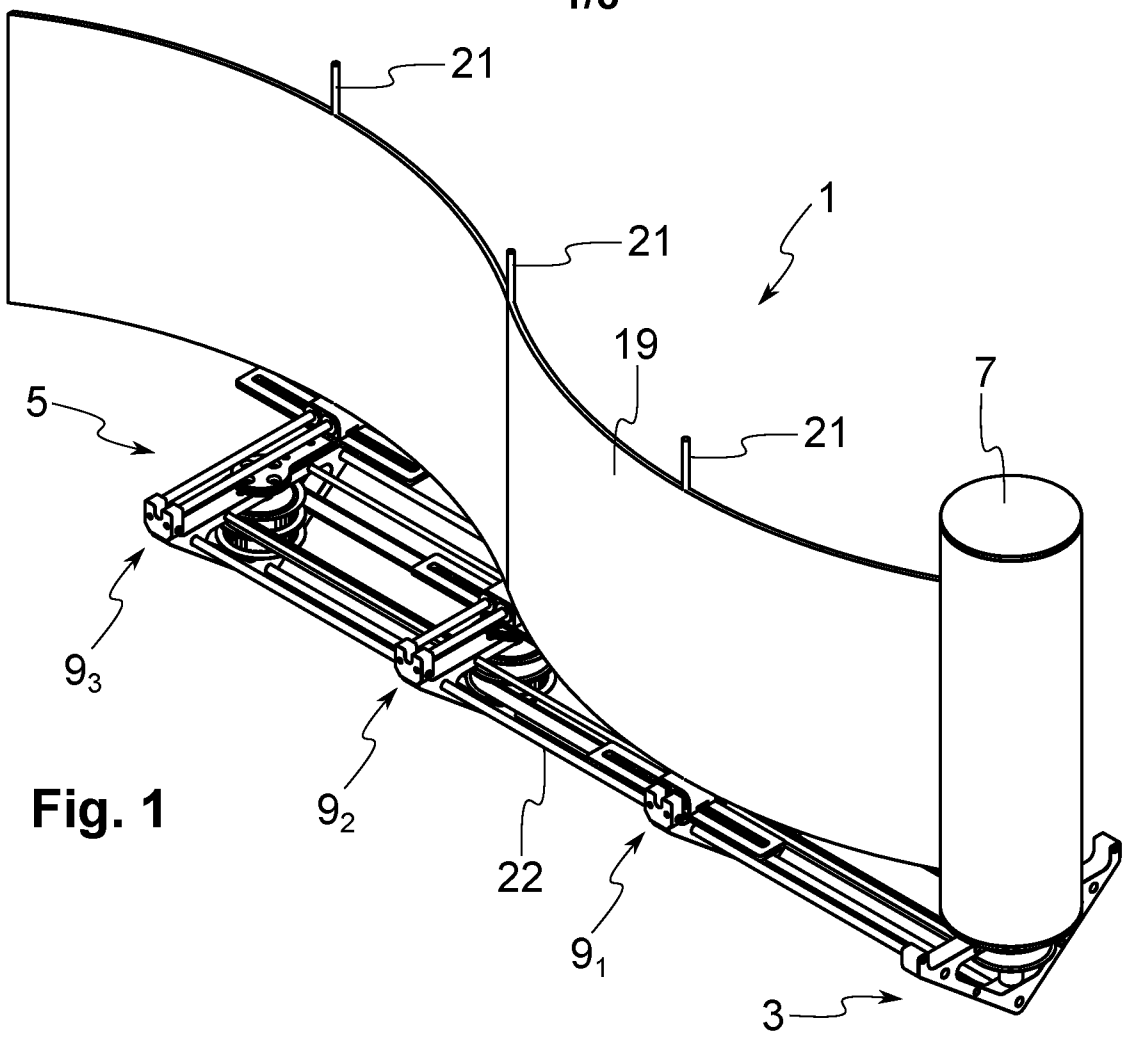


Fig. 1

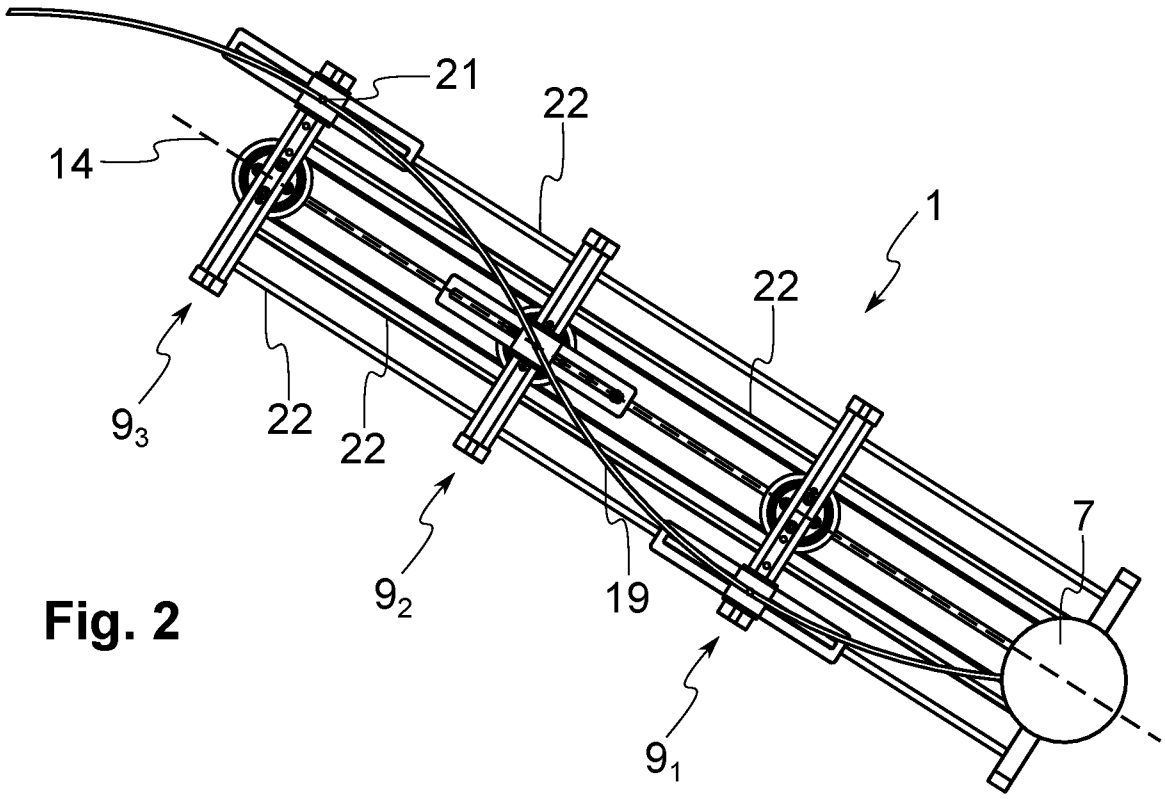


Fig. 2

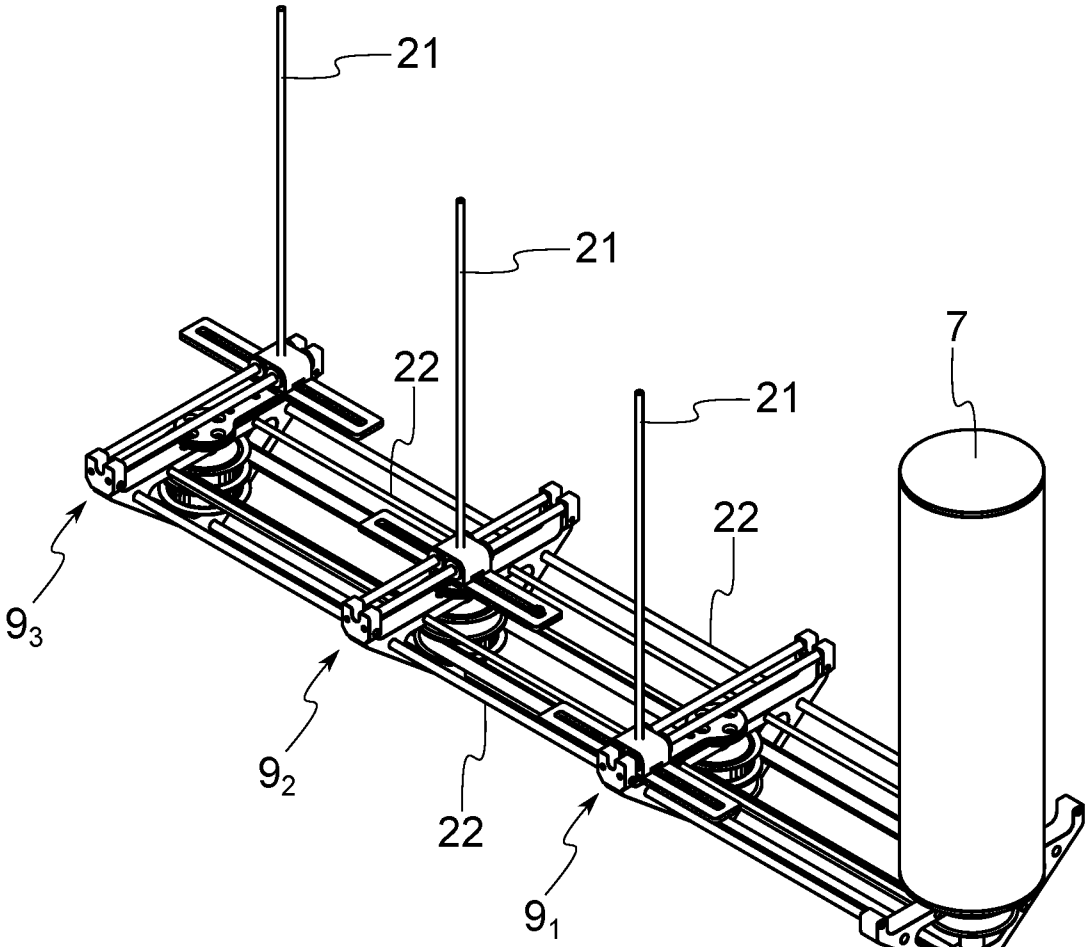


Fig. 3

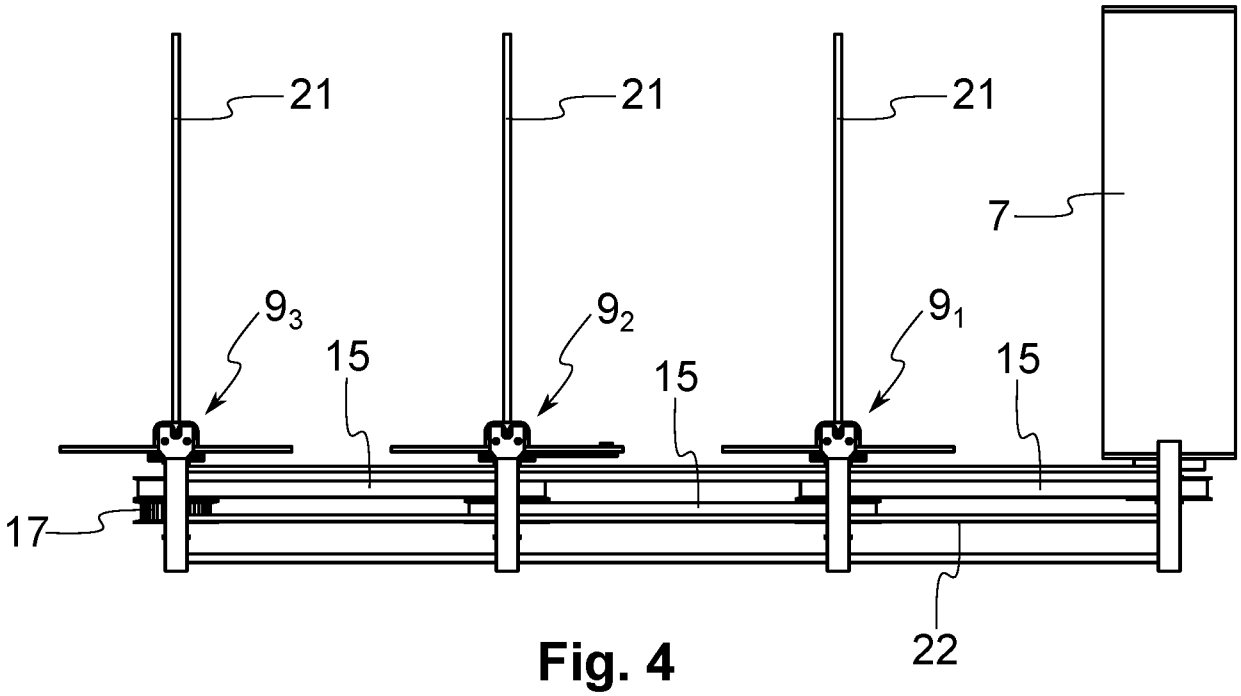


Fig. 4

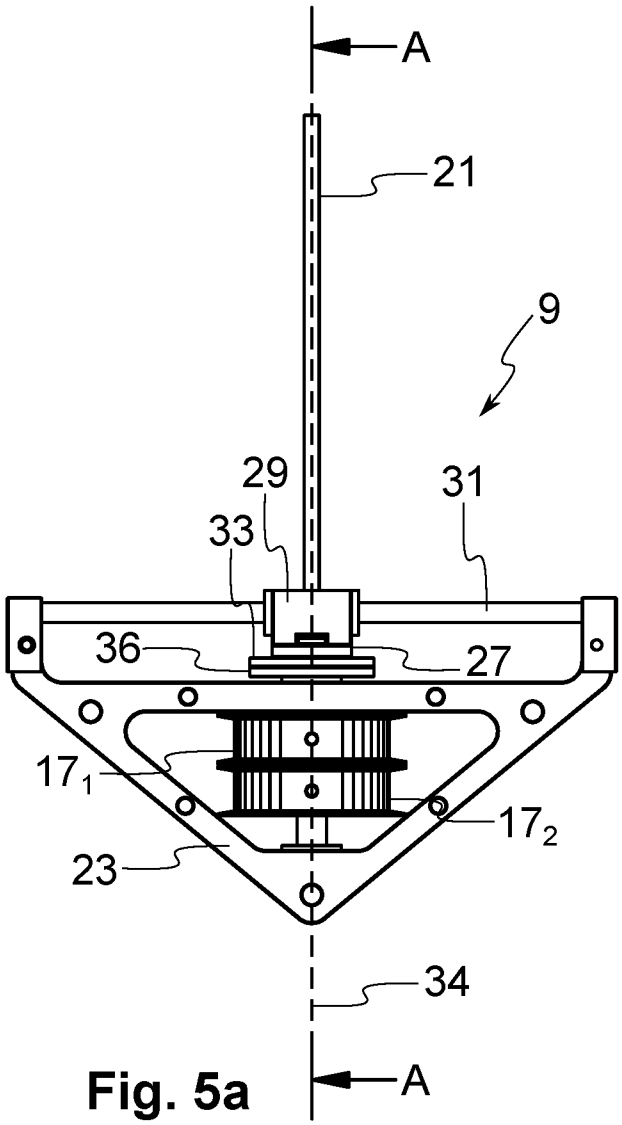


Fig. 5a

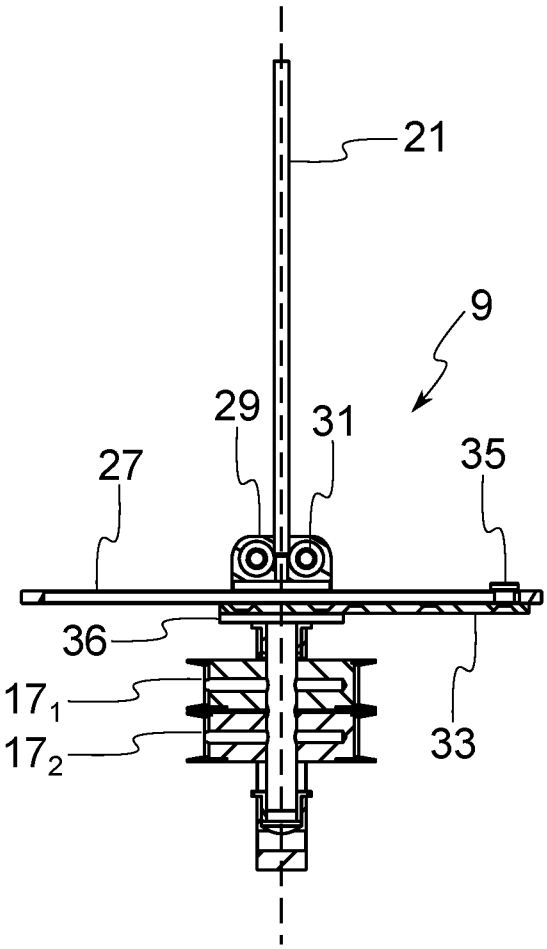


Fig. 5b

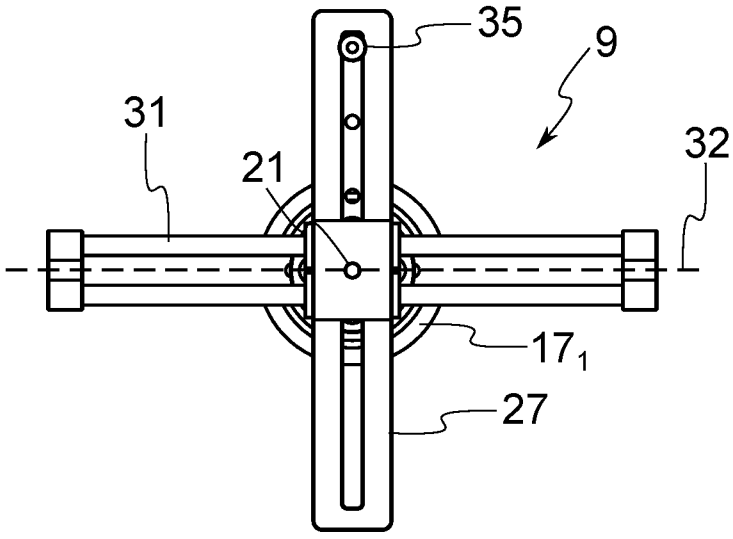


Fig. 5c

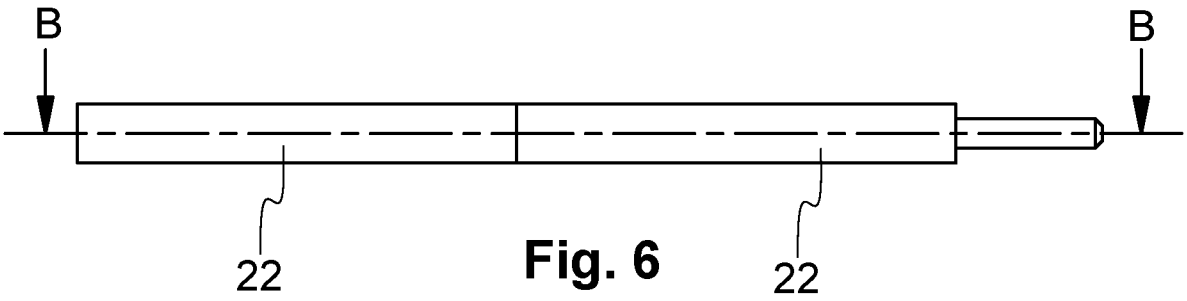


Fig. 6

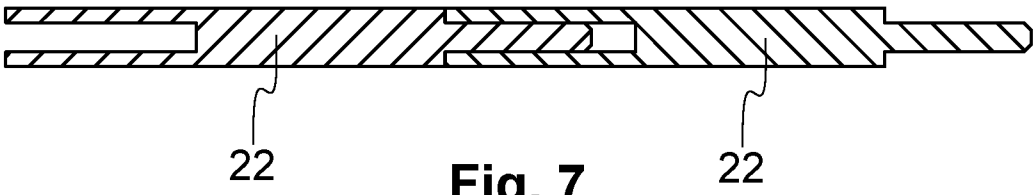


Fig. 7

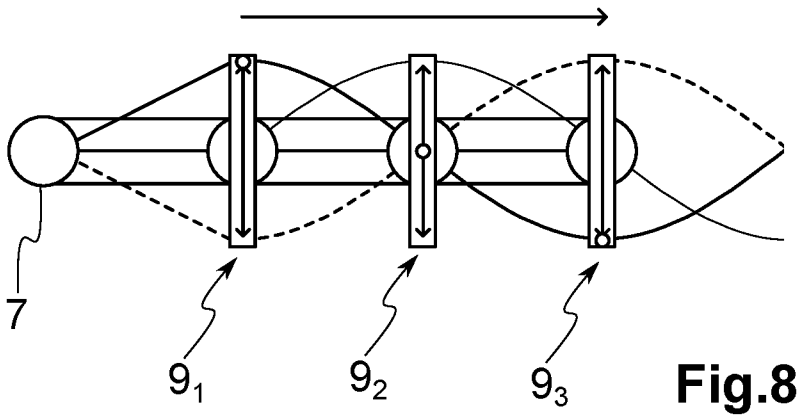


Fig.8

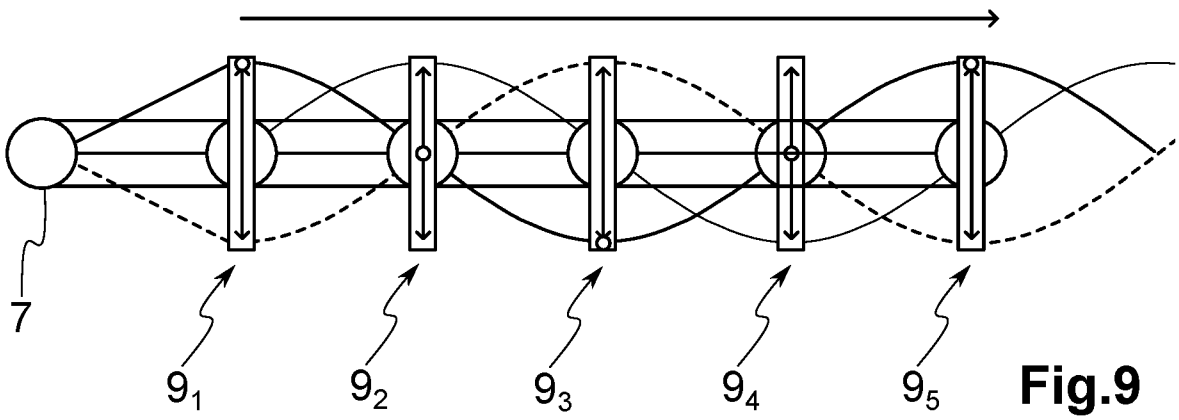


Fig.9

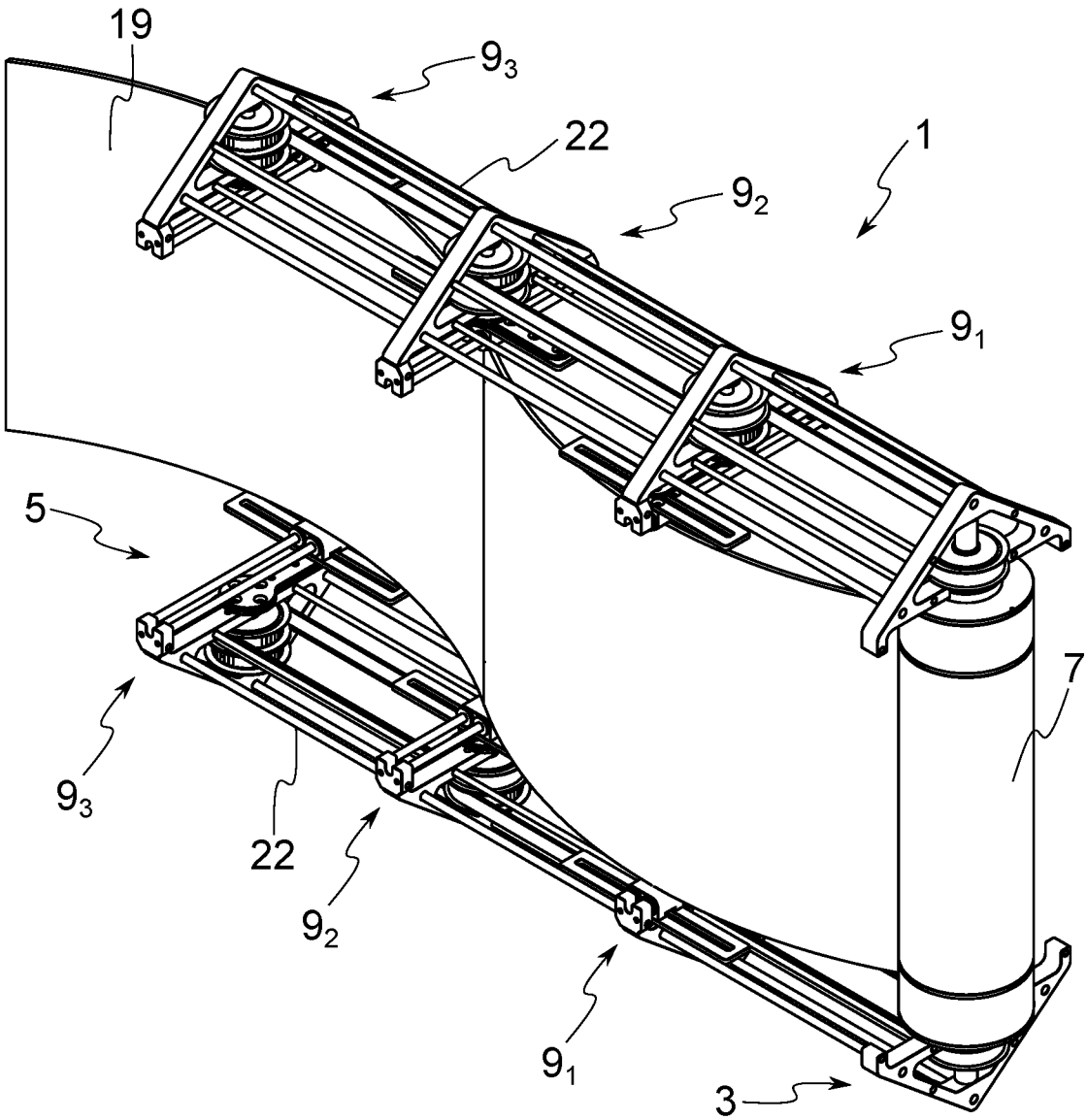


Fig. 10

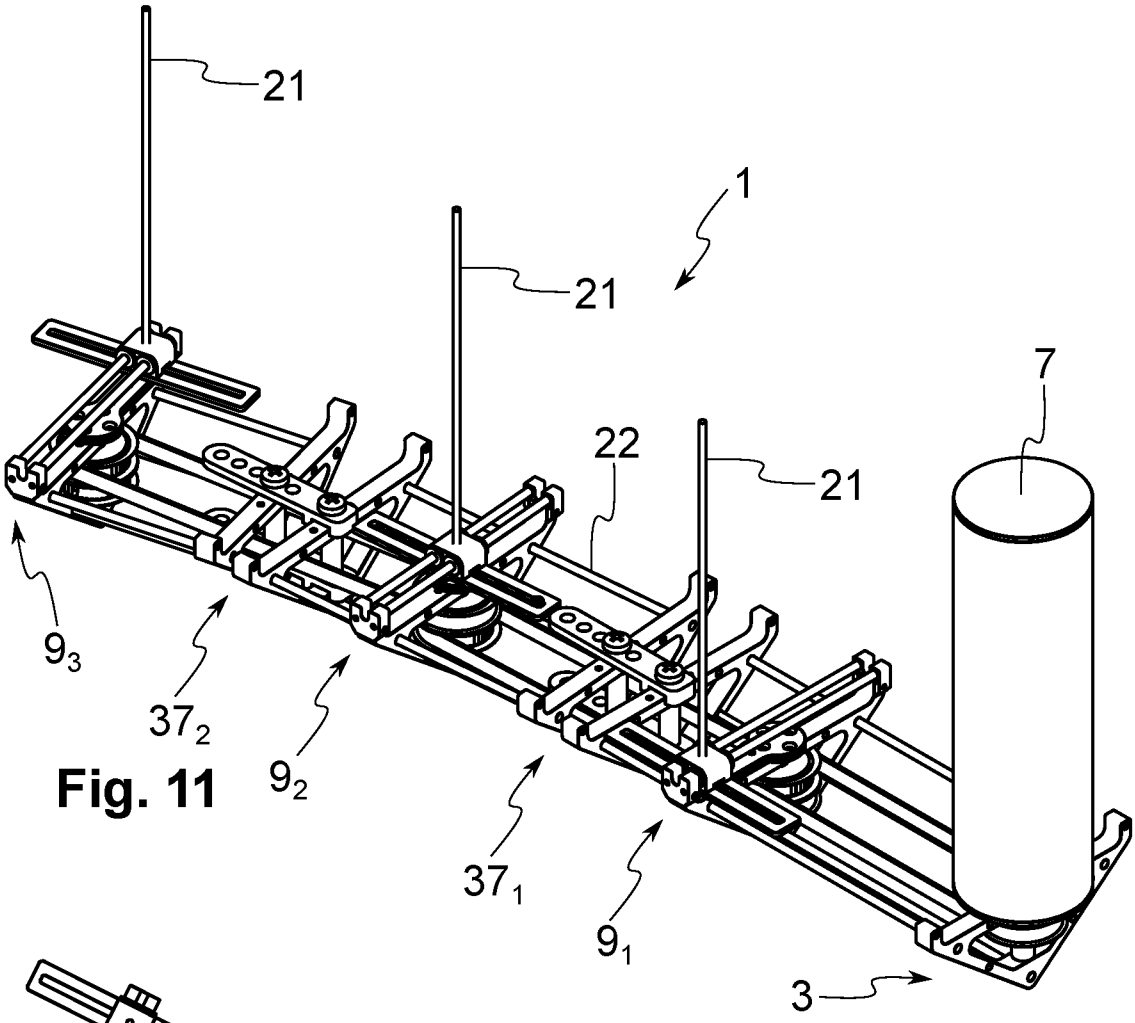


Fig. 11

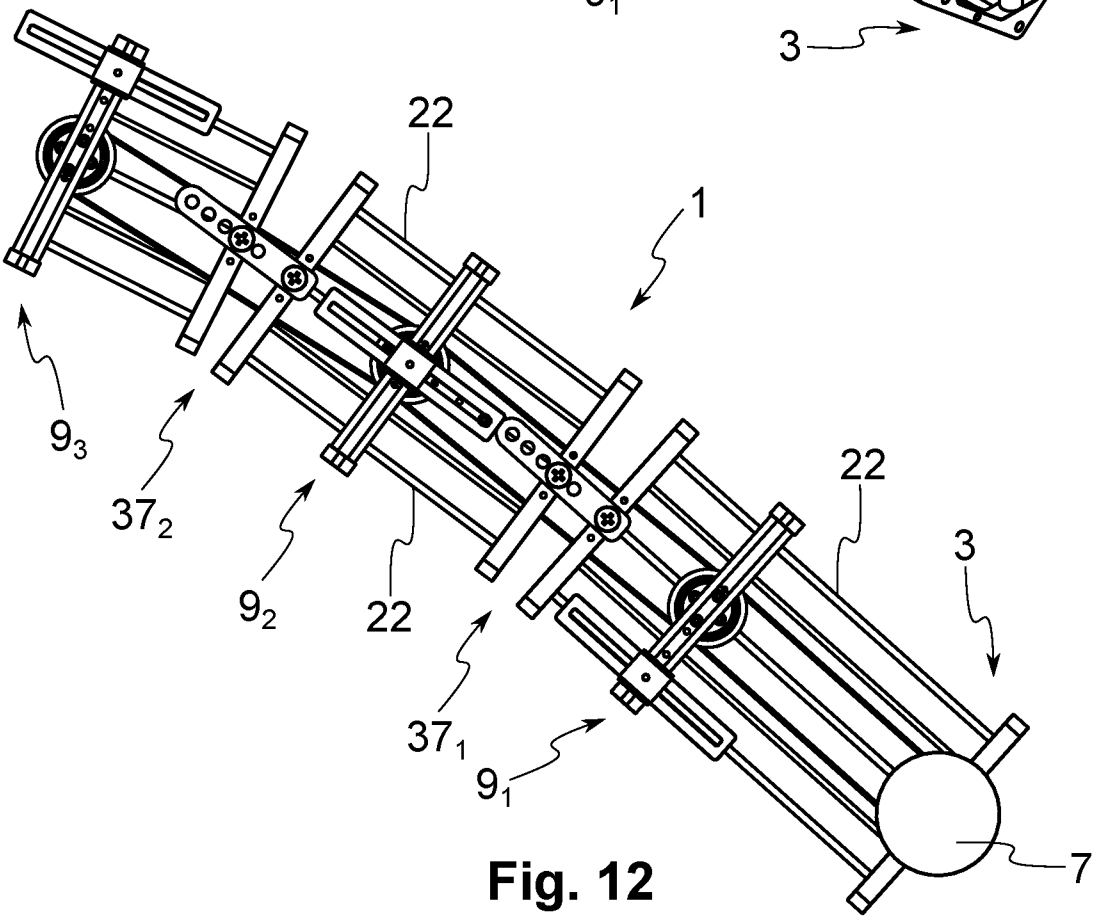


Fig. 12

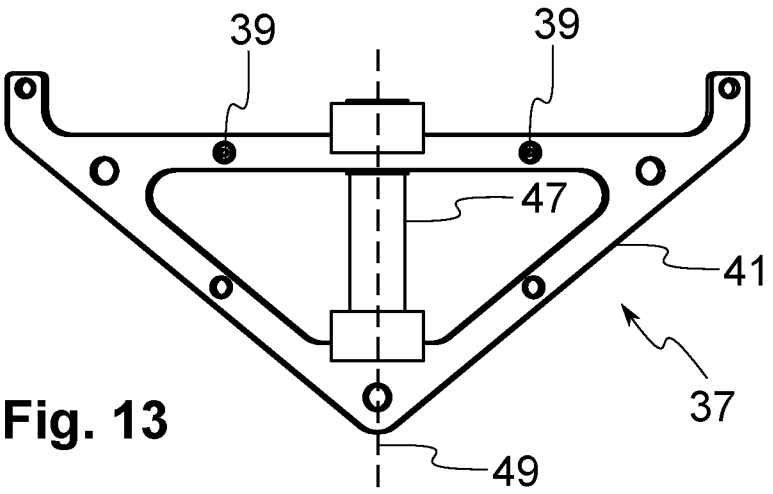


Fig. 13

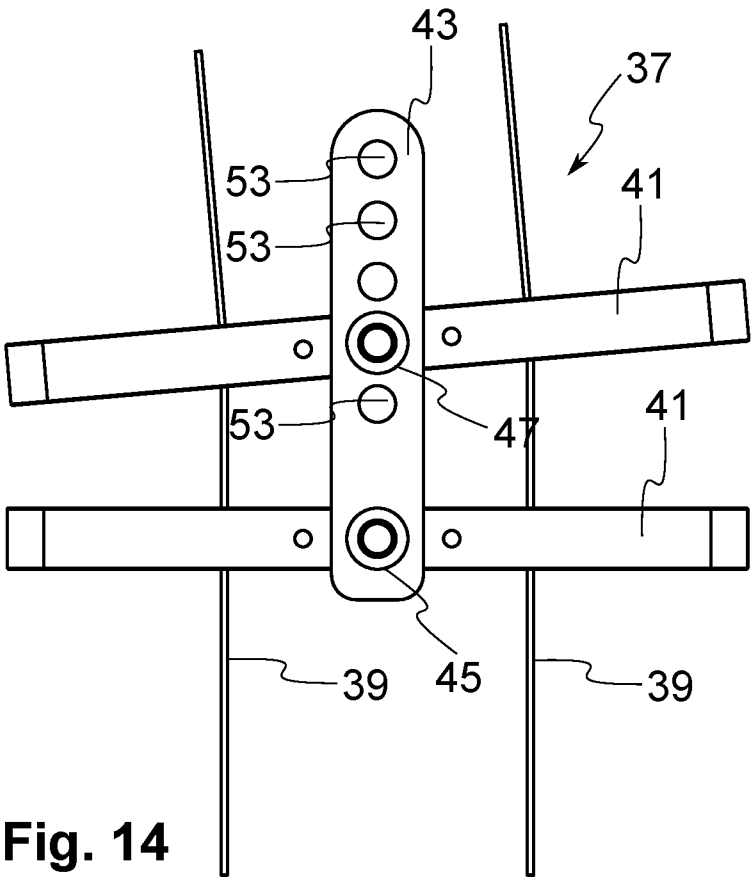


Fig. 14

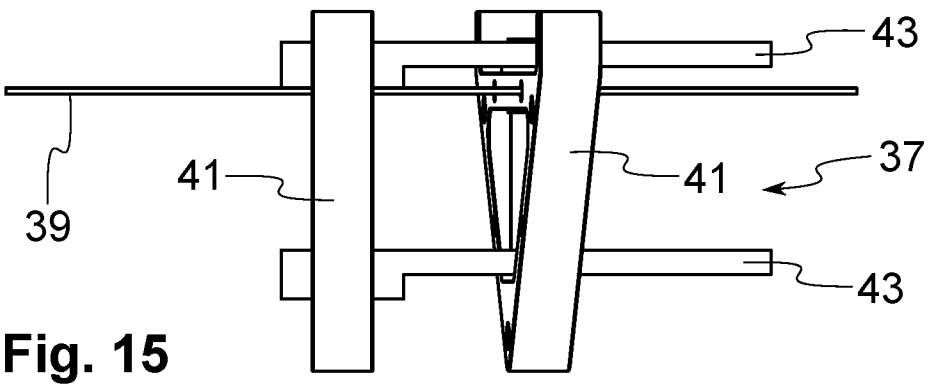


Fig. 15

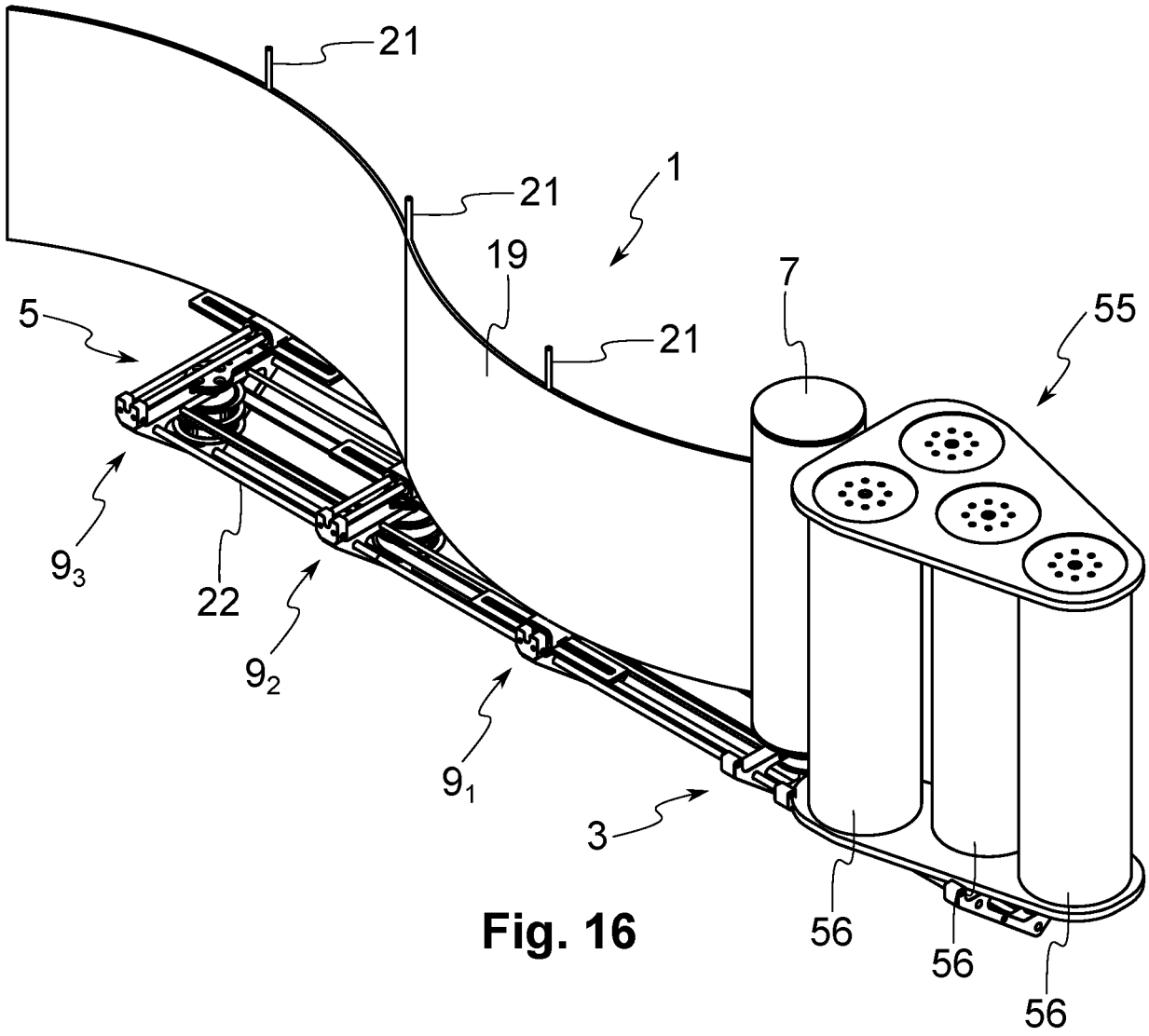


Fig. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2019/050610

A. CLASSIFICATION OF SUBJECT MATTER
INV. B63H1/36 B63H1/37 F03B17/06
ADD.

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)
B63H F03B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 278 565 A1 (BOUIX MAURICE [FR]) 13 February 1976 (1976-02-13) page 7, line 8 - line 38; figures 1-4	1-3,9,15
A	DE 98 999 C (MHC SHANN [GB]; RE CHURCHILL SHANN [GB]) 27 September 1898 (1898-09-27) page 2, left-hand column; figures 1-6	1-4,9, 11,12
A	WO 2015/119589 A1 (SIDORENKO YURI GRYGOROVYCH [UA] ET AL.) 13 August 2015 (2015-08-13) figures 1-5	1-3,9,15
A	EP 2 029 425 A2 (LATACZ MICHAL [PL]) 4 March 2009 (2009-03-04) paragraphs [0008], [0009]; figures 1,2,6	1-3,9, 11,15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 September 2019	17/09/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Mauriès, Laurent

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2019/050610

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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WO 2015119589 A1	13-08-2015	NONE	
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		EP 2029425 A2	04-03-2009
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