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(54) Titre : SYSTEME D'AILE PORTANTE A MOUVEMENT DE TRANSLATION PERMETTANT DE RECUPERER DE L'ENERGIE CINETIQUE DU VENT ET DES EAUX VIVES
 (54) Title: TRANSLATING FOIL SYSTEM FOR HARVESTING KINETIC ENERGY FROM WIND AND FLOWING WATER

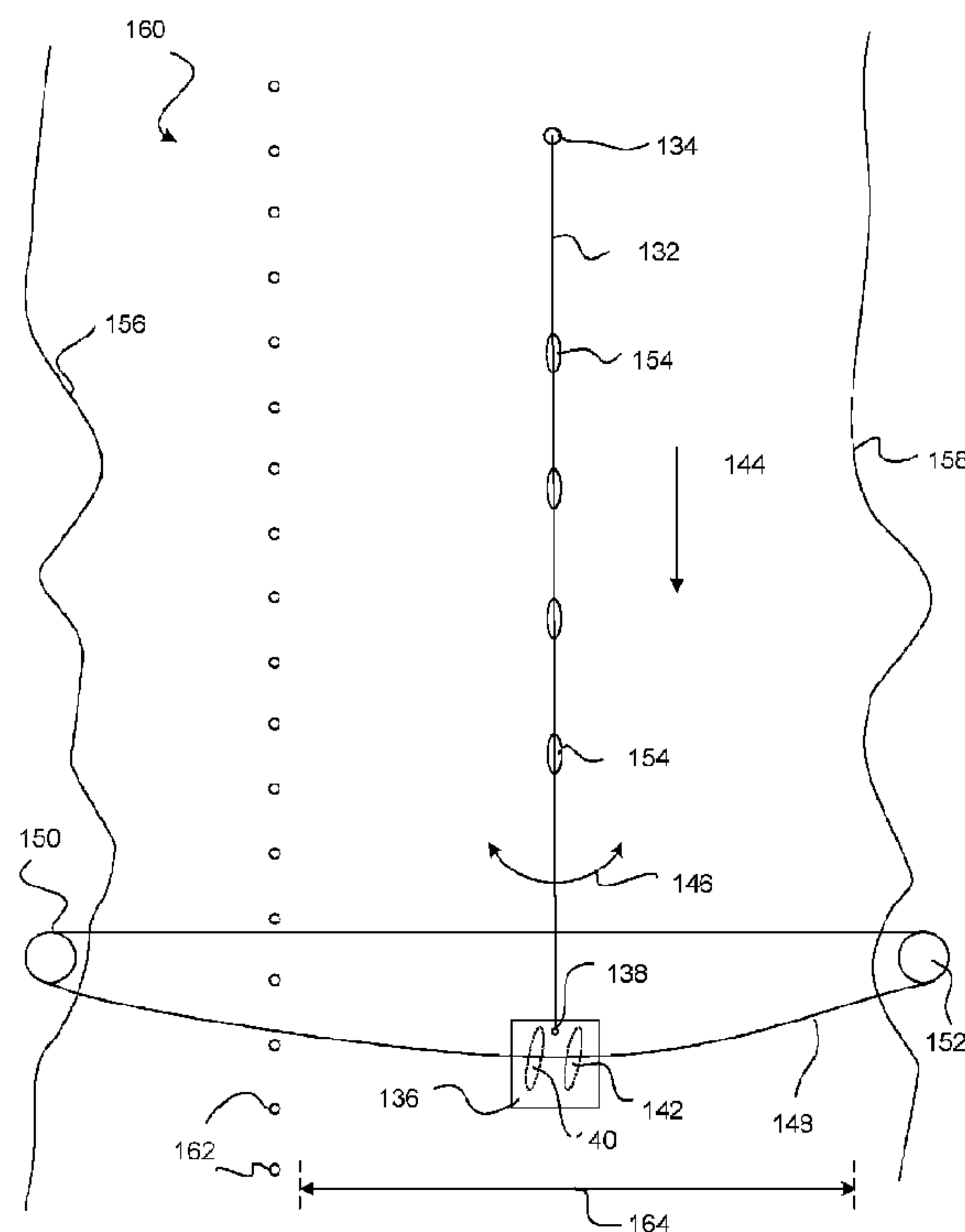


Fig. 6

(57) **Abrégé/Abstract:**

Consistent kinetic energy is harvested from wind and from flowing water in streams, rivers and tidal flows using a translating large sail, foil or wing which is permitted to translate in one direction, followed by translating in the opposite direction while pushing or pulling a cable, rod, or tether which in turn turns a pulley, wheel or other device from which traditional sources of power can be generated. The pulley wheel can be used to generate electricity, create hydrogen from water by electrolysis, compress air for transmission or storage, charge batteries, or perform work such as pumping water, heating water, moving objects, etc.

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(54) Title: TRANSLATING FOIL SYSTEM FOR HARVESTING KINETIC ENERGY FROM WIND AND FLOWING WATER

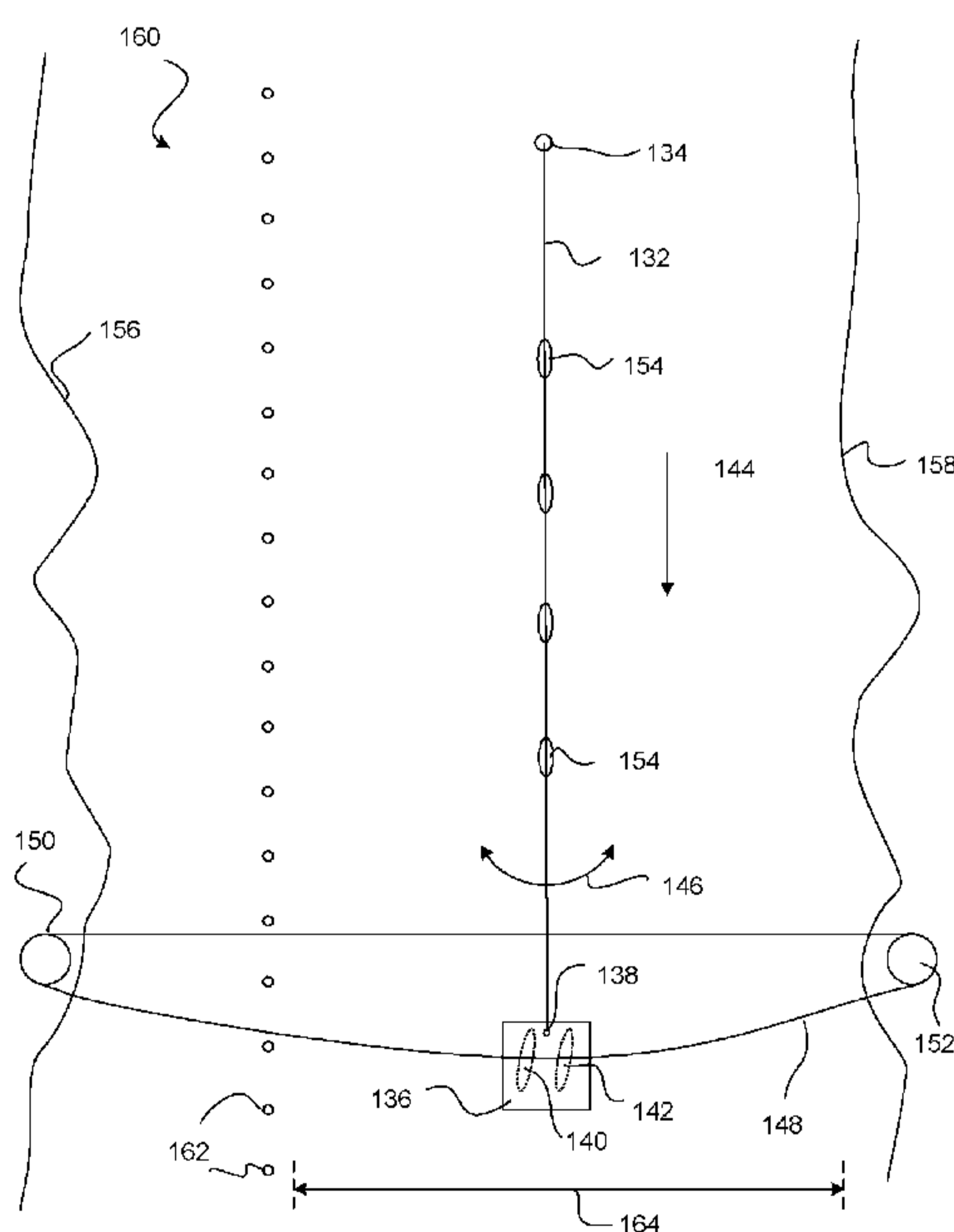


Fig. 6

(57) Abstract: Consistent kinetic energy is harvested from wind and from
flowing water in streams, rivers and tidal flows using a translating large sail,
foil or wing which is permitted to translate in one direction, followed by
translating in the opposite direction while pushing or pulling a cable, rod, or
tether which in turn turns a pulley, wheel or other device from which tradi-
tional sources of power can be generated. The pulley wheel can be used to
generate electricity, create hydrogen from water by electrolysis, compress air
for transmission or storage, charge batteries, or perform work such as pump-
ing water, heating water, moving objects, etc.

Description

Title of Invention: Translating Foil System for Harvesting Kinetic Energy From Wind and Flowing Water

Technical Field

[0001] This invention relates to harvesting kinetic energy from wind and flowing water using a translating foil and converting the kinetic energy into other forms of useable energy such as mechanical energy, electricity, hydrogen, pumped-hydro, heat, and compressed air.

Background Art

[0002] The world's population has a growing need for low-cost, reliable, usable energy, whether that energy is created by burning fossil fuels or by harnessing renewable energy resources, commonly referred to as "clean energy".

[0003] The use of fossil fuels as an energy source is falling out of favour due to growing concerns over the associated environmental impact of greenhouse gas and carbon emissions. Further, there is a concern that fossil fuels are a finite resource that one day will be depleted.

[0004] Various systems of harvesting renewable energy have been explored and/or used with varying degrees of success and expense.

[0005] Horizontal axis turbines are an example of current methods for harvesting kinetic energy from wind and water flow.

[0006] Horizontal axis wind turbines have been used in wind to cause blades to rotate around a central pivot point to generate electricity. Horizontal axis water turbines have been used underwater as a method for harvesting energy in flowing water, such as tidal flows or ocean currents.

[0007] Horizontal axis fluid turbines all have limitations and deficiencies. The relative rotational speed of the blades near the pivot point is considerably lower than the relative rotational speed of the blades near the outer tips. The speed of the blades near the tips can be so fast that the blades can be a serious hazard to birds or marine wildlife that come near the turbine. Further, the added torque created by gusts and/or very high fluid flows can cause structural failure.

[0008] If all the energy coming from fluid movement through a horizontal axis turbine was extracted as useful energy, the fluid speed behind the turbine would drop to zero. However, if the fluid was not moving behind the turbine, no new fluid would pass through the harvest plane and the turbine would stop. In order to keep fluid moving through the turbine harvest plane there has to be some fluid movement behind the turbine, which creates a limit on the efficiency of a horizontal axis fluid turbine.

- [0009] The power output available from a horizontal axis turbine can be calculated and is directly proportional to a power coefficient relating to how efficiently a turbine converts the kinetic energy in the fluid stream to mechanical energy and then to electricity.
- [0010] German physicist Albert Betz calculated that no wind turbine could convert more than 59.3% of the available kinetic energy into mechanical energy as the balance of the available kinetic energy is needed to keep the wind moving through the turbine. This became known as the "Betz Limit" which holds that the absolute maximum power coefficient for a horizontal axis turbine is 0.593. Current conventional technology horizontal axis wind turbines achieve power coefficients that are considerably lower than the Betz Limit.
- [0011] The Betz Limit is inherent to all currently used horizontal axis wind turbines because of the nature of their operation. Current technology wind turbines operate at a fixed location such that the foils are restricted to harvesting kinetic energy from the 'stream-tube' immediately in front of the foils.
- [0012] Other inherent factors which directly contribute to the power output of conventional horizontal axis fluid turbines include: the area of their harvest plane (more commonly referred to as the 'swept area'); the total area of the foil/s employed; the tip speed of the foils; the fluid speed; and, the aspect ratio of the foil. The length of currently employed wind turbine air foils are inherently limited due the extreme lever forces acting on the blade root mounting structure.
- [0013] Other forms of renewable energy generation include various forms of hydro generation, such as dams, tidal flows and small scale run-of-river. All have limitations and some have considerable environmental impacts. Large scale hydroelectric installations have significant environmental impacts due to the need to flood large areas of otherwise arable lands. Further, initial building costs of hydroelectric installations can run into the low billions of dollars per site, with an overall time span from initial site assessment and planning, through to first electricity production that can be more than a decade.
- [0014] The need for viable, reliable, low cost, clean energy sources is growing. There is a need for a new clean and sustainable energy source with low initial cost infrastructure, with low direct operating costs, with fast construction time frames, that is installable in a wide variety of locations, that has few operating limitations, and that creates few, if any, short or long-term hazards to people, wildlife or the planet as a whole.

Summary of Invention

- [0015] Apparatus is provided for converting kinetic energy from a flowing fluid into usable energy. A foil is coupled to a closed-loop cable such that translational movement of the

foil causes translational movement of the foil. The foil has an angle of attack that is adjustable between a first angle position and a second angle position such that flowing fluid acting on the foil when in the first angle position causes translational movement of the foil in a first translational direction. When the flowing fluid acts on the foil when in the second angle position the foil is then caused to move translationally in a second translational direction. The cable loops around first and second pulleys such that movement of the cable in the first translational direction causes rotational movement of the pulleys in a first rotational direction. Movement of the cable in the second translational direction causes rotational movement of the pulleys in a second rotational direction. A power-take-off is coupled to one of the pulleys for harvesting usable energy. Control means are incorporated for increasing the load at the power-take-offs to reduce movement of the foil upon the foil reaching an end of the translational operating range. Means are provided for adjusting the angle of attack of the foil between the first angle position and the second angle position.

[0016] Apparatus is provided for converting kinetic energy from flowing fluid into useable energy. A tether line is strung between first and second anchor points on opposing hillsides. First and second pulleys are anchored to the tether line. Third and fourth pulleys are anchored to a valley floor. A first closed-loop cable passes around the first, second, third and fourth pulleys. First and second foils are coupled to the first cable such that translational movement of the first and second foils causes translational movement of the first cable. First and second foils have an angle of attack adjustable between a first angle position and a second angle position, such that flowing fluid acting on the first and second foils when in the first angle position causes translational movement of the first and second foils in a first translational direction, and the flowing fluid acting on the first and second foils when in the second angle position causes translational movement of the first and second foils in a second translational direction. The first cable loops around each of the first, second, third and fourth pulleys such that movement of the first cable in the first translational direction causes rotational movement of the first, second, third and fourth pulleys in a first rotational direction. Movement of the first cable in the second translational direction causes rotational movement of the first, second, third and fourth pulleys in a second rotational direction. A power-take-off is coupled to the first or third pulley for harvesting useable energy. Control means is provided for increasing a load at the power-take-off to reduce movement of the first and second foils upon the first and second foils reaching an end of a first translating operating range. Means are provided for adjusting the angle of attack of the first and second foils between the first angle position and the second angle position.

[0017] Fifth and sixth pulleys are also anchored to the tether line. Seventh and eighth

pulleys are anchored to the valley floor. A second closed-loop cable passes around the fifth, sixth, seventh and eighth pulleys. Third and fourth foils are coupled to the second cable such that translational movement of the third and fourth foils cause translational movement of the second cable. The third and fourth foils have an angle of attack adjustable between a third angle position and a fourth angle position, such that flowing fluid acting on the third and fourth foils when in the third angle position causes translational movement of the third and fourth foils in a third translational direction, and flowing fluid acting on the third and fourth foils when in the fourth angle position causes translational movement of the fifth and sixth in a fourth translational direction. The second cable loops around each of the fifth, sixth, seventh and eighth pulleys such that movement of the second cable in the third translational direction causes rotational movement of the fifth, sixth, seventh and eighth pulleys in a third rotational direction, and movement of the cable in the fourth translational direction causes rotational movement of the fifth, sixth, seventh and eighth pulleys in a fourth rotational direction. A second power-take-off is coupled to the fifth or seventh pulley for harvesting useable energy. Second control means increase load at the second power-take-off to reduce movement of the third and fourth foils upon the third and fourth foils reaching an end of a second translating operating range. Means is also provided for adjusting the angle of attack of the third and fourth foils between the third angle position and the fourth angle position.

- [0018] A method for converting kinetic energy from a flowing fluid into usable energy involves adjusting an angle of attack of the foil with respect to fluid flow to cause the foil to laterally translate. Translating the foil laterally in a first lateral direction pulls a cable which in turn causes the first pulley to rotate in a first rotational direction. Applying a load to the first pulley harvests useable energy and helps brake the foil. Adjusting the angle of attack of the foil with respect to fluid flow causes the foil to laterally translate. Translating the foil laterally in a second lateral direction pulls the cable, the cable causing the first pulley to rotate in a second rotational direction as the foil laterally translates. Applying a second load to the pulley harvests useable energy and brakes the foil.

Brief Description of Drawings

- [0019] The attached Figures illustrate non-limiting embodiments of the invention.

Fig.1

- [0020] [fig.1] is a side view of a closed-loop four cable system embodiment of the invention.

Fig.2

- [0021] [fig.2] is a side view of another closed-loop four cable system embodiment of the invention.

Fig.3

[0022] [fig.3] is a top plan view of another closed-loop four cable system embodiment of the invention.

Fig.4

[0023] [fig.4] is a top plan view of a multi-system power generation embodiment of the invention.

Fig.5

[0024] [fig.5] is a top plan view of an anchored single-cable-loop embodiment of the invention.

Fig.6

[0025] [fig.6] is a top plan view of another anchored single-cable-loop embodiment of the invention.

Fig.7

[0026] [fig.7] is a top plan view of another anchored single-cable-loop embodiment of the invention.

Fig.8

[0027] [fig.8] is a side view of the embodiment of Figure 5.

Fig.9

[0028] [fig.9] is a top plan view of a shuttle-anchored single-cable-loop embodiment of the invention.

Fig.10

[0029] [fig.10] is a top plan view of another shuttle-anchored single-cable-loop embodiment of the invention.

Fig.11

[0030] [fig.11] is a side view of a self-orienting foil single-cable-loop embodiment of the invention.

Fig.12

[0031] [fig.12] is a perspective view of another self-orienting foil single-cable-loop embodiment of the invention.

Fig.13

[0032] [fig.13] is a top plan view of another self-orienting foil single-cable-loop embodiment of the invention.

Fig.14

[0033] [fig.14] is a top plan view of a self-orienting foil.

Fig.15

[0034] [fig.15] is a perspective view of another self-orienting foil single-cable-loop embodiment of the invention.

Fig.16

[0035] [fig.16] is a side view of an "air dam" multi-system embodiment of the invention.

Fig.17

[0036] [fig.17] is a side view of another "air dam" multi-system embodiment of the invention.

Description of Embodiments

[0037] Throughout the following description, specific details are set forth in order to provide a more thorough understanding of the invention. However, the invention may be practiced without these particulars. In other instances, well known elements have not been shown or described in detail to avoid unnecessarily obscuring the invention. Accordingly, the specification and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

[0038] Fluids, namely air/wind and freshwater and saltwater, are in constant movement around the planet. A translating foil apparatus designed to harness the power in fluid motion (including wind, river flows, tidal flows, and ocean currents), can avoid the limitations of horizontal fluid turbines. The limitations on the amount of power that can be extracted from fluid movement is not constrained by Betz Law in situations where a foil, such as a blade, wing or sail, moves quickly into clean fresh new air. Further, limitations on the maximum surface area for a fluid harvesting system may be significantly reduced or eliminated with a translating foil apparatus.

[0039] With reference to the figures, various embodiments of translating foil systems for harvesting kinetic energy from fluid motion and converting the energy into usable forms of energy is shown and described.

[0040] Figure 1 shows a four cable translating foil system **10** having two foils **12** and **14**. Foils **12** and **14** could be of any suitable material chosen for durability and suitability in a given installation. Suitable foil materials may include: carbon fibre; Kevlar® (a para-aramid synthetic fiber); stainless steel; canvass; polymer; aluminum; and mild and/or high strength steel. Foils **12** and **14** could be manufactured at centralized facilities in sections or pieces and transported, assembled and replaced in pieces. System construction and reassembly is often possible without the need for extreme cranes onsite or other highly specialized equipment. The use of steel cables and/or steel framing rods and steel hooks can facilitate the 'sewing' or piecing together of flexible material into extra large foils. In system **10**, each foil **12** and **14** is firmly attached to each of closed-loop cables **16**, **18**, **20** and **22** at each corner respectively.

[0041] In system **10**, the upper cables **16** and **18** rotate around two pulleys whereas the lower cables **20** and **22** rotate around four pulleys. Cable **16** rotates around pulleys **24** and **26**. Cable **22** rotates around pulleys **28**, **30**, **32**, and **34**. At least one of the pulleys is connected to a power take-off to remove power from the system **10**.

- [0042] System **10** is shown in Figure 1 as a water-based system with foils **12** and **14** below the waterline **36** and above the water bed **38**, which is suitable to operate in a river or tidal flow, as the case may be. A similarly designed system could be used to harness wind power if the waterline was removed from the figure. Natural terrain features can be utilized to provide elevation points for mounting a foil suspension system. For both river and wind installations, system suspension apparatus can be mounted on valley sidewalls.
- [0043] In the case where system **10** is located in a flowing river, the river flow will be into or out of the plane of the paper of Figure 1. System **10** can also function in a bidirectional flow into or out of the plane of the paper. Foils **12** and **14** will translate/shuttle sideways dragging/pushing cables **16**, **18**, **20**, and **22**, thereby causing the pulleys to rotate, thereby generating mechanical energy at the power-take-off pulley. The total side-to-side distance traveled by foils **12** and **14** is the translational operating distance **40**. As the foils **12** and **14** near the end of the translational operating distance **40**, the power-take-off can increase the load to slow the translational velocity until the foils **12** and **14** come to a stop. A set of two cables, such as cables **16** and **20** can then be moved relative to the other set of two cables **18** and **22**, such that the angle of attack of foils **12** and **14** relative to the stream-flow is changed. This causes the foils **12** and **14** to commence a translation in the opposite direction.
- [0044] The amount of power taken off and the angle of attack of the foils **12** and **14** can be monitored and adjusted by computer throughout the entire translational operating distance **40** to ensure optimum system output and performance at all times relative to fluid flow velocity.
- [0045] The relevant conditions can be monitored to constantly adjust system operating parameters to adapt to changing conditions. For example, in a river or tidal installation, the river or ocean level may rise or fall and that may affect the depth of the water and the optimum translational operating distance **40**. Hazards such as floating or submerged debris may also affect the navigability of the system operation from time to time. On-site hazard avoidance systems, such as radar, can be incorporated into the 'full authority' system control logic to allow real-time adjustment to the translational operating distance **40** or the course of the foils **12** and **14** to avoid approaching hazards, optimize performance, and avoid surface vessel traffic by locating conflicting debris or surface traffic and momentarily securing the foil array in a safe, non-conflicting portion of the translational operating distance **40**.
- [0046] System **10** is shown with support towers **44** on shore **42** that supports pulleys **24**, **26**, **28**, **30**, **32** and **34**. Most of the serviceable parts of the system are above the waterline and require little maintenance. With water installations, one or both support towers **44** could be located on anchored barges or using another manner of mounting pulleys

above the waterline.

- [0047] The translational operating distance **40** can be as large as the geography of the location permits and/or cable strength allows. For example for harvesting ocean currents the translational operating distance **40** may be kilometers long whereas for harvesting river flow the translational operating distance **40** may be 50 meters long, or less, as the location permits.
- [0048] System **10** is shown with two foils **12** and **14**, however system **10** can be viable with as few as one foil, and may be viable with over one hundred foils. The number of foils used can be chosen to suit the installation swept area available and/or to optimize system performance in a given location. As the number of foils increases, the total foil surface area increases and the power generated in each power stroke increases. However the lateral distance taken up by the addition of more foils reduces the translational operating distance **40**.
- [0049] Figure 2 shows a four cable translating foil system **50** similar to system **10** except that each of cables **16**, **18**, **20** and **22** has a second set of foils (not shown) instead of having a closed-loop cable return that is unburdened.
- [0050] Figure 3 shows a four cable translating foil system **60** having two sets of foils. The first set of foils **62A**, **62B**, **62C**, **62D**, **62E**, and **62F**, collectively foil set **62**, is comprised of six foils but is otherwise analogous to the set of two foils **12** and **14** in system **50**. The second set of foils **64A**, **64B**, **64C**, **64D**, **64E**, and **64F**, collectively foil set **64**, is comprised of six foils which is attached to the same four cables as foil set **62**. As Figure 13 is a top plan view only cables **66** and **68** are shown, each of which is attached to a top corner of each foil in foil sets **62** and **64**.
- [0051] Closed-loop cable **66** passes around pulleys **70**, **72**, **74** and **76**. Closed-loop cable **68** passes around pulleys **78**, **80**, **82** and **84**.
- [0052] Foil set **62** shuttles back and forth along a translational path in the directions indicated by arrow **86**. Foil set **64** shuttles back and forth along a translational path as indicated by arrow **88**. As foil set **62** and **64** are attached to the same cables, each set of foils move in coordinated fashion, yet in opposite directions, across the fluid stream. The increased number of foils on the same cable loop increases the power that can be generated in a single power stroke. Power is taken off the system at one or more of the pulley locations. Although not seen in this view, underneath cable **66** and **68** and its associated pulleys, there are an additional two cables and corresponding sets of pulleys to complete the four cable translating foil system **60**.
- [0053] Typical fluid flow for a system as shown in Figure 3 is unidirectional or bidirectional as shown by arrow **90**. The angle of attack of foils **62** and **64** can be adjusted according to fluid direction by way of system-specific dedicated computer processing. Computer-calculated adjustments can be made in real-time as described above with respect to

system **10**.

[0054] Figure 4 shows a top plan view of a multi-system power generation setup **100**. Eight translating foil power generation systems **102, 104, 106, 108, 110, 112, 114** and **116** are shown. Alternate embodiments could include many more translating foil power generation systems linked together. Each of these foil power generation systems could be system **10, 50, or 60** or any combination thereof or any other suitable translating foil generation system. Each system **102, 104, 106, 108, 110, 112, 114** and **116** has power taken from the system via connection **118** to power house **120** for processing, storage and/or transmission. The power-take-off process could be a number of known and proven processes, including compressed air, direct current (DC), pumped hydro, etc. The Power House **120** will convert the raw translating foil system energy to more useable energy, which could be dispatchable grid quality electricity, temporary compressed air mechanical energy, molten salt, heat or steam energy, etc.

[0055] In the case where setup **100** is used directly to generate grid quality dispatchable electricity, DC electricity may be generated at each system **102, 104, 106, 108, 110, 112, 114** and **116** and then fed into the power house **120** for conversion and stepping up to transmission line high voltage. At shorter transmission distances to the power house, distance of less than 50 km, much lower cost DC can be more cost effectively utilized to transmit and 'pool' the 'raw' or unconditioned energy produced by many linear motions systems. Since the cost of producing 'grid quality electricity' is a substantial cost of electricity production, the low cost DC or compressed air 'short distance energy transfer approach' will facilitate a number of linear motion variant systems to operate in unison as a 'single generation unit'. In this manner wind, tidal and ocean current linear motion systems could all pool their 'raw' harvested energy in a highly cost-effective manner, to one single, local, energy conditioning, dispatchable grid quality electricity production center. When this approach is coupled with many translating foil systems working together, a highly consistent power output can be realized.

[0056] For example, a single operating group may have one hundred or more translating foils attached, all systems will be controlled by centralized computer processing which will control individual system end of travel/harvest stop points. By doing so, it is possible to greatly diminish or even avoid completely, any noticeable drops in overall system output. When a number of translating foil systems are centrally controlled and operating at consistent speeds, as adjusted by way of real-time angle of attack adjustments across the operating translational distances, smooth power output can be created.

[0057] Single stand-alone translating foil systems can produce smooth dispatchable grid quality power, by way of integrating an intermediary 'short term' energy storage

process such as the use of capacitors, molten salts, or compressed air, etc.

- [0058] In alternate cases, setup **100** can be used to compress air or generate hydrogen via simple DC production at the power-take-off of each system. The produced hydrogen can then be stored and/or transported via pipeline, barge, rail or road truck. The production of ultra low-cost hydrogen as the energy product of remote location translating foil farms, will make remote location translating foil farms highly viable (as hydrogen is a relatively easily transportable fuel and more and more uses for hydrogen are being found today).
- [0059] Figure 4 shows a shoreline or mountainside **122**, and an optional shoreline or mountainside **124**. Shoreline or mountainside **124** is optional because there is no requirement that there be shore or dryland as one or both sides of a system could be mounted on a barge on water or on another suitable structure. A typical fluid flow for setup **100** is in one or both directions as shown by arrow **126**, although the systems can accommodate considerable variations in the direction of fluid flow.
- [0060] Figure 5 shows an anchored single-cable-loop translating foil system **130** having a tether line **132** that is anchored at an anchor point **134**. Tether line **132** connects to foil ferry **136** at connection point **138**. Foil ferry **136** has foils **140** and **142** in the fluid stream. System **130** is suitable for a river flow installation where fluid flow is generally in a unidirectional direction as indicated by arrow **144**. As the angle of attack is adjusted for foils **144** and **142**, foil ferry **136** can shuttle back and forth along a translational operating distance while tether line **132** rotates in the directions **146** about anchor point **134**. As the foil ferry **136** moves side-to-side, it drags and/or pulls dragline **148** which in turn turns pulleys **150** and **152**. At least one of the pulleys **150** and **152** is connected to a power-take-off to remove usable power from the system.
- [0061] Tether line **132** may be equipped with various flotation devices **154** and/or lights to mark its presence for marine navigation.
- [0062] To complete the picture of system **130**, this is typically designed as a river flow situation between shorelines **156** and **158**. Foil ferry **136** may be equipped with flotation devices to ensure that it remains on the surface. Pulleys **150** and **152** may be elevated to permit marine traffic navigation under dragline **148**.
- [0063] Figure 6 shows a top plan view of a single-cable-loop system **160** which is similar to system **130** except that a portion of the waterway has been marked off by buoys **162** to clearly indicate to marine traffic or other users of the waterway that the foil ferry **136** and the anchor line **132** will not pass into that area. Foil ferry **136** will shuttle back and forth along its operating translational distance **164**.
- [0064] Although anchor point **134** is shown located on water in systems **130** and **160**, in some cases it may be suitable to place anchor point **134** on land, particularly in locations with a curved shoreline, such as where a river has a significant bend.

- [0065] Figure 7 shows a top plan view of a single-cable-loop system **161** suitable for bidirectional water flow. System **161** is similar to system **134** except that it has a second tether line **133** that is anchored at anchor point **135**. Second tether line **133** is on the opposite side of foil ferry **136** than tether line **132** and is slack when tether line **132** is taut. When the water flow reverses, tether line **132** will become slack and second tether line **133** will become taut. Foil ferry **136** can operate whether water is flowing generally in direction **144** or generally in direction **145**.
- [0066] Figure 8 shows a side plan view of system **130** which was shown in a top plan view in Figure 5. Figure 8 shows that pulleys **150** and **152** can be elevated by support structures **44** to raise dragline **148** above the water. Dragline **148** has enough slack to allow for higher or lower water levels due to rising or falling rivers or ocean tides. As discussed previously, translational operating distance **164** can be adjusted by onboard computer means for controlling the angle of attack of foils **140** and **142**. Further, radar or other location detection means can be used to automatically assess potential hazards and adjust the course of the foil ferry **136** to optimize performance and avoid danger.
- [0067] Figure 9 shows a single closed-loop cable system **170** where the foil ferry **136** is anchored against fluid flow by connection **172** to shuttle **174** which freely rides side-to-side along tether line **176**. Tether line **176** is an elevated tether system retention line connected to two elevated tower anchors **178** and **180**. Dragline **148** is connected to shuttle **174** at point **182**. By elevating dragline **148** and tether line **176**, the waterway can remain navigable to other marine traffic as foil ferry **136** makes its way back and forth.
- [0068] System **170** can operate in a bidirectional fluid flow **184**.
- [0069] Figure 10 shows a top plan view of a single closed-loop cable system **119** having two foil ferries **136** and **136B** which shuttle back and forth along separate shuttles **174** and **174B**, which in turn travel along anchor lines **176** and **176B** respectively. Both shuttles **174** and **174B** are connected to dragline **192**, which in turn follows a path around pulleys **194**, **196**, **198** and **200**.
- [0070] Figure 11 shows a single closed-loop cable system **210** having a series of self-orienting foils **212A**, **212B**, **212C**, and **212D**, hereinafter collectively foil set **212**. Foil set **212** is affixed to one or more support cables **214**, which in turn pass around pulleys **216**, **218** and **220**. Although it may appear to be a single cable **214** in Figure 11, a second or third cable can be included along the same path to provide redundancy to avoid the full system crashing in the event that a single cable ever breaks. The pulleys are attached to the ground at points **212**, **224** and **226** respectively. In the system **210**, pulley **220** is a mechanical power-take-off so that the mechanical energy converted by the foils from the kinetic energy fluid stream can be accessed at the most easily accessible, lowest cost location, for example at the valley floor **228**. In system **210** it is

anticipated that sides **230** and **232** can be any kind of natural terrain elevation feature such as mountaintops, mountainsides, hillsides, valley sides, etc.

[0071] In operation, foil set **212** shuttles back and forth along the translational operating distance **234**.

[0072] Figure 12 shows a perspective view of a simplified single-cable-loop, bidirectional, self-weathercocking foil system **240**. Self-orienting foil **242** is comprised of a top portion **244** and a bottom portion **246** connected by a central rod **248**. Foil **242** is affixed to cable **250** via rod **248** at point **252**. The central rod **248** is offset from center to allow for weathercocking of the foil **242** into the wind at all times. Cable **250** passes around pulleys **254**, **256**, **258**, and **260**.

[0073] Foil **242** is self-orienting such that leading edge **262** faces toward the direction **264** of the oncoming flow of fluid and trailing edge **266** faces away from the fluid flow.

[0074] Embodiment **240** may be suitable for stringing between two mountain peaks, between two towers, or between two structures between which wind typically flows in the general direction of one of the arrowheads of arrow **264**. Foil **242** may be of any suitable shape and size as known in the art and/or as appropriate for the particular installation. The larger the size of the foil the greater the power output that may be attained. One or more of the pulleys **254**, **256**, **258** and **260** may incorporate a power-take-off such that power generated by movement of the cable is translated into usable energy, such as generating electricity, creating hydrogen from water electrolysis, compressing air, charging batteries, or the like.

[0075] Foil **242** has an onboard system for adjusting the angle of attack of the foil with respect to the wind. A small onboard horizontal wind turbine **268** is used by the controller in the equipment control battery box **270** to charge a battery back-up and to power a system for monitoring conditions and controlling the orientation of the foil. The orientation of the foil is adjusted by causing a leading edge device **272** to move towards or away from the wind, and similarly by causing trim tab **274** to move towards or away from the wind. Movement of the relatively small trim tab **274** will result in movement of the longer flap **276** which will effectively create a large camber on the side of the foil in which travel direction is desired. By coordinated controlled movement of leading edge device **272** and trim tab **274** the movement of the foil **242** will pull cable **250** back and forth in a shuttling motion **278**.

[0076] Embodiment **240** operates by positioning foil **242** with an angle of attack to the wind such that when it is close to pulley **254** foil **242** begins translating towards pulley **260** pulling cable **250** with it.

[0077] As foil **242** begins its acceleration, no power is taken off from the power-take-off. This facilitates a very rapid acceleration to the desired translational velocity at which to begin the energy harvest process. The unloaded acceleration time is determined by

the onboard computer through airspeed measuring devices. The airspeed information for foil **242** may come from aircraft type Pitot tubes and/or from anemometers or from a suitable alternative or a combination thereof. Once foil **242** has reached a predetermined minimum translational velocity, the power-take-off begins to take power from the rotation of one of pulleys **254**, **256**, **258** or **260**. The load applied at the power-take-off can be used to control the translational velocity of foil **242** as it translates between pulley **254** and **260**. As foil **242** nears the end of its available translational space, as it nears pulley **260**, it is slowed by increasing the load placed on the cable at the power-take-off. Like all other translating foil systems, if a power-take-off system happens to fail, and the translating foil(s) enters a runaway condition, foil **242** can be slowed and stopped by applying a conventional friction brake mounted on one or more of the system pulleys.

[0078] Once foil **242** has stopped its translational velocity, leading edge device **272** and trim tab **274** are returned to the neutral position which allows **242** to weathercock into the wind. From the neutral position, the leading edge device **272** and trim tab **274**, are then repositioned via servo power, to form a camber on the opposite side of the foil. This adjustment then causes a pressure differential on the opposite side of the foil, causing the created thrust to move the foil in the opposite translational direction. As foil **242** begins translating away from pulley **260**, initially no load is placed on it at the power-take-off. Once foil **242** reaches a predetermined minimum translational velocity, the harvest load begins to be applied at the power-take-off again.

[0079] In embodiment **240** power is taken off as foil **242** shuttles between opposing ends of its translational operating range, moving from proximate to pulley **254** to proximate to pulley **260**. Alternate embodiments may include more than one foil **240** attached to cable **250**. An increase in the number of foils on the same cable between pulleys **254** and **260** will result in a shorter translational operating range, but will result in an increase in power during translational power harvesting.

[0080] Foil **242** will consist of rigid frames and be covered using any suitable material, preferably material that is lightweight, durable and has a demonstrated long service life under extreme operating conditions. Carbon fiber or Kevlar® are two examples of suitable material, along with aircraft grade alloys, etc. The aerodynamic properties of the foil and its material may be, in part, chosen to reduce the weight on the system.

[0081] Figure 13 shows a single-cable-loop double weathercocking foil embodiment **280** having two weathercocking foils **282** and **284** attached to cable **286**. Cable **286** passes around pulleys **288**, **290**, **292** and **294**. One of the pulleys, such as pulley **288** is combined with a power-take-off to apply load to the system and remove power. Foils **282** and **284** are attached to cable **286** somewhat off-center so that the wind immediately weathercocks the foils such that the leading edge **296** is positioned to face

the prevailing wind.

[0082] The relative angle of attack for each of foil **282** and **284**, with respect to the direction of the wind **306**, is adjusted and controlled using an onboard computer or programmable logic controller system to adjust the positioning of leading edge devices **296** and trim tabs **298** to positions which will yield the maximum or desired harvest potential. Trim tab adjustments cause movement of flap section **300**. Embodiment **280** shows a leading edge device **296** comprised of a relatively simple moveable flap which is an alternate functioning example as compared to the leading edge device **272** shown in embodiment **240**. The orientation of the leading edge device **296** is shown in a solid line to indicate a position for the leading edge device **296** that could cause foils **282** and **284** to translate in directions **302** and **304** respectively. Reorientation of leading edge device **296** to the position shown in a dotted line would result in an adjustment to the angle of attack of foils **282** and **284** such that the translational direction of the foils would be reversed.

[0083] Figure 14 shows an enlarged cross-sectional view of self-orienting (weathercocking) foil **282** which is affixed to cable **286** at a central rod **308**. Leading edge device **296** is shown in the first position **310** and is moveable into second position **312** to reverse the angle of attack. In practice, the positions in which the leading edge device **296** can be positioned for adjusting the angle of attack is a highly variable continuum, but these two positions are shown as examples of positions to adjust the angle of attack to reverse the direction of the foil **282**.

[0084] Figure 14 shows trim tab **298** in the instance that it has just been adjusted to the right to create a camber on one side of the foil before the wind-flow adjusts the positioning of tail tab **300** to move tail tab **300** to the left. As indicated by arrow **314**, the positioning of trim tab **298** can be adjusted by the onboard controller to move side-to-side in the directions shown in arrow **314**, which in turn will cause the larger tail flap **300** to adjust its position, affecting the angle of attack of the foil.

[0085] Figure 15 shows single-cable-loop embodiment **320** located on terrain ranging from a mountainside **322** to a valley **334**. Groups of self-orienting foils **326** and **328** are attached to different runs of closed-loop cable **330**. Cable **330** passes around pulley **332**, **334**, **336** and **338** to complete its loop. Foil groups **326** and **328** shuttle up and down the mountainside **322**, generating power taken at a power-take-off at pulley **336** or **338**.

[0086] Figure 16 shows a multi-system "air dam" power generating system **340** which would be suitable for locating between two mountains **342** and **344** or across a canyon or between two tall and strong towers. System **340** is constructed with a strong tether support line **346** anchored to natural elevation feature **342** at point **348** and anchored to natural elevation feature **344** at point **350**. Hanging down from tether support line **346**

are a series of single cable systems **352, 354, 356, 358, 360, 362, 364, 366, and 368** which each are comprised of groups of self-orienting foils **370** which shuttle up and down pulling respective cables, which in turn causes the four pulleys in each system to rotate, one of which is combined with a power-take-off to remove power from the system. The power-take-offs in system **340** are located on or near the valley floor **372**. The power removed from each system can then be fed via connections **374** to power house **376** for further processing, storage or transmission.

[0087] Grid power is not required to carry out 'black starts', i.e. starting a translating foil system from a prolonged standstill condition. All necessary starting energy can be provided by onboard or system associated supplies.

[0088] Figure 17 shows a multi-system "air dam" power generating system **380** with additional reinforcing structure added to support the system weight. Support line **382** is anchored to natural elevation features **342** and **344** and strung across the tether support line **346**. Suspension support cables **384** connect support line **382** to tether support line **346** to support and distribute weight, similar to known technology used in supporting suspension bridges.

[0089] Multiple air dam systems **340** and **380** can be installed in rapid succession in a local geographic area, for example it may be possible for air dam systems to be separated by a distance of as little as **500** meters resulting in a being able operate a number of high output air dam systems in a very close proximity to each other. Such system density brings with it significant economies such as reduced road building, single centralized maintenance facilities and any crew quarters as well as a single grid connection.

[0090] In alternate embodiments, a system similar to **340** or **380** could be employed under water, likely with the power-take-offs at or near the surface. In situations of underwater currents that occur a distance below the water surface the translational operating ranges may be adjusted to best harness the kinetic energy in the current.

[0091] In accordance with this invention, power is removed from the system in a shuttling, start and stop operation. Generally the longer the translational operating range, the longer the energy harvesting duration before the foil must stop and reverse direction. For most translating foil systems, the shuttle motion along the translating operating range can be arranged to operate horizontally, vertically, or diagonally in relation to the ground and seafloor. Run of river and tidal installations are usually best suited for horizontal operations.

[0092] Changing the direction of foils by reversing the necessary high and low pressure areas of the foils, can be achieved in several ways. In a multi-cable suspended system such as described in embodiments **10, 50** and **60**, the upper downstream cable lengths can be lengthened or shortened to change the collective foils' angle of attack by way of selectively rotating pulleys with respect to, one, two or more of the four cables.

Similarly, two of the cables can be effectively lengthened at one end and shortened at the other end to adjust the angle of attack of the foils by adding and removing additional pulleys or obstacles in the path of the cables. As the flow rate is monitored, the relative location of each of the cables can be adjusted to adjust the relative angle of attack. A reversed angle of attack for a foil, relative to the fluid flow, causes the foil to reverse direction.

- [0093] Computer controls supported by real-time fluid velocity measurements taken onboard each foil are used to adjust each foil's angle of attack to make each individual foil, within a standalone multi-foil system, harvest energy at its peak potential at any given moment. Computer controls can also be used to control the velocity of a desired shuttle such that it hits the end of travel point at an exact point in time. Calculations and micro adjustments can be made many times per second, taking into account each foil's translational velocity and local wind stream velocity.
- [0094] Operating foil systems in a co-generation fashion with existing long proven temporary energy storage means, facilitates the ability to operate translating foil systems at full harvest potential, all the time, for every hour of every day of every year.
- [0095] The translating foil approach to kinetic energy harvesting lends itself well to scaling, this is demonstrated by a range of applications of sailboats starting with a child's small toy sailboat, to the very largest commercial sailing vessels which today have almost 100 meter tall sails. Consequently, commercial applications are viable for translating foil installations as small 1 kW installations for remote mining or villages, all the way through to very large installations producing 10s of megawatts. The viability of scaling translating foil systems is directly attributable to the simplicity of components used and the lack of extreme stress to components, in contrast to other conventional wind or water energy conversion systems.
- [0096] Extremely large underwater foils, or sails, can be used at very low overall cost, to effectively harvest the immense kinetic energy contained in slow moving ocean currents. The use of extremely large hydrofoils, such as ones with surface areas each of 5000 m² or more, make it possible for hydrofoils to make contact with tens of thousands, or even hundreds of thousands, of cubic meters of slow moving ocean current. Such foil systems would operate at slow translational velocities, however the power output combined with extreme torque will allow a single foil system, using a number of large submarine hydro-sail foils to harvest into the hundreds of megawatts with each shuttle travel along the translational operating range.
- [0097] In waterborne foil systems in accordance with the invention the use of on-board computer systems located on large floating structures such as barges restrained to the ocean floor by way of cables similar to large oil drilling platforms, can facilitate the reliable and low cost harvest of available kinetic energy even hundreds of kilometers

offshore. The reliability of such systems is greatly increased given that in many cases no high maintenance systems need to be located underwater. As foils are cable suspended, harvesting from very deep ocean depths is possible without impeding surface vessel travel.

[0098] Foils can be used in run of river and tidal flow installations to operate in virtually all flow conditions, from very low up to high flow conditions. The continuous and reliable operation increases the viability and reduces the overall cost of implementing such systems.

[0099] The foils in accordance with this invention can be equipped with a foil stabilization augmentation system, whether a canard or empennage or similar stabilization controller, that can be adjusted in real-time by an onboard computerized control system. A stability augmentation system senses movement of the foil in up or down motions and makes slight adjustments to counteract any undesired oscillation of the foil. The foils described above in single-cable-loop systems have separate upper and lower leading and trailing edges which, when controlled separately, can be used as a stabilization augmentation system to avoid unnecessary bouncing of the foils. The four-cable-systems, particularly those with single foils, could make use of selectively adjusting each cable to adjust the angle of attack of the foil to counteract oscillation. In other cases stabilization means may be added to individual foils to provide longitudinal (pitch) and/or directional (yaw) stability and control.

[0100] As will be apparent to those skilled in the art in the light of the foregoing disclosure the present invention is not limited by what has been particularly shown and described herein. Rather the scope of the present invention includes both combinations and sub-combinations of the features described hereinabove as well as modifications and variations thereof which would occur to a person of skill in the art upon reading the foregoing description and which are not in the prior art. Furthermore, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof. Accordingly, the scope of the invention is to be construed in accordance with the substance defined by the following claims.

Claims

- [Claim 1] Apparatus for converting kinetic energy from a flowing fluid into useable energy comprising:
a first closed-loop cable;
a first foil coupled to said first cable such that translational movement of said first foil causes translational movement of said first cable;
said first foil having an angle of attack adjustable between a first angle position and a second angle position, such that flowing fluid acting on said first foil when in said first angle position causes translational movement of said first foil in a first translational direction, and said flowing fluid acting on said first foil when in said second angle position causes translational movement of said first foil in a second translational direction;
first and second pulleys, said first cable looping around each of said first and second pulleys such that movement of said first cable in said first translational direction causes rotational movement of said first and second pulleys in a first rotational direction, and movement of said first cable in said second translational direction causes rotational movement of said first and second pulleys in a second rotational direction;
a power-take-off coupled to said first pulley for harvesting useable energy;
control means for increasing a load at said power-take-off to reduce movement of said first foil upon said first foil reaching a first end of a translating operating range; and
means for adjusting said angle of attack of said first foil between said first angle position and said second angle position.
- [Claim 2] An apparatus as in claim 1, further comprising braking means at said first pulley for braking said first foil upon said first foil reaching said first end of said translating operating range.
- [Claim 3] An apparatus as in claim 2, wherein harvesting useable energy comprises generating electricity.
- [Claim 4] An apparatus as in claim 2, wherein harvesting useable energy comprises compressing air.
- [Claim 5] An apparatus as in claim 2, wherein harvesting useable energy comprises producing hydrogen by electrolysis of water.
- [Claim 6] An apparatus as in claim 2, wherein harvesting useable energy comprises charging a battery.

- [Claim 7] An apparatus as in claim 2, further comprising third and fourth pulleys, said first cable looping around each of said third and fourth pulleys such that movement of said first cable causes movement of said third and fourth pulleys.
- [Claim 8] An apparatus as in claim 7, further comprising a second foil coupled to said first cable such that translational movement of said second foil causes translational movement of said first cable.
- [Claim 9] An apparatus as in claim 8, further comprising second, third and fourth cables, said first, second third and fourth cables coupled to said first and second foils at corners of said first and second foils.
- [Claim 10] An apparatus as in claim 9, further comprising a generator; and, said harvesting useable energy comprising said generator generating grid power electricity.
- [Claim 11] An apparatus as in claim 8 said first foil further comprising a leading edge and a trailing edge whereby said means for adjusting said angle of attack comprises adjusting a relative positioning of said leading edge and said trailing edge with respect to said foil.
- [Claim 12] An apparatus as in claim 11, said harvesting useable energy comprising storing energy in a short term energy storage.
- [Claim 13] An apparatus as in claim 12, further comprising a generator, said generator generating grid power electricity from said energy stored in said short term energy storage.
- [Claim 14] Apparatus for converting kinetic energy from a flowing fluid into useable energy comprising;
a tether line strung between first and second anchor points on opposing natural terrain elevation features;
first and second pulleys anchored to said tether line;
third and fourth pulleys anchored to a valley floor;
a first closed-loop cable passing around said first, second, third and fourth pulleys;
first and second foils coupled to said first cable such that translational movement of said first and second foils causes translational movement of said first cable;
said first and second foils having a first loop angle of attack adjustable between a first angle position and a second angle position, such that flowing fluid acting on said first and second foils when in said first angle position causes translational movement of said first and second foils in a first translational direction, and said flowing fluid acting on

said first and second foils when in said second angle position causes translational movement of said first and second foils in a second translational direction;

said first cable looping around each of said first, second, third and fourth pulleys such that movement of said cable in said first translational direction causes rotational movement of said first, second, third and fourth pulleys in a first rotational direction, and movement of said cable in said second translational direction causes rotational movement of said first, second, third and fourth pulleys in a second rotational direction;

a first power-take-off coupled to said first or third pulley for harvesting useable energy;

first control means for increasing a first load at said first power-take-off to reduce movement of said first and second foils upon said first and second foils reaching a first end of a translating operating range;

means for adjusting said first loop angle of attack of said first and second foils between said first angle position and said second angle position;

fifth and sixth pulleys anchored to said tether line;

seventh and eighth pulleys anchored to said valley floor;

a second closed-loop cable passing around said fifth, sixth, seventh and eighth pulleys;

third and fourth foils coupled to said second cable such that translational movement of said third and fourth foils causes translational movement of said second cable;

said third and fourth foils having a second loop angle of attack adjustable between a third angle position and a fourth angle position, such that flowing fluid acting on said third and fourth foils when in said third angle position causes translational movement of said third and fourth foils in a third translational direction, and said flowing fluid acting on said third and fourth foils when in said fourth angle position causes translational movement of said third and fourth foils in a fourth translational direction;

said second cable looping around each of said fifth, sixth, seventh and eighth pulleys such that movement of said second cable in said third translational direction causes rotational movement of said fifth, sixth, seventh and eighth pulleys in a third rotational direction, and movement of said cable in said fourth translational direction causes rotational

movement of said fifth, sixth, seventh and eighth pulleys in a fourth rotational direction;

a second power-take-off coupled to said fifth or seventh pulley for harvesting useable energy;

second control means for increasing a second load at said second power-take-off to reduce movement of said third and fourth foils upon said third and fourth foils reaching a third end of a second translating operating range; and

means for adjusting said angle of attack of said third and fourth foils between said third angle position and said fourth angle position.

[Claim 15]

An apparatus as in claim 14, said harvesting useable energy comprising storing energy in a short term energy storage.

[Claim 16]

An apparatus as in claim 15, further comprising a generator, said generator generating grid power electricity from said energy stored in said short term energy storage.

[Claim 17]

A method for converting kinetic energy from a flowing fluid into useable energy comprising:

adjusting an angle of attack of a first foil with respect to fluid flow to cause said first foil to laterally translate in a first translational direction; translating said first foil laterally in said first translational direction, said first foil pulling a cable, said cable causing a first pulley to rotate in a first rotational direction as said first foil laterally translates; applying a first load to said first pulley to harvest useable energy and to brake said first foil;

adjusting said angle of attack of said first foil with respect to fluid flow to cause said first foil to laterally translate in a second translational direction;

translating said first foil laterally in said second translational direction, said first foil pulling said cable, said cable causing said first pulley to rotate in a second rotational direction as said first foil laterally translates; and

applying a second load to said first pulley to harvest useable energy and to brake said first foil.

[Claim 18]

The method of claim 17 wherein adjusting an angle of attack of a first foil with respect to fluid flow to cause said first foil to laterally translate comprises repositioning a leading edge of said first foil.

[Claim 19]

The method of claim 18 wherein adjusting an angle of attack of a first foil with respect to fluid flow to cause said first foil to laterally translate

[Claim 20]

further comprises repositioning a trailing edge of said first foil.

The method of claim 19 wherein applying a first load comprises one or more of generating electricity, producing hydrogen, pumping water, generating heat, charging a battery, moving objects, and compressing air.

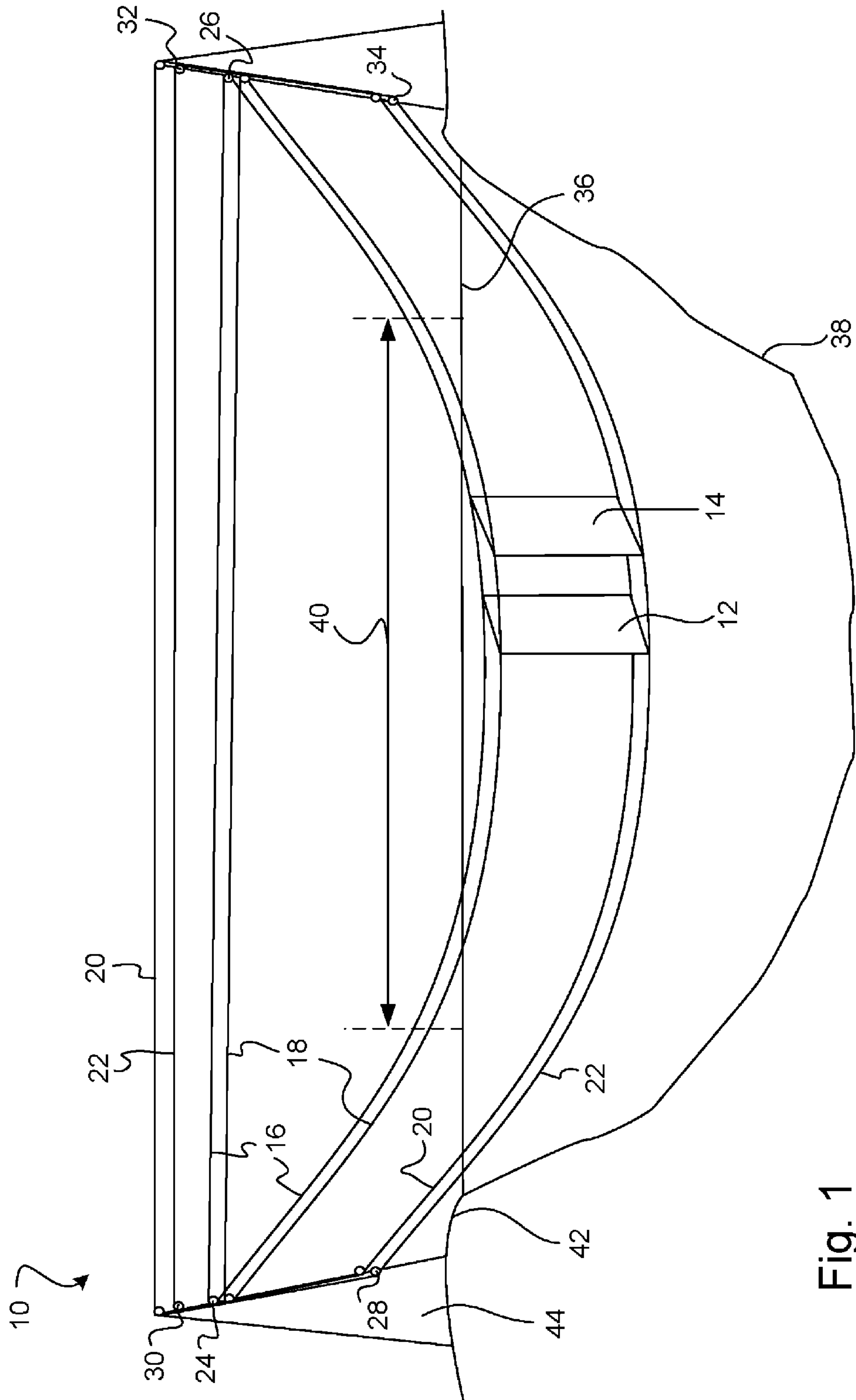


Fig. 1

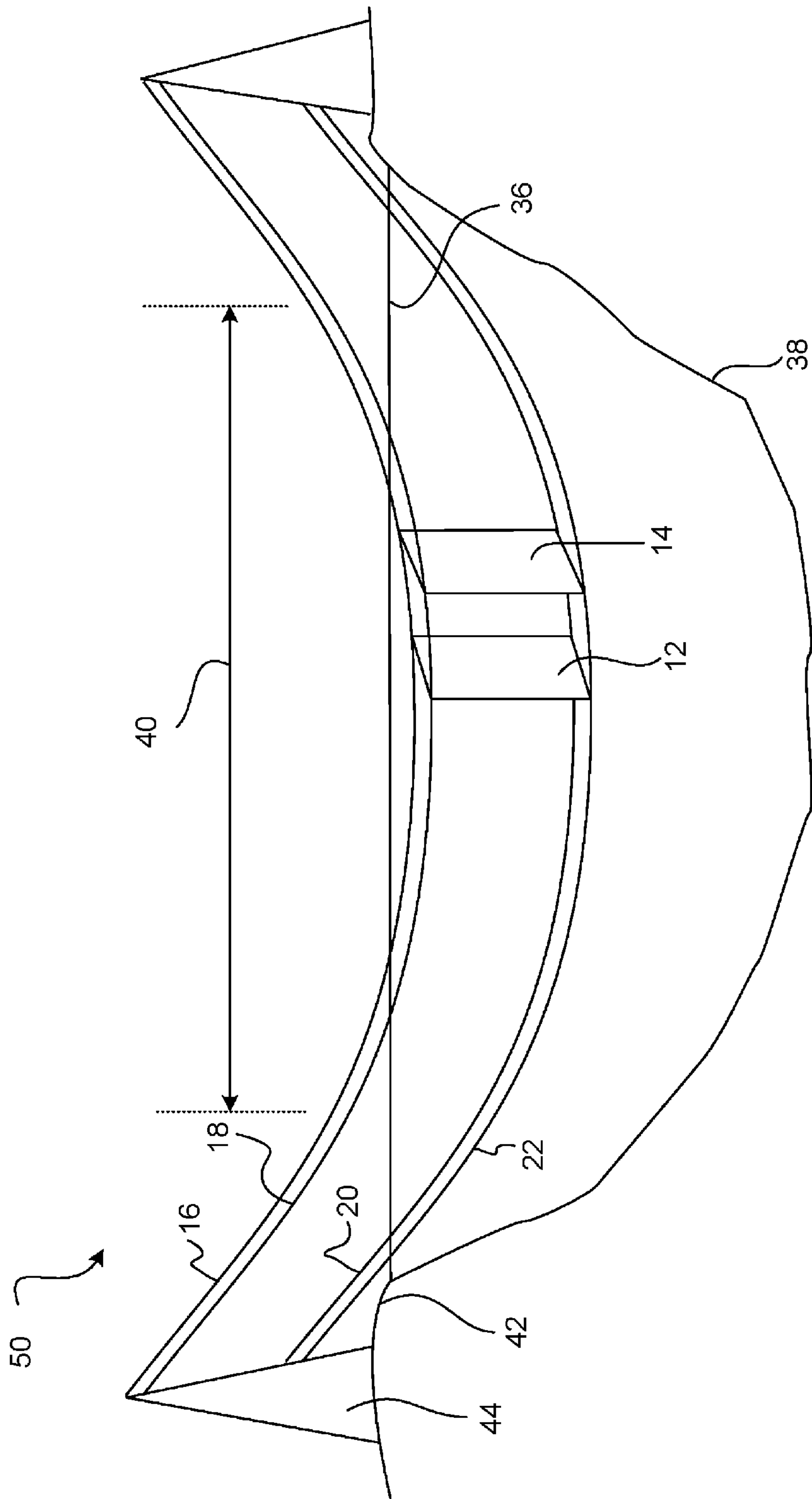


Fig. 2

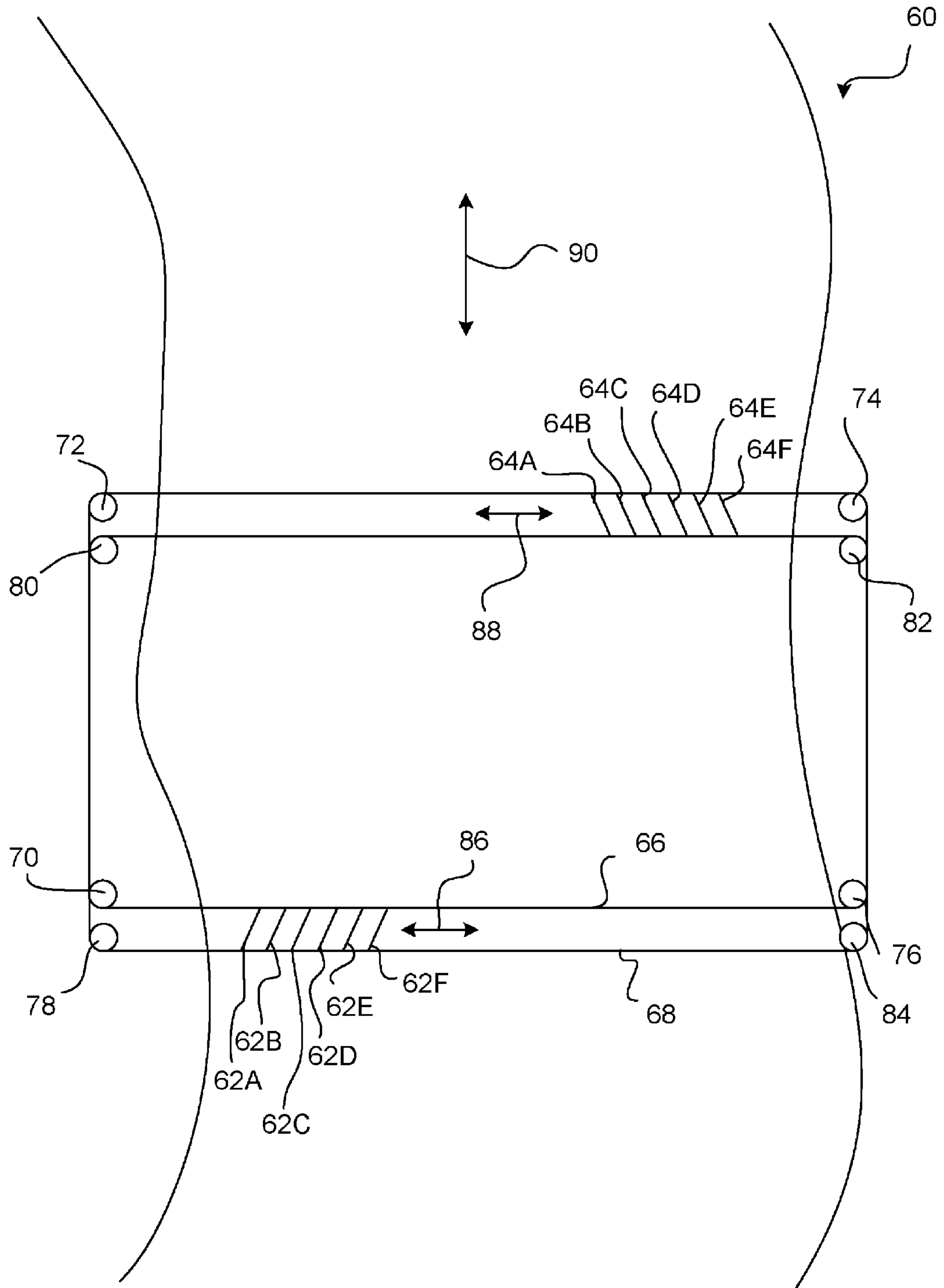


Fig. 3

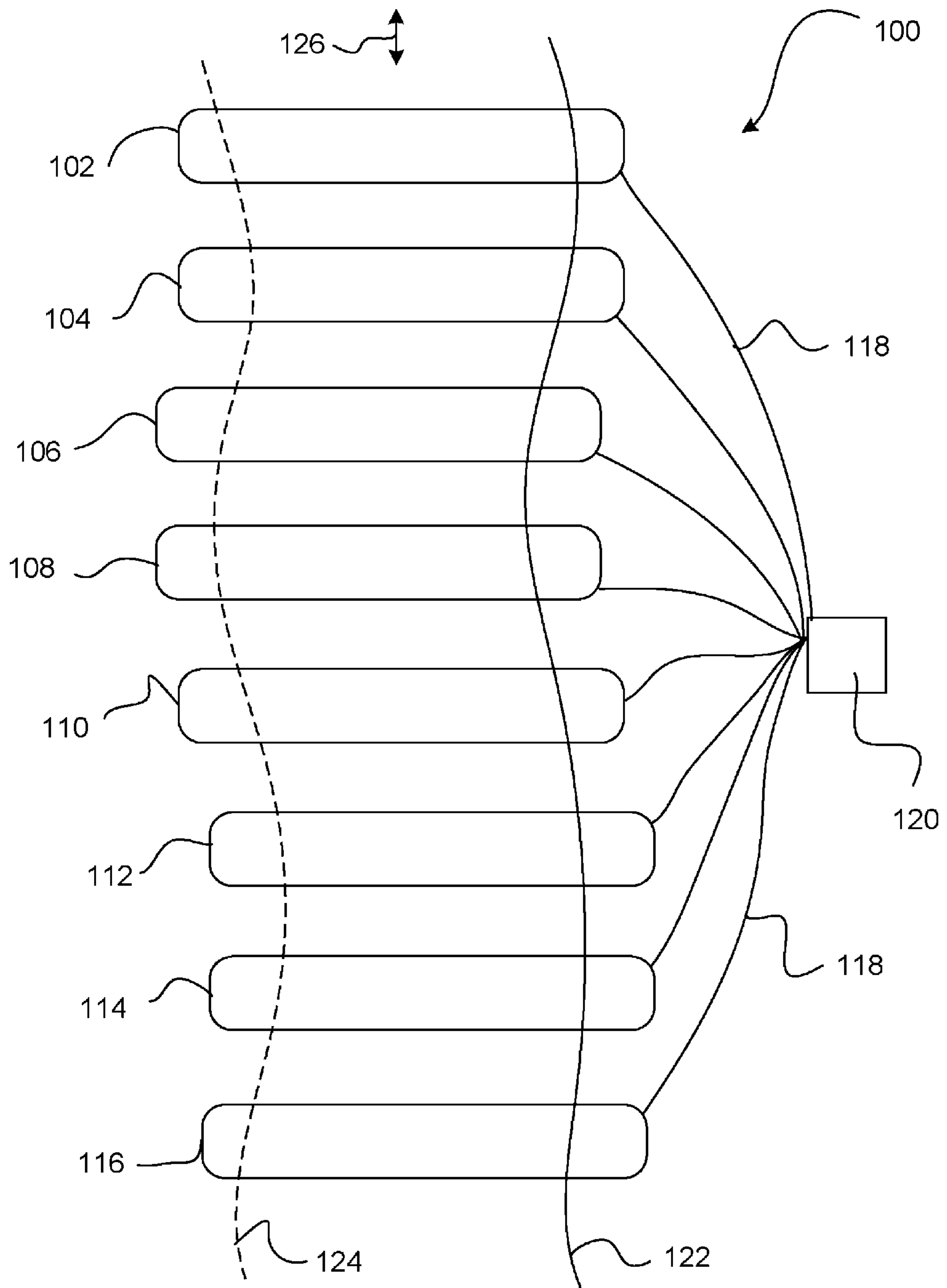


Fig. 4

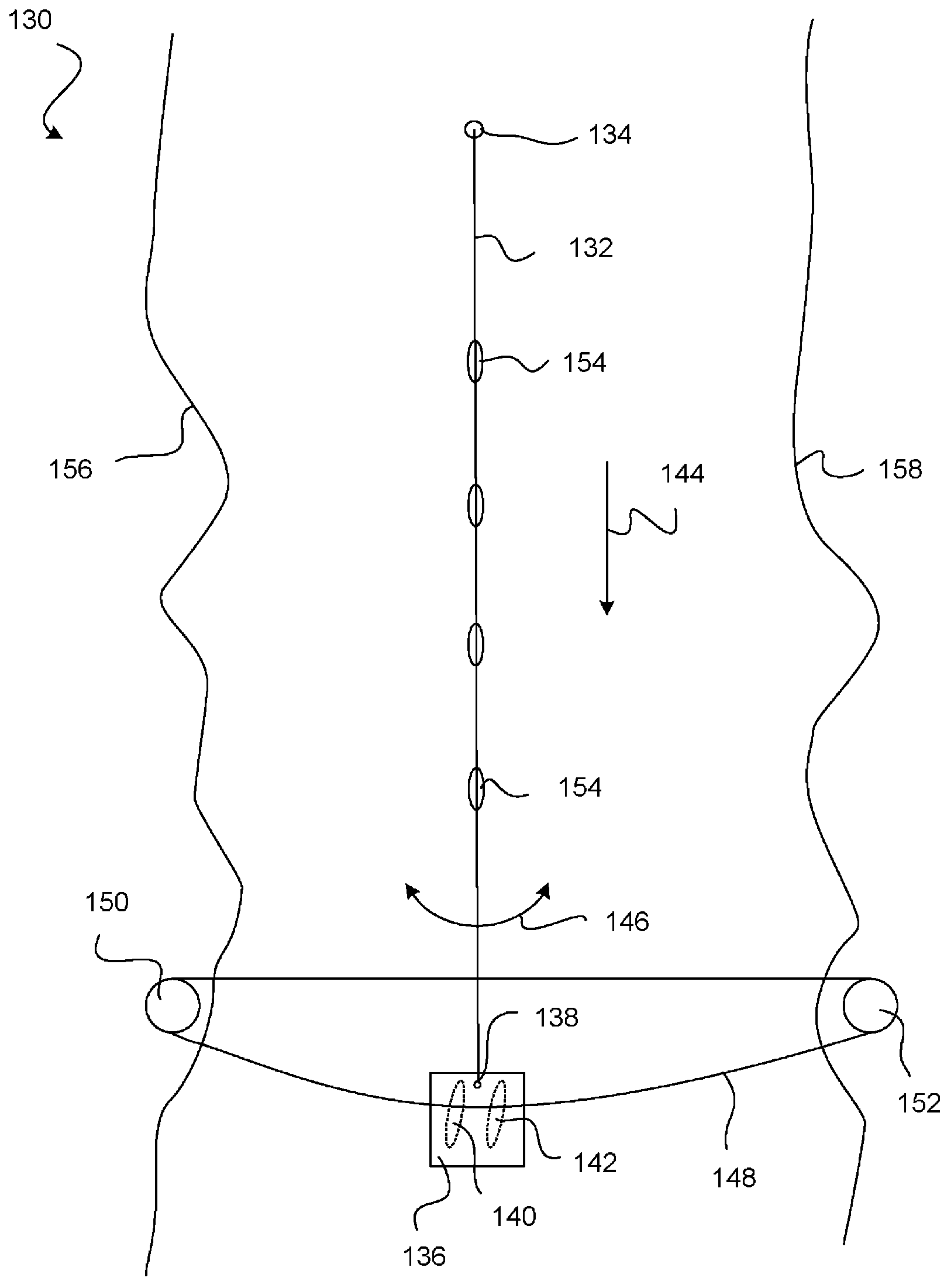


Fig. 5

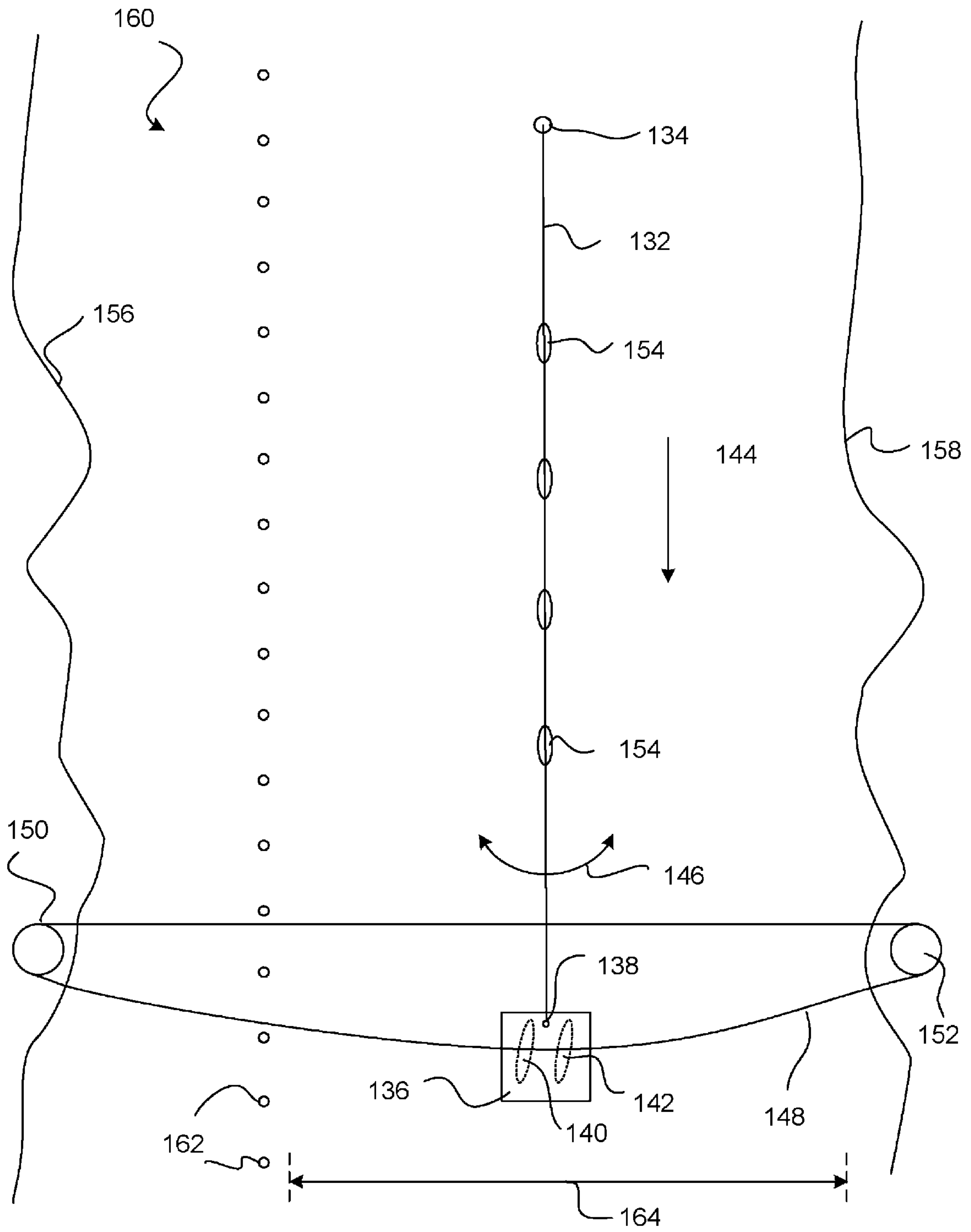


Fig. 6

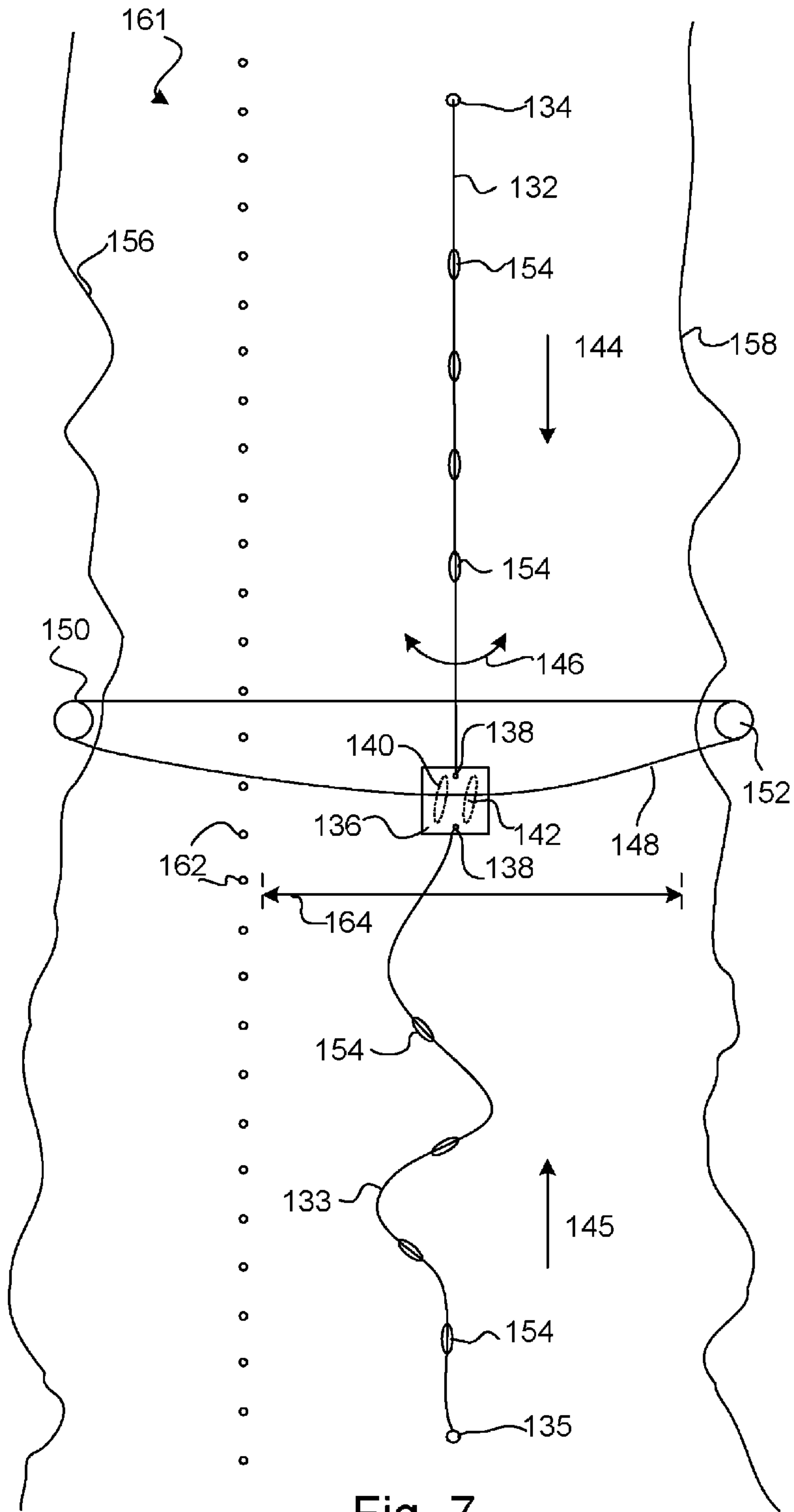


Fig. 7

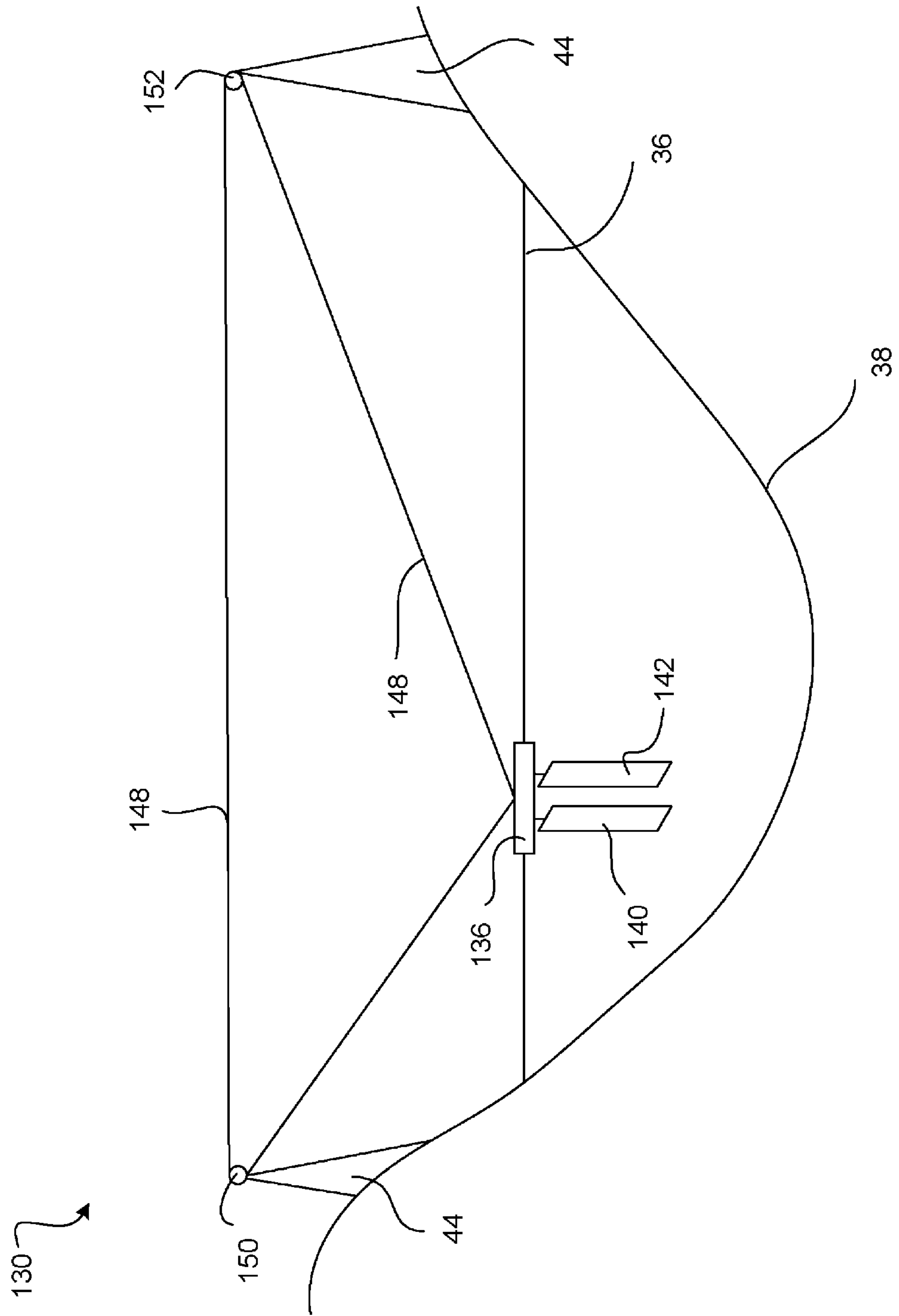


Fig. 8

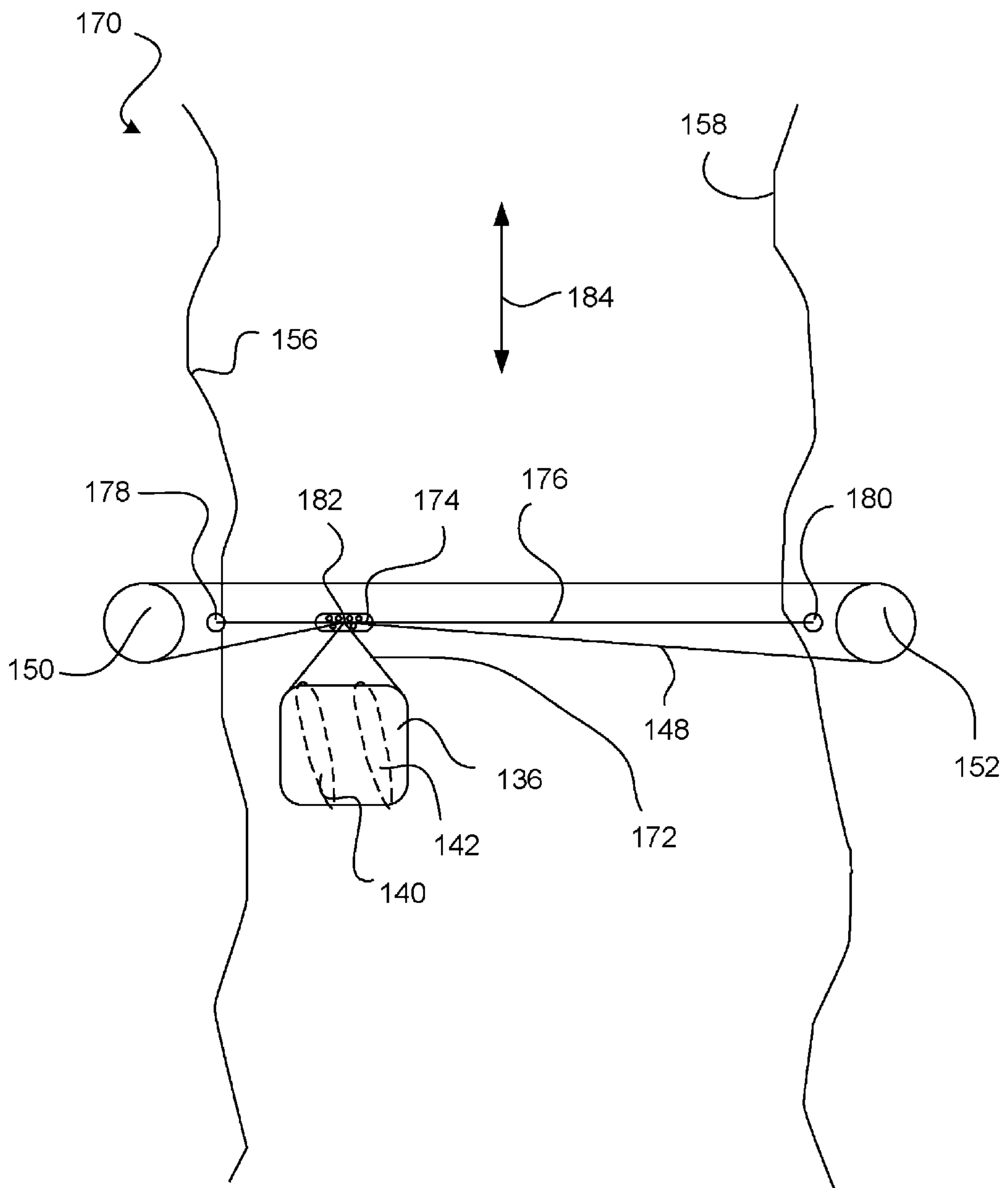


Fig. 9

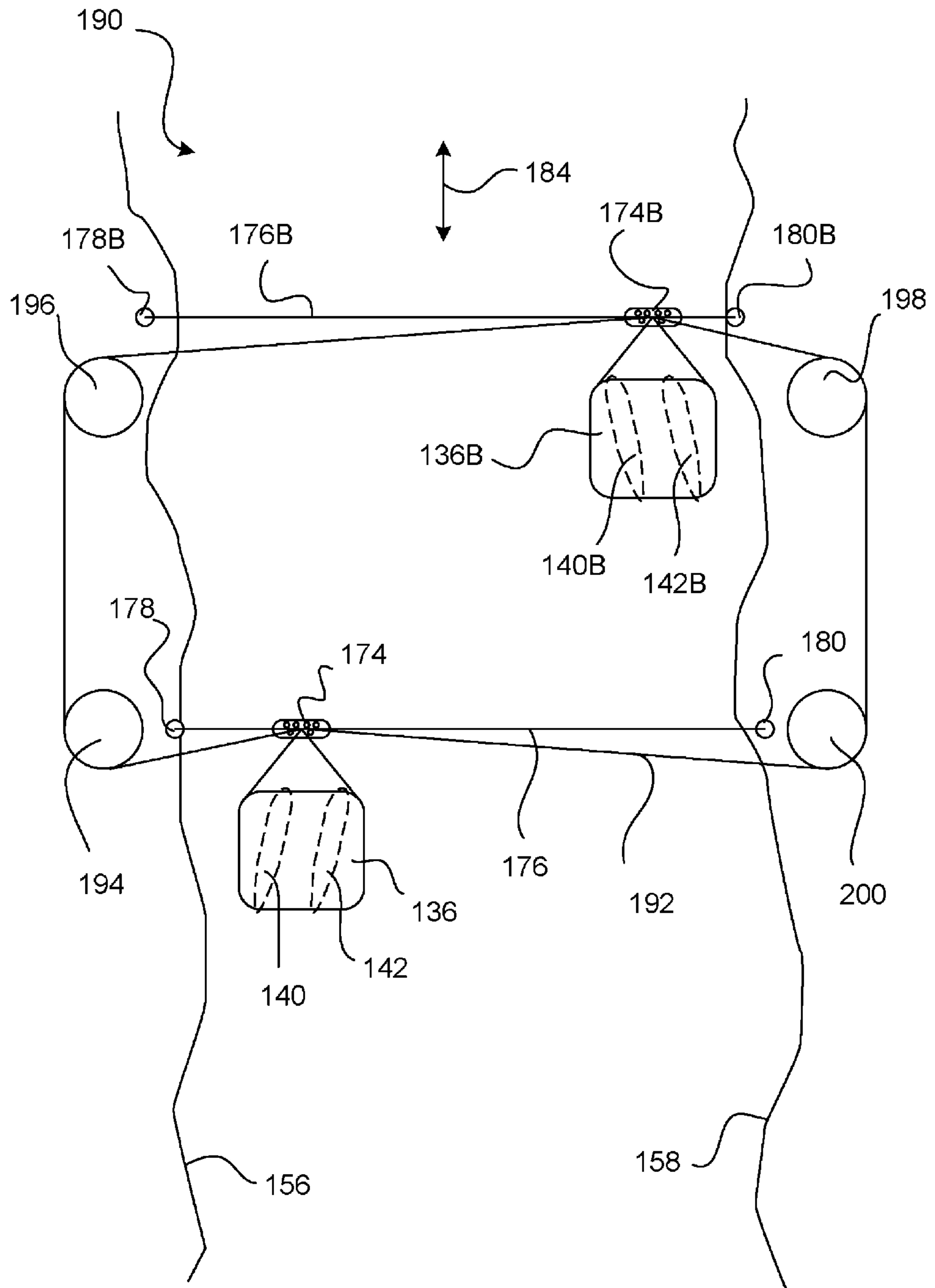


Fig. 10

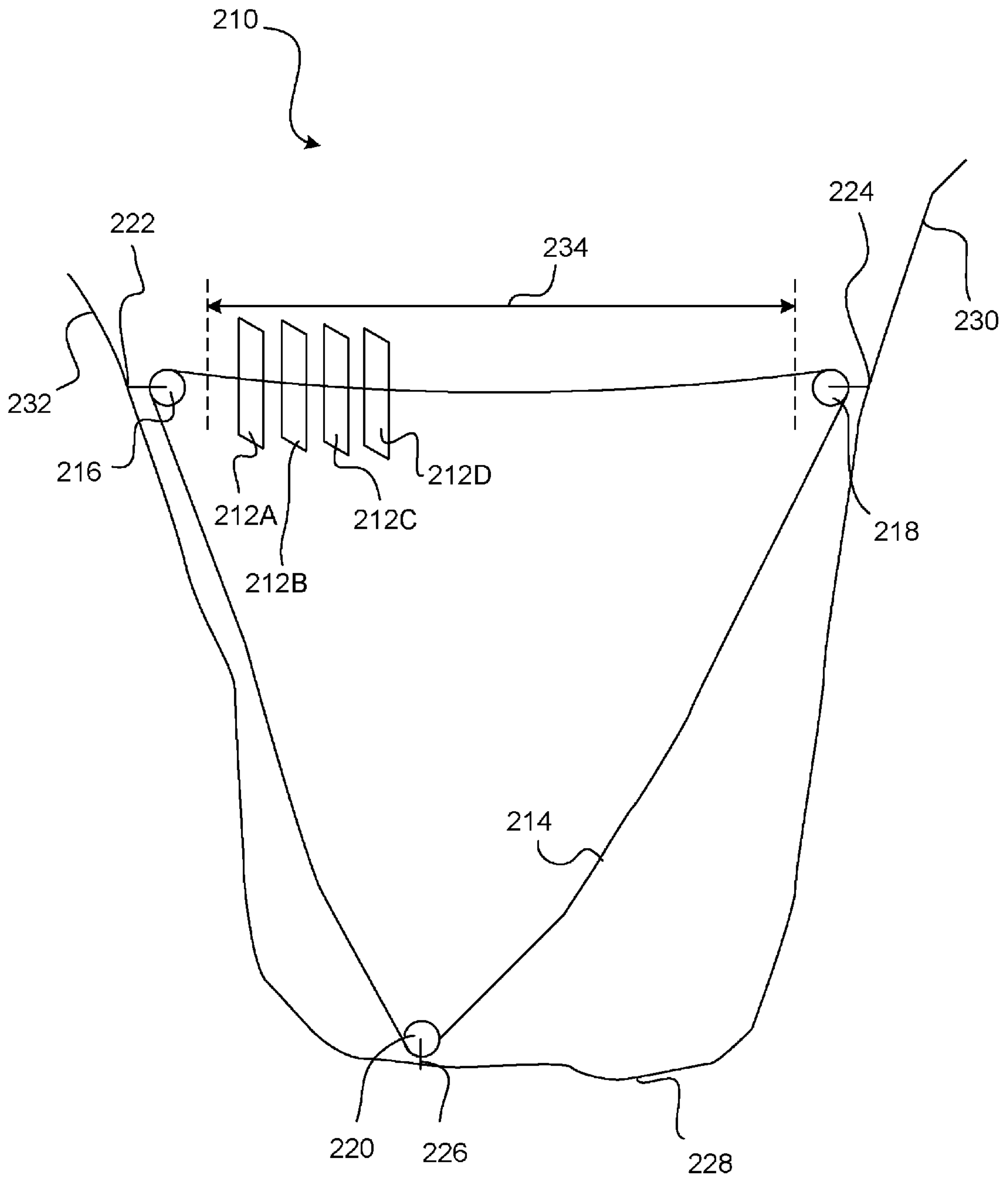
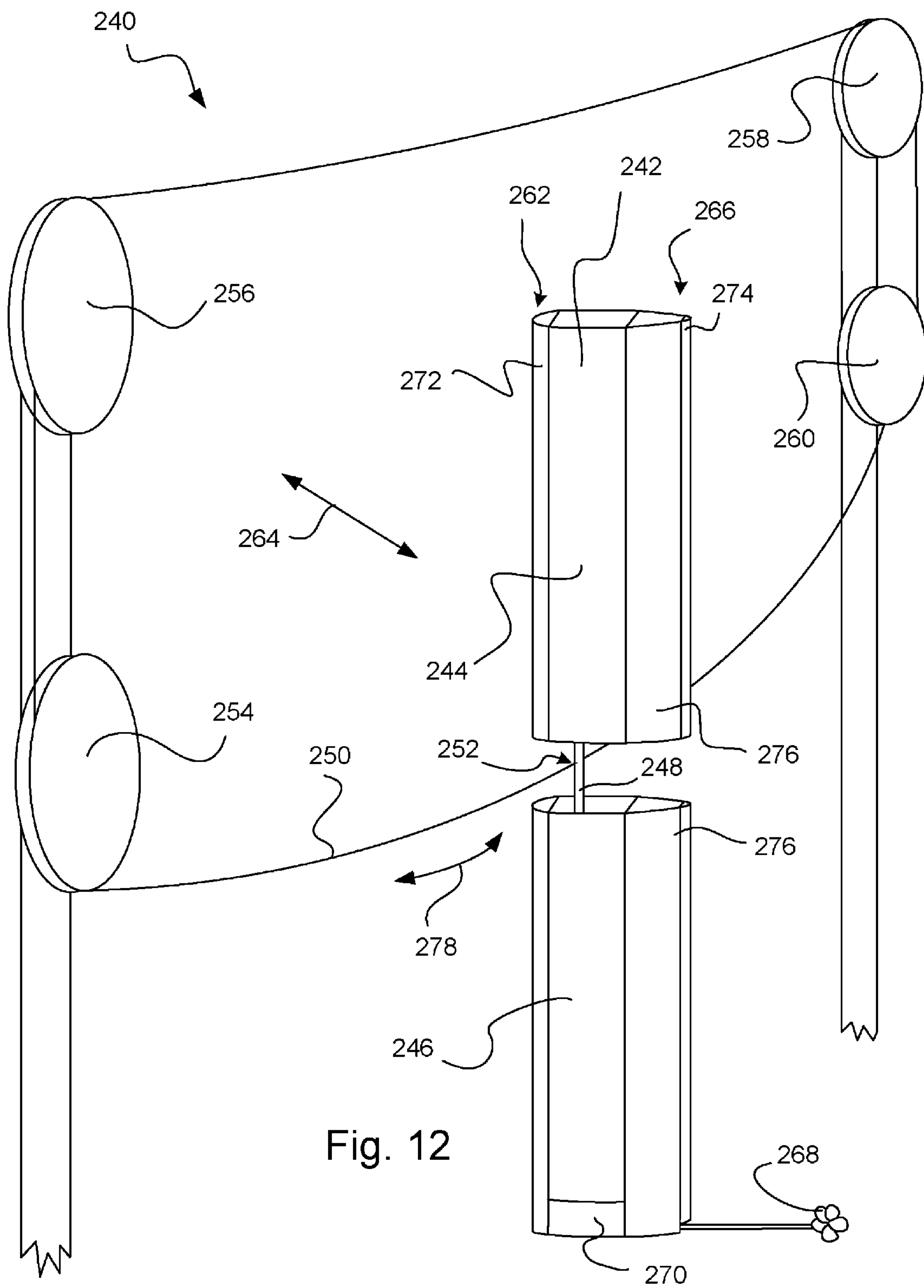


Fig. 11



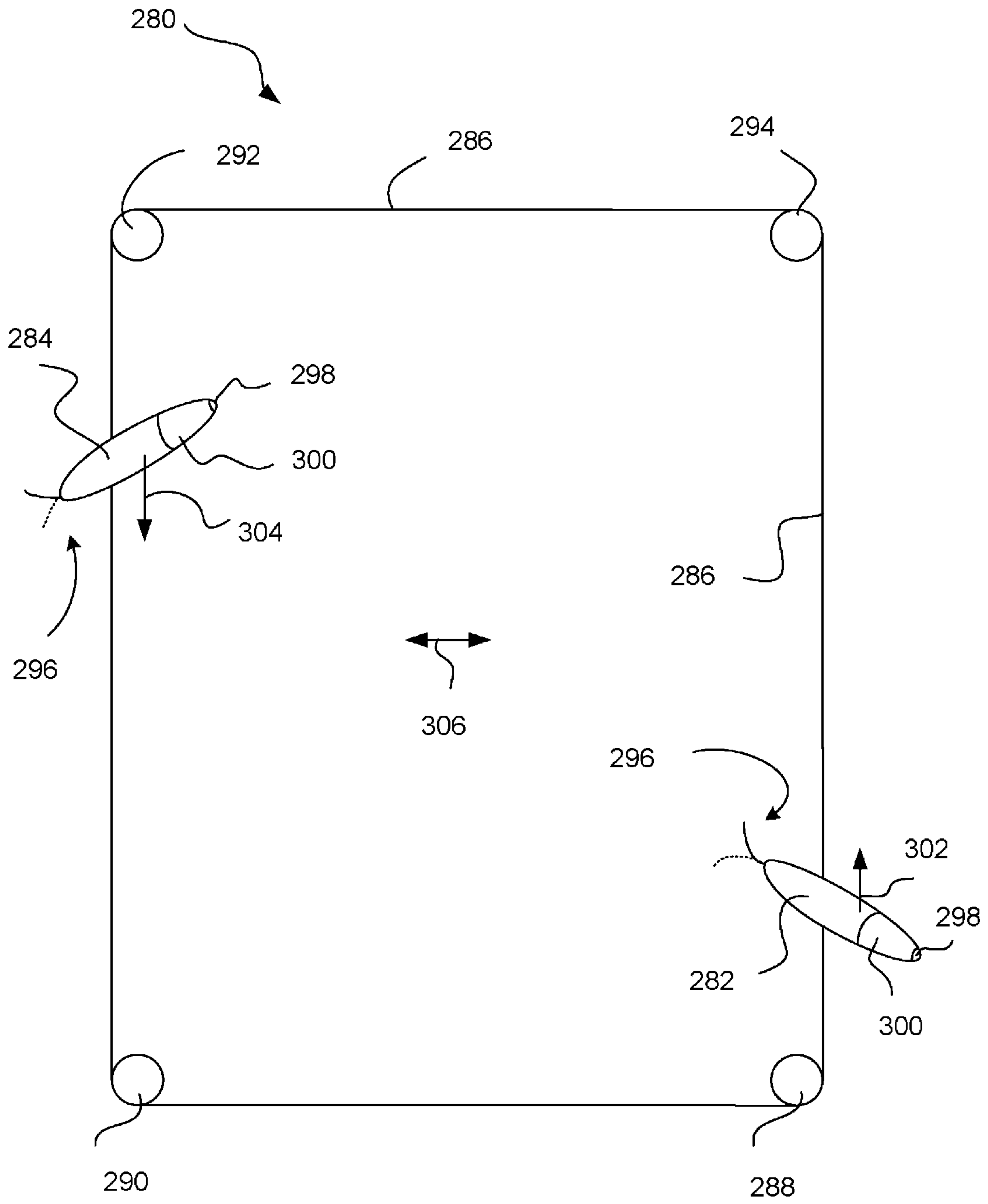


Fig. 13

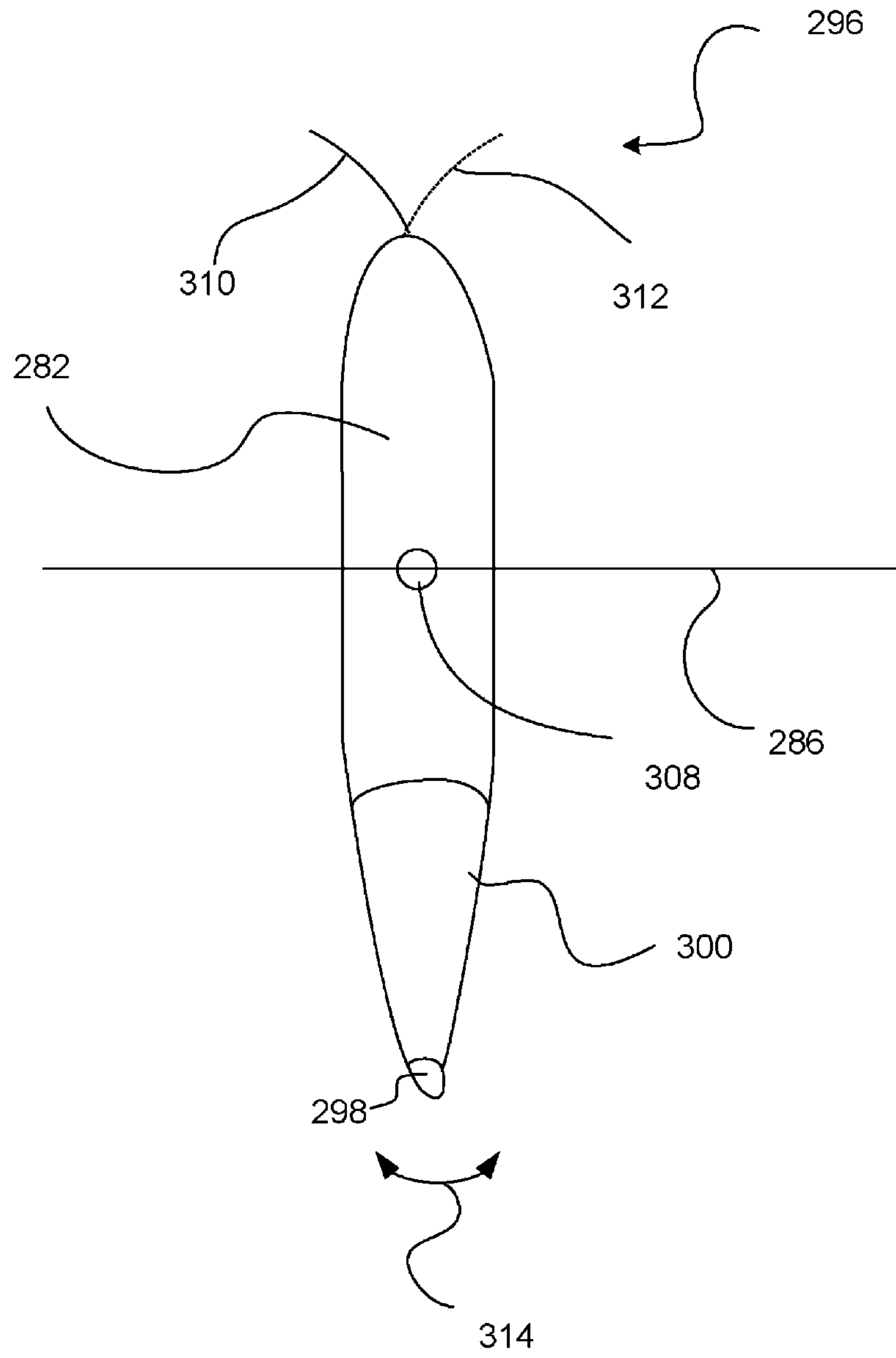


Fig. 14

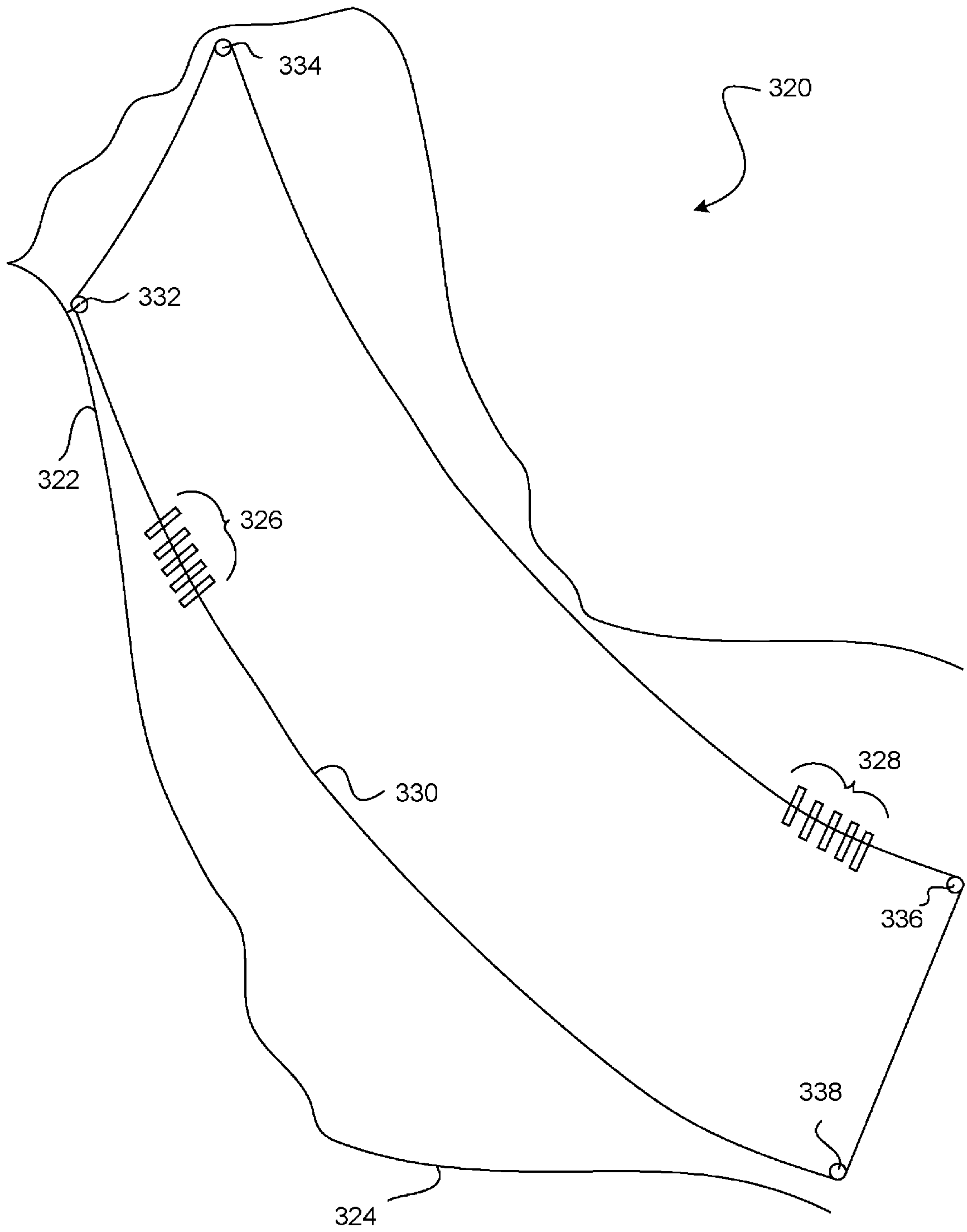


Fig. 15

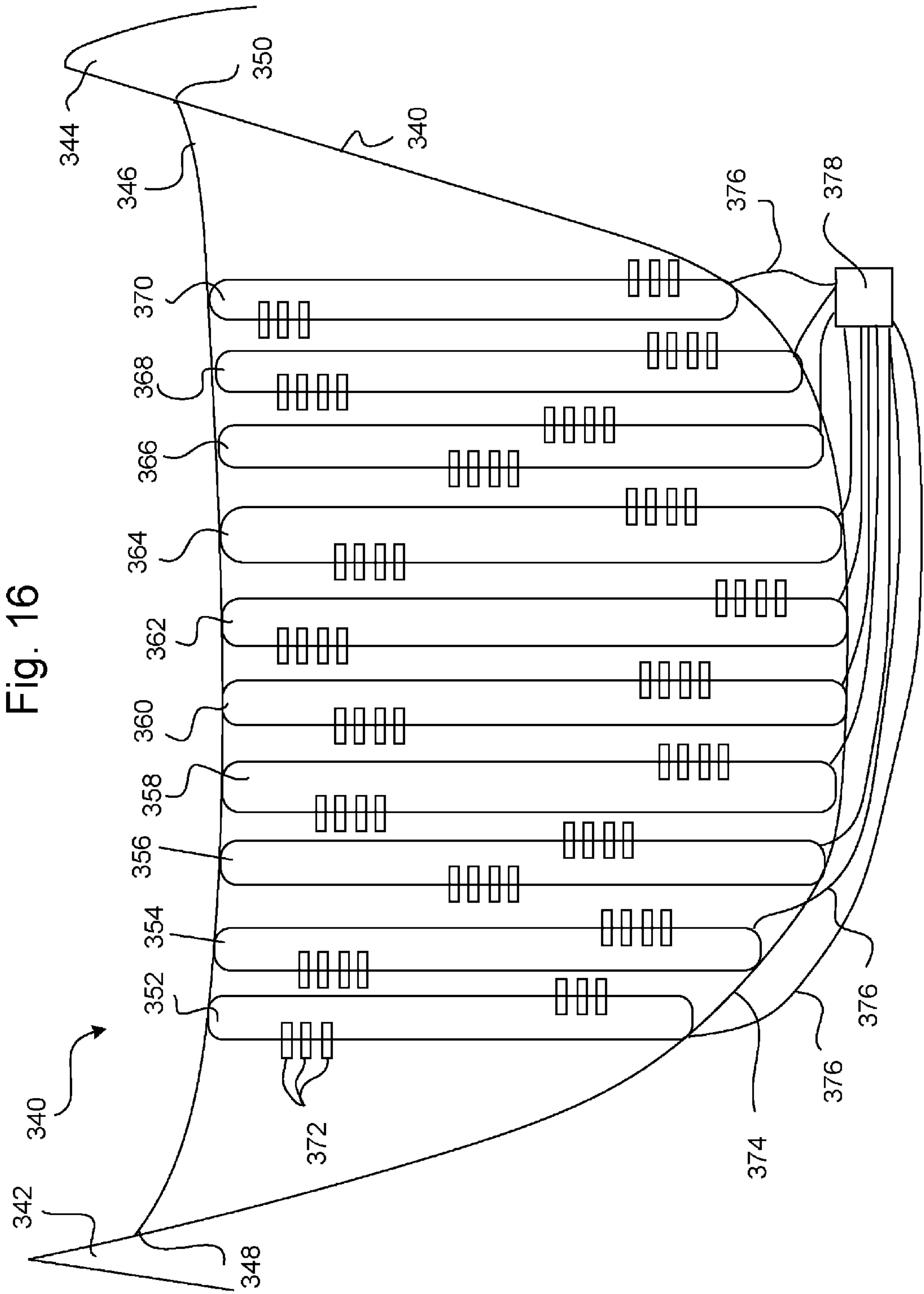
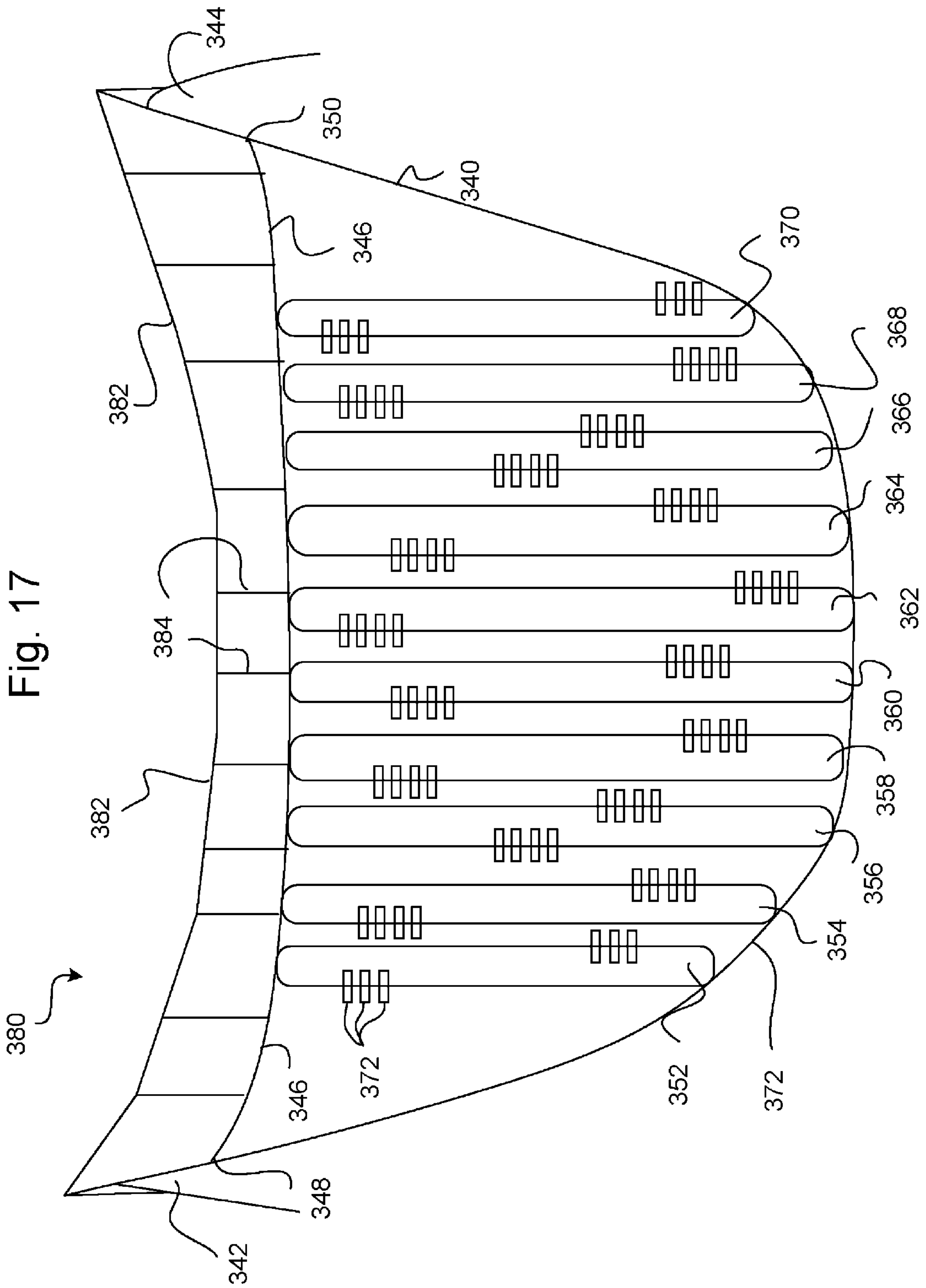


Fig. 16



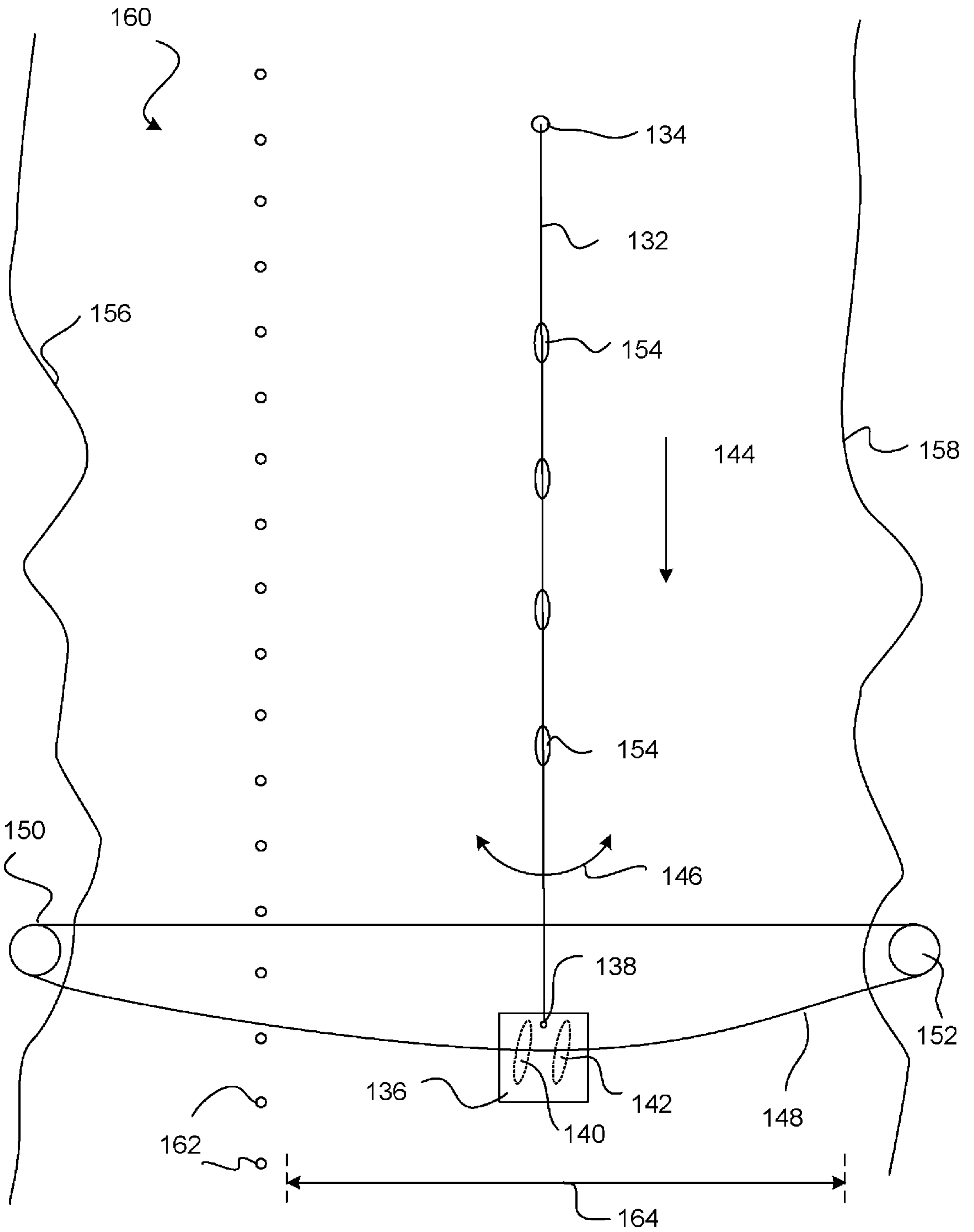


Fig. 6