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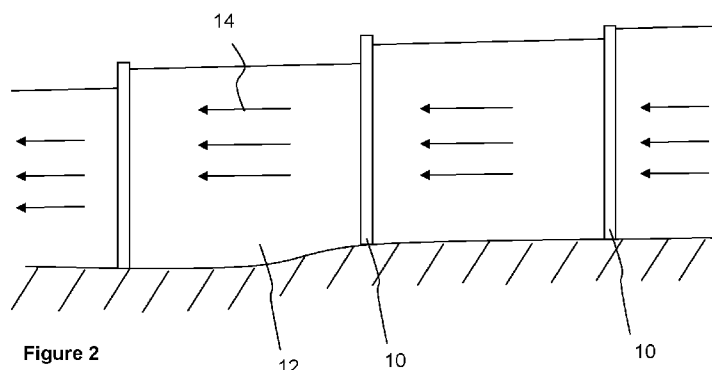


Figure 2

(57) Abstract: A method of installing a series of structures across a body of flowing water for generating electricity from current flow is described. Each structure is formed from at least one module which comprises a manifold structure carrying a planar array of pipe structures, each pipe provided with a series of holes spaced along its length and being in a spaced, side-by-side arrangement such that a venturi is defined between the walls of adjacent pipes. The method comprises - positioning a first module across the body of water to form a first structure substantially perpendicular to the direction of the current flow, - positioning a second module across the body of water to form a second structure substantially perpendicular to the direction of the current flow and spaced apart and upstream from the first structure.



Description**Method and Apparatus for Generating Power from Current Flow****Technical field**

[0001] This invention relates to systems and methods for converting tidal or current energy in a body of flowing water into electricity. In particular, the invention provides a system and method for generating electricity using current flow in a body of water.

Background art

[0002] They have been a number of proposals for converting current flows into electricity as a non-polluting approach to power generation.

[0003] Offshore barrages have been proposed to concentrate the incidental energy of a large cross section of water flow by trapping the flow behind a containing wall and funnelling it through turbines of much smaller cross sectional area, as in a conventional dam. However such systems, typically across estuary or large rivers, are expensive and can be environmentally disruptive due to the damming of the river significantly increasing the minimum river level behind the installed barrage, thus permanently inundating what may be important wildlife habitats.

[0004] Other such installations have been proposed for the ocean or at the mouths of rivers where there is still a significant tidal flow or a high velocity current from which energy can be extracted. However not all the population can live near coastal bodies of water having a high velocity flow, and therefore the power is not necessarily being generated where it is needed.

Disclosure of the invention

[0005] The invention seeks to overcome some of the disadvantages outlined above. In particular the invention seeks to provide a system that is capable of generating electricity while minimising the environmental impact from the system.

[0006] A first aspect of the invention provides a method of installing a series of structures across a body of water for generating electricity from a current flow, each structure being formed from at least one module, each module comprising a manifold structure carrying a planar array of pipe structures, each pipe provided with a series of holes spaced along its length and being in a spaced,

side-by-side arrangement such that a venturi is defined between the opposing walls of adjacent pipes, the method comprising:

- positioning a first module across the body of water to form a first structure substantially perpendicular to the direction of tidal or current flow;
- positioning a second module across the body of water to form a second structure substantially perpendicular to the direction of tidal or current flow and spaced apart and upstream from the first structure.

- [0007] The structures can be installed across the entire width of the body of water. Each structure may be formed from a series of structures modules. The method may comprise positioning a first series of modules across the body of the water to form the first structure and positioning a second series of modules across the body of water to form the second structure.
- [0008] The method can further comprise positioning a third module across the body of water to form a third structure substantially perpendicular to the direction of tidal or current flow, the third structure spaced apart and upstream from the first and second structures. Further structures can be installed along the body of water upstream and/or downstream of the existing structures as necessary.
- [0009] The length of the pipes used, and the size of the system may be varied and will depend upon factors such the range of depth the system is to be used over, the desired use, the depth of water concerned and the current flow within the water. The system may extend over a range of tens of meters to several hundreds of metres and can depend on the width of the body water the system is to be installed.
- [0010] The body of water can be a river and the modules are positioned across the width of the river.
- [0011] The method can comprise floating each module into position on the body of water and lowering it into position by controlled flooding of a self buoyant mechanism of the module.
- [0012] The method can comprise allowing partial flooding of the self buoyant mechanism to maintain the modules in an upright position.

- [0013] The method can comprise positioning each module such that the lower end of the module extends to the river bed.
- [0014] The modules are positioned in the body of water such that there is an increase in water depth behind each structure.
- [0015] A second aspect of the invention provides a system for generating electricity, the system having been installed by the method according to the first aspect, the system comprising:
- a plurality of structures for extending across a body of water wherein each structure is spaced apart from the others, wherein each structure comprises a series of modules and each module comprises:
- a manifold structure;
 - an inlet in the manifold housing an turbine that is connected to drive a generator; and
 - a planar array of pipe structures, each pipe provided with a series of holes spaced along its length and wherein the pipes are in a spaced, side-by-side arrangement such that a venturi section is defined between the walls at or near the holes such that flow of water through the venturi section causes water to be drawn through the pipe and out via the holes, the resulting flow driving the turbine.
- [0016] The array of pipes preferably comprises pipes arranged substantially vertically and connected at their lower ends to the manifold structure arranged substantially horizontally.
- [0017] In one embodiment the pipes are arranged substantially horizontally and are connected to the manifold structure arranged substantially vertically.
- [0018] The pipes have may have an upstream side and a downstream side corresponding to the direction of fluid flow and a flow passage. The pipes may have a tapered cross-sectional profile. The pipes may taper at the downstream side such that opposing walls of adjacent tapering pipes define a venturi section and a first diffuser section extending downstream from the venturi section. The cross-sectional profiles of the upstream and downstream sides may be similar or substantially different.

[0019] Cross-sectional profiles of the pipes include hexagonal and elliptical shapes.

[0020] The system may comprise a buoyancy means in order to control or vary the buoyancy of the system and for example to raise or lower its depth in the water. The buoyancy means may be a self buoyant mechanism provided in a section of the pipes and may be provided at the downstream side. The buoyancy means may be an airtight chamber into which air may be introduced or removed. The buoyancy means may comprise a low or high density material to respectively raise or lower the system in the water. The extent of submersion of the system may thus be controlled. For example the system may be submerged, temporarily or on a permanent basis, to allow for shipping to pass above.

[0021] The invention provides in a third aspect the use of a system according to the second aspect for generating electricity.

[0022] The system is a Spectral Marine Energy Converter (SMEC).

Brief description of the drawings

[0023] The invention will now be described by way of example with reference to the accompanying drawings:

Figure 1 shows a bird's eye view of structures installed along the length of a body of water;

Figure 2 shows a side view of structures installed along the length of a body of water;

Figure 3 shows an embodiment of SMEC tubes which are aligned in a series to form a structure across a current flow that can be used according to the invention;

Figure 4 shows schematic profiles of an array of pipes for use with the invention;

Figures 5-10 show schematic profiles of pipes for use in unidirectional flow according to the invention;

Figures 11 and 12 shows profiles of pipes for use in bidirectional flow according to the invention;

Figure 13 shows one embodiment of a module for use in the invention;
Figure 14 shows a side view of pipes in different water levels;
Figure 15 shows a schematic of a structure installed across part of the width of a body of the water;
Figure 16 shows a side view of Figure 15; and
Figure 17 shows a schematic of a structure having a gap, installed across a body of water.

Detailed Description of the Invention

- [0024] The principle behind the invention is to use a series of modules positioned along a length of a river or other body of water, such as an estuary, fjord, channel etc, which can use the current or tidal flow of the water to generate electricity.
- [0025] The invention is based on SMEC technology which uses the current or tidal flow to generate electricity. One type of such technology is broadly disclosed in WO2008/015047 which describes apparatus for generating electricity using tidal, wave or current flow in a body of water. The apparatus described in WO2008/015047 comprises an arrangement of first and second pipes, each first pipe being provided with a series of holes spaced along its length, and the first pipes being arranged relative to the second pipes such that a venturi is defined between the walls of adjacent first and second pipes near the holes. A flow conduit is provided having an inlet and an outlet with a turbine located in the flow conduit; a generator is connected to the turbine. Water from the body of water can enter the flow conduit via the inlet, and the first pipes are connected to the outlet of the flow conduit such that flow of water past the arrangement of first and second pipes causes the first pipes to act as venturi pumps inducing flow from the inside of the first pipes through the holes so as to draw water through the flow conduit and drive the turbine.
- [0026] Other types of SMEC technology include that described in co-pending application PCT/GB2011/050523 entitled "Apparatus for generating power from fluid flow" filed 16 March 2011 in the name of VerdErg Ltd.

- [0027] As shown in Figure 1 the basic principle of the invention is to install a series of structures 10, each formed from one or more SMEC modules, along the length of the river 12 or other body of water. Each structure is positioned across the width of the river perpendicular to the flow 12 of the water. The SMEC modules forming the structures are capable of generating electricity from the current flow by driving turbine units. By installing the structures across the entire width of the river by-pass flow can be reduced.
- [0028] Each structure comprises a series of modules connected together to form a fence across the body of water. Each module comprises a series of pipes, through which the water from the river flows between as it flows downstream, and a turbine connected to a generator which is driven by the water flow through the module.
- [0029] Figure 2 shows a general view of the SMEC structures in operation, with three structures 10 positioned along the length of the river 14. Further structures can be installed as required. The SMEC structure forms an obstruction to the water as it flows down the river and a slight increase in river level will occur behind the SMEC. This increase in the river depth is the low head driver of the device. As the free board elevation formed behind each structure is minimal compared to complete damming of a river, the up-stream environmental impact is less damaging.
- [0030] The distance the structures are spaced apart will play a part in determining the ultimate increase in river level upstream of the array of structures. The distance between each structure will depend on the environment in which it is installed. The distance between the structures can vary depending on the contours of the land the rivers flow over. The distance between each structure can be sufficient such that the flow level of the river where an upstream structure is to be positioned is substantially unaffected by any down stream SMEC. If the structures are spaced sufficiently apart the river level upstream of the structures will reach its original level, despite the localised increase in head immediately behind each structure.

- [0031] The heights of the pipes are selected to suit the depth of the river where the structure is to be installed. The length of the pipes will be of a length such that the modules will extend down to the river bed to minimise by-pass flow.
- [0032] The SMEC module may also comprise a self-buoyant mechanism, to help position the module in the river. The self buoyant mechanism allows the module to stay substantially submerged as the water level rises and falls.
- [0033] Providing a series of structures along the length of a body of water enables the amount of energy to be extracted without the environmental consequences upstream and downstream caused by a singular damming across a river to obtain the equivalent energy.
- [0034] The structure can be formed from any suitable SMEC system such as that described in GB0816942.7 or WO2008/015047. In a one embodiment each structure is formed from modules such as that described in copending application PCT/GB2011/050523 entitled 'Apparatus for generating power from fluid flow' filed 16 March 2011 in the name of VerdErg Ltd, which is incorporated herein by reference.
- [0035] Figure 3 shows one embodiment of part of a module that can be used to form the structure. A series of pipes 20 forms a module which is set across a current flow 14. The arrangement comprises an array of pipes 20 arranged in a parallel spaced side-by-side arrangement in essentially the same plane with a venturi defined between adjacent pipes 20. Each pipe 20 has a holes 30 spaced along the length of the pipe. The lower ends of the pipe are connected to a common horizontal manifold structure 34 which is connected to a flow conduit housing a turbine 36. The turbine 36 is connected to a generator.
- [0036] A head drop from the upstream water surface head to the downstream water level occurs as current flows between the pipes 20 and power is extracted. As the current flows through the venturi between the pipes an amplified head loss occurs in the venturi. This induces a flow of water 28 out through the holes 30. This amplified head drop across the pipes, flow conduit and turbine induces a low volume, high velocity secondary flow 32 through the manifold 34. The

secondary flow 32 drives the turbine 36 located in the inlet of the manifold which is connected to a generator.

- [0037] The number, shape and arrangement of holes can vary. The pipes can have any suitable opening into the flow passage including holes, slots and continuous slots.
- [0038] Where the structure is relying on the current flow to generate the electricity, the pipes used can preferably have a tapered side. Figure 5 shows a cross sectional view of pipes that can be used in one embodiment of the invention. Each pipe 42 forming the array can comprises an upstream side 44 and a tapered downstream side 46. A flow passage 48 is positioned between the sides. A series of holes or slots 50 are formed along the length of the flow passage. Adjacent pipes are positioned such that a venturi section 52 and a diffuser section 54 is formed between opposing walls of adjacent pipes. The downstream side 46 can be closed off from the upstream end and can include a buoyancy section 56. Controlled flooding of the buoyancy section can help in positioning the structure in the body of water.
- [0039] In operation the primary flow 58 accelerates into the venturi section between the pipes and flows through the venturi section 52 and then decelerates out of the venturi between the faces of the pipes that form the diffuser section. As the pressure outside the holes 50 is reduced, this induces a secondary flow 60 of water from the pipes out through the holes.
- [0040] Figures 5-12 shows details of other arrangement of pipes that can be used to form the modules of the structure. Figures 5-10 shows the profiles of pipes for use in unidirectional flow. Each pipe 42 forming the array can comprises an upstream side 44 and a tapered downstream side 46 with a flow passage 48 positioned between the ends. A series of holes or slots 50 are formed along the length of the flow passage. The tapered downstream side allows a diffuser section to be formed between adjacent pipes. Bracing 62 and struts can help strengthen the pipes. Figures 11 and 12 show cross sectional profiles of pipes that can be used in bidirectional flows. The pipes comprise a tapered upstream side 44 and a tapered downstream side 46 to form two diffuser sections 54, 58.

The symmetrical shape of the pipes, such as ellipsoidal and hexagonal, allows the entrance throat to become the diffuser section 58 when the flow 58a is reversed 58b.

- [0041] As shown in Figure 3 each module can comprises an array of pipes 20 arranged vertically in a parallel spaced side-by side arrangement with a venturi defined between adjacent pipes. The lower ends of the pipes 20 are connected to a common horizontal manifold 34 having an inlet housing a turbine 36. Each pipe comprises a tapered side, a flow passage and a row of holes spaced along the length of the pipe. Adjacent pipes are positioned such that a venturi section and a diffuser section are formed between adjacent pipes. Flow of water 16 between the pipes causes a reduction of pressure in the venturi which draws water 28 out of the pipes through the holes 30. Consequently, water 32 is drawn through the flow conduit and into the manifold, driving the turbine 36 and hence powering the generator.
- [0042] In different embodiment of the invention a module can comprise pipes arranged substantially horizontally as shown in Figure 13. The horizontal pipes 70 are arranged in a parallel spaced side-by-side array in essentially the same plane such that a venturi and a diffuser section is defined between adjacent pipes. The pipes are provided with a series of holes 72 spaced along its length. The pipes 70 extend between vertical manifold pipes 74, the interior of the pipes communicating with the interior of the vertical manifold. The vertical manifold pipe 74 is connected to a flow conduit 76 housing a turbine 78 connected to the drive shaft to drive a generator.
- [0043] The method of installing the structures can vary depending on the type of structure that is used. Methods can include floating the modules into position on the body of water, lowering the modules into position by controlled flooding of a self buoyant mechanism of the modules and/or lowering into position by cranes or other lifting apparatuses.
- [0044] The modules can be installed to be moveable within the body of water. As shown in Figure 14 the modules can comprise a buoyancy section 92 or external float, which keeps the top of the pipe 20 at the water surface level 94.

As the water level 94 falls the SMEC can roll on the river bed 96 such that the holes 30 of the pipes 20 and the module will stay substantially submerged as the water level rises and falls.

- [0045] Once a first structure has been positioned in the river, further structures can be positioned across the river upstream and/or downstream of the first structure. The number of structures that are installed will depend on the environment and the amount of electricity that is required to be generated.
- [0046] Locks can be incorporated into the SMEC structures as for a conventional barrage to permit passage of shipping.
- [0047] Gaps can be incorporated into the SMEC structure to permit passage of water craft, fish or marine mammals up and down the river.
- [0048] Partial obstruction of the flow as with an artificial island or closed lock gates can function to increase the flow rate and guide the flow through the SMEC resulting in enhanced flow velocity and enhanced electricity generation.
- [0049] In the embodiment of Figure 15 and Figure 16 the structure 80 are installed only partially across the width of the water 82. In order to minimise edge losses in such an arrangement, a surface 84 can be attached to the free end of the structure extending at right angles upstream of the structure 80. The surface can help direct water through the pipes 86 and minimise flow around the edge. The inlet 88 for the secondary flow 90 can be located at the free edges to encourage the primary flow to pass between the pipes 86 rather than around the free edges.
- [0050] In the embodiment of Figure 17 a SMEC structure 80 is installed substantially across the full width of the water 82, with a gap 98 part-way across in which an inlet comprising a turbine 100 is located. A surface 84 is attached to each of the free ends of the modules on either side of the gap 98 to help inhibit by pass flow, while still maintaining an open passage in the structure. Secondary flow 90 through the turbine accommodates head drop across the SMEC.
- [0051] This system is particularly applicable for inland river systems, when coastal currents and tidal forces are not available to harness the energy from. The SMEC modules do not rely on the tidal height range, and rely on the volumetric

inflow and outflow. This makes the SMEC particularly suitable in bodies of water where there is a large volume water which is not necessarily flowing at high velocity, for example rivers having significant depth or width.

[0052] Further changes can be made within the scope of the invention.

Claims

1. A method of installing a series of structures across a body of flowing water for generating electricity from current flow, each structure being formed from at least one module, each module comprising a manifold structure carrying a planar array of pipe structures, each pipe provided with a series of holes spaced along its length and being in a spaced, side-by-side arrangement such that a venturi is defined between the walls of adjacent pipes, the method comprising:
 - positioning a first module across the body of water to form a first structure substantially perpendicular to the direction of the current flow;
 - positioning a second module across the body of water to form a second structure substantially perpendicular to the direction of the current flow and spaced apart and upstream from the first structure.
2. A method as claimed in claim 1, wherein each structure is installed across the entire width of the body of water.
3. A method as claimed in claim 1 or claim 2 wherein each structure is formed from a series of modules and the method comprises positioning a first series of modules across the body of the water to form the first structure and positioning a second series of modules across the body of water to form the second structure.
4. A method as claimed in claim 1, 2 or 3 wherein the pipes are arranged substantially vertical and connected at their lower ends to the manifold structure arranged substantially horizontal.
5. A method as claimed in claim 1, 2 or 3 wherein the pipes are arranged substantially horizontally and connected to the manifold structure arranged vertically.
6. A method as claimed in any preceding claim further comprising positioning a third module across the body of water to form a third structure substantially perpendicular to the direction of tidal or current flow, the third structure spaced apart and upstream from the first and second structure.
7. A method as claimed in any preceding claims comprising positioning the modules across the width of a river.

8. A method as claimed in any preceding claim, comprising floating each module into position on the body of water and lowering it into position by controlled flooding of a self buoyant mechanism of the module.
9. A method as claimed in claim 8 comprising allowing partial flooding of the self buoyant mechanism to maintain the modules in an upright position.
10. A method as claimed in any preceding claim comprising positioning each module such that the lower end of the modules extend below the current in the body of water.
11. A method as claimed in any preceding claim wherein each pipe comprises a flow passage, an upstream side and an elongate downstream side, the downstream side tapering away from the flow passage and the pipes are arranged such that opposing walls of adjacent pipes define a venturi section and a first diffuser section extending away from the venturi section.
12. A method as claimed in any preceding claim wherein the modules are positioned in the body of water such that there is an increase in water depth behind each structure.
13. A system for generating electricity, the system having been installed by the method as claimed in any preceding claim, the system comprising:
 - a plurality of structures for extending across a body of water wherein each structure is spaced apart from the other structures and comprises at least one module, and wherein each module comprises:
 - a manifold structure;
 - an inlet in the manifold housing an turbine that is connected to drive a generator;
 - and
 - a planar array of pipe structures, the pipes provided with a series of holes spaced along its length and wherein the pipes are in a spaced, side-by-side arrangement such that a venturi section is defined between the walls at or near the holes such that flow of water through the venturi section causes water to be drawn through the pipe and out via the holes, the resulting flow driving the turbine.
14. A system as claimed in claim 13 wherein each pipe of the structure comprises a flow passage, an upstream side and a downstream side, and the pipe tapers at the

downstream side such that opposing walls of adjacent pipes define a first diffuser section extending away from the venturi section.

15. A system as claimed in claim 13 or claim 14 wherein the pipes are arranged substantially vertically and connected at their lower ends to the manifold structure arranged horizontal at their lower ends.
16. A system as claimed in claim 15 wherein the pipes include a self buoyant mechanism.
17. A system as claimed in claim 13 or claim 14 wherein the pipes are arranged substantially horizontally and are connected to the manifold structure arranged vertically.

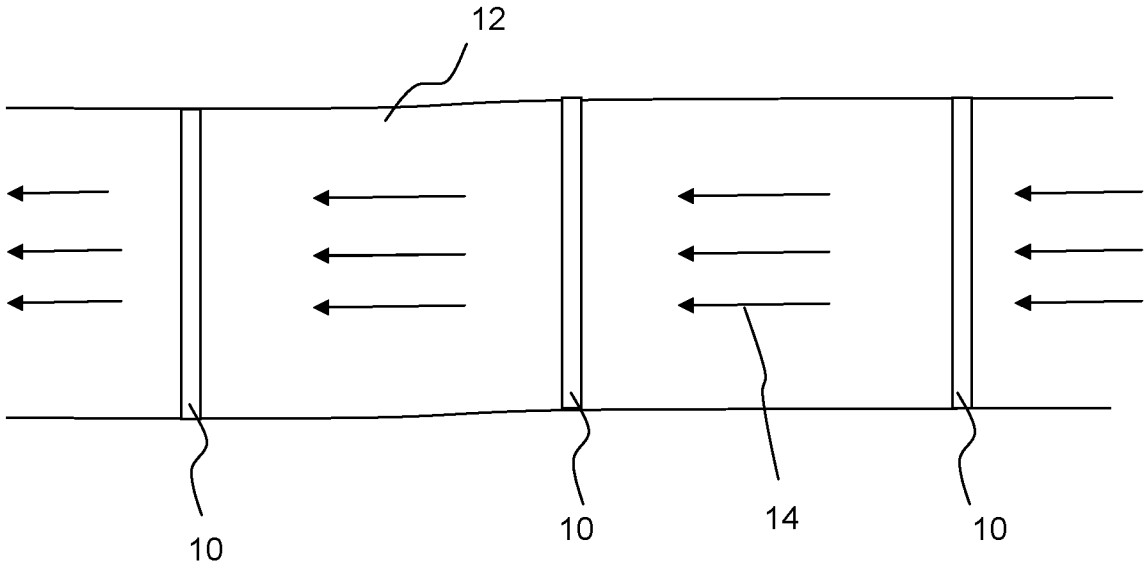


Figure 1

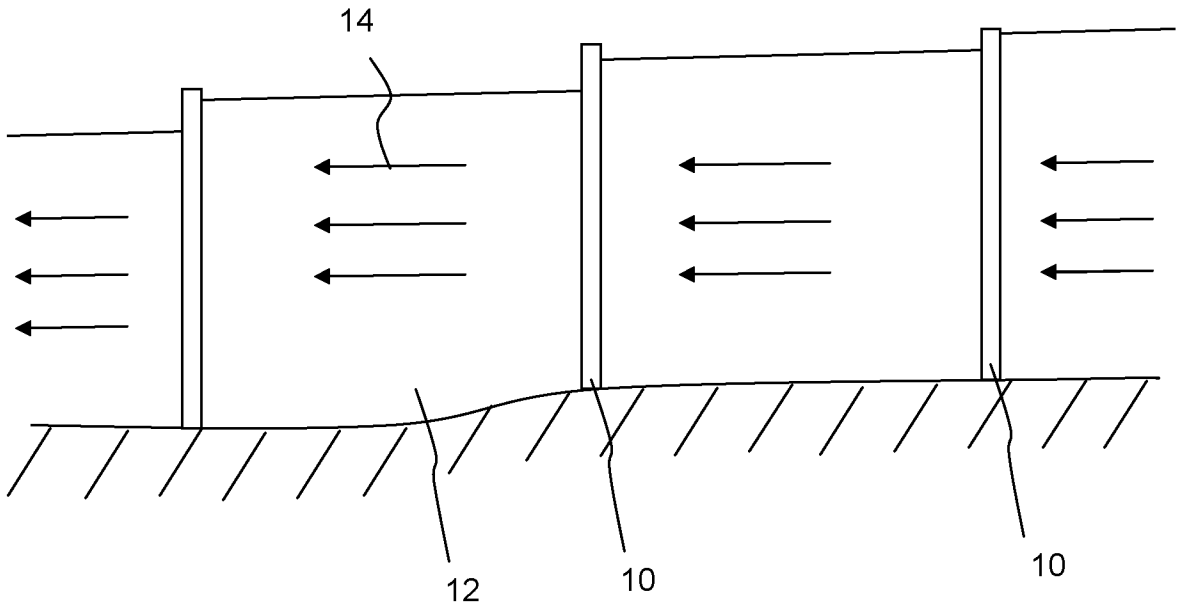


Figure 2

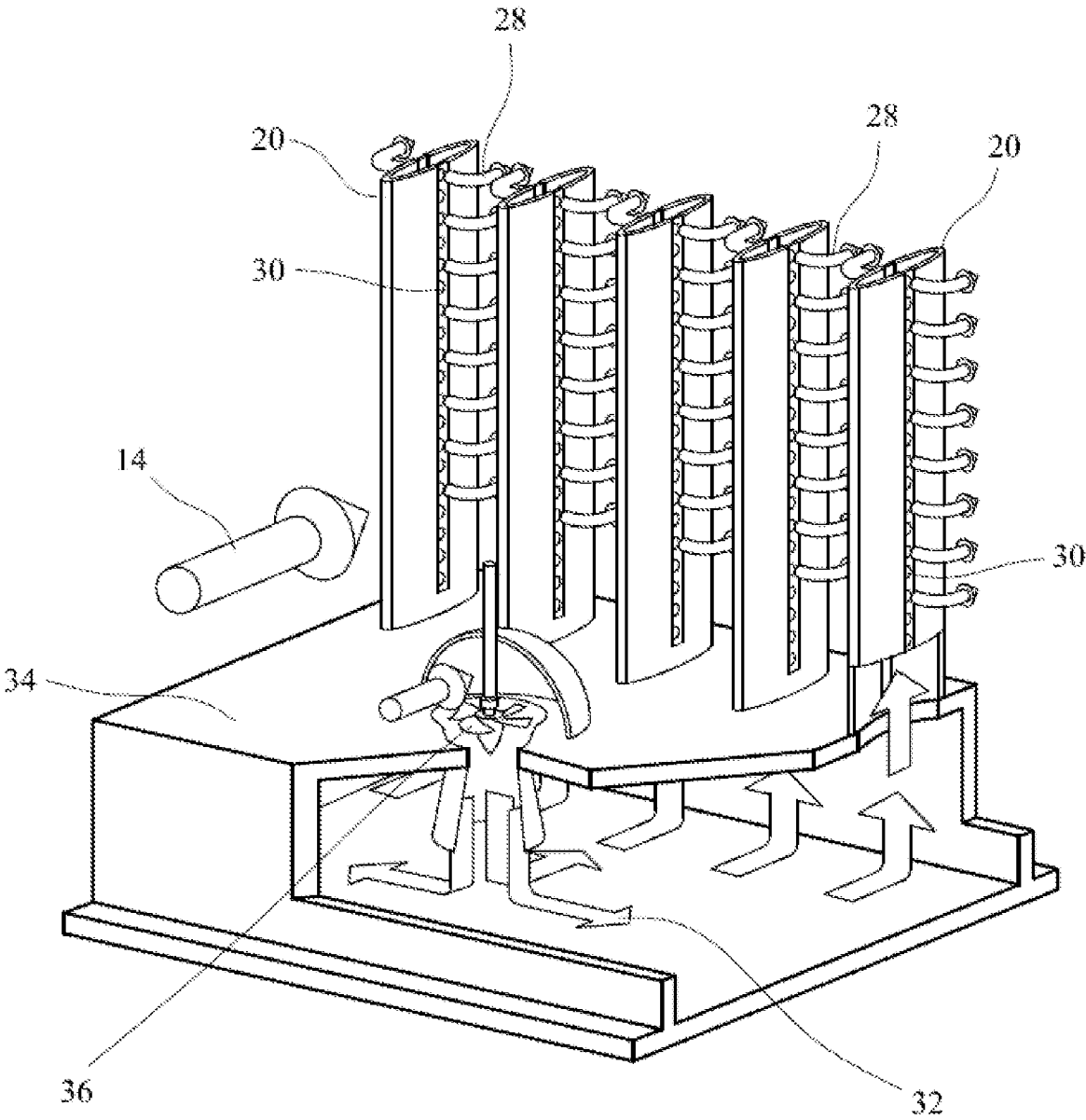


Figure 3

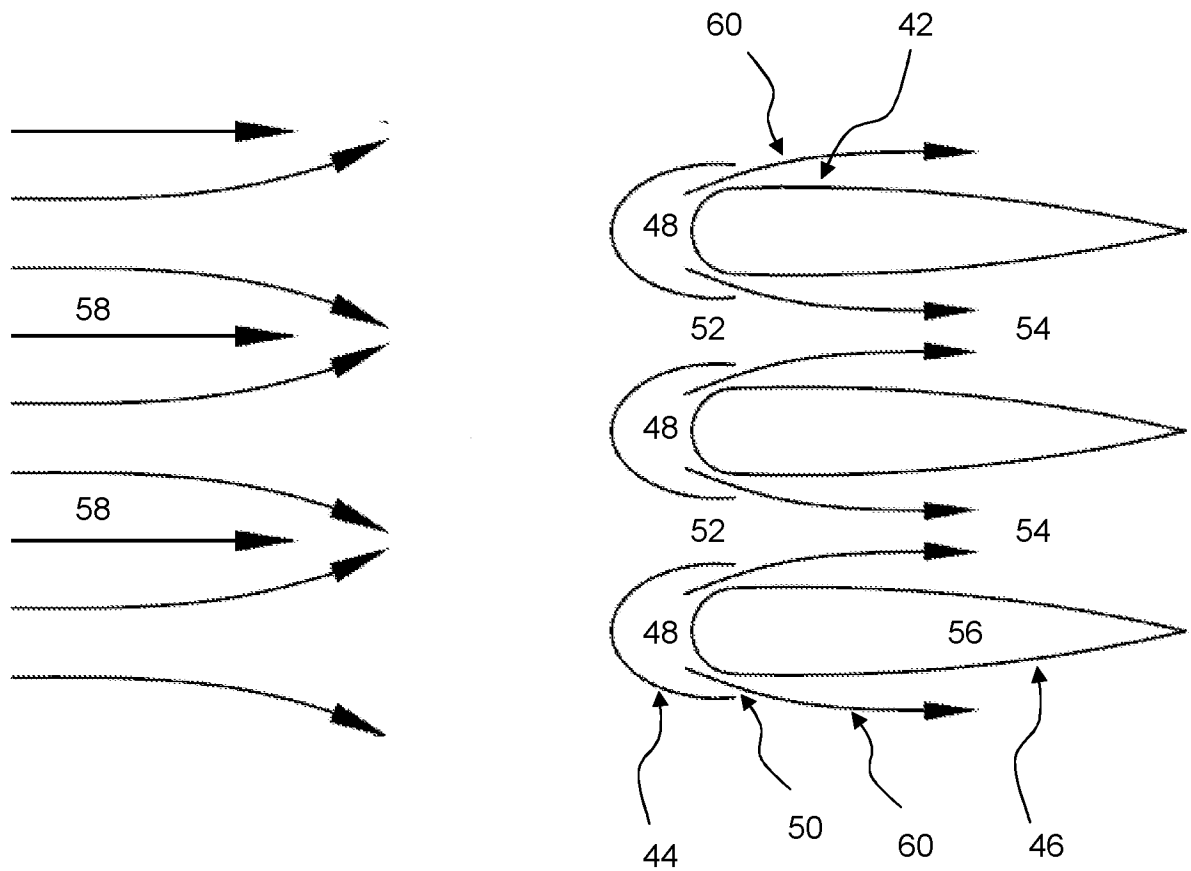


Figure 4

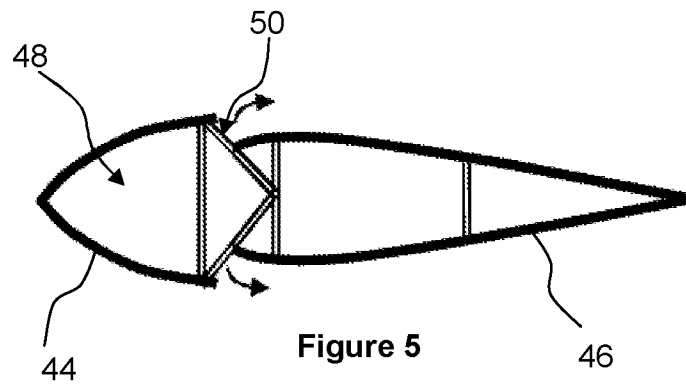


Figure 5

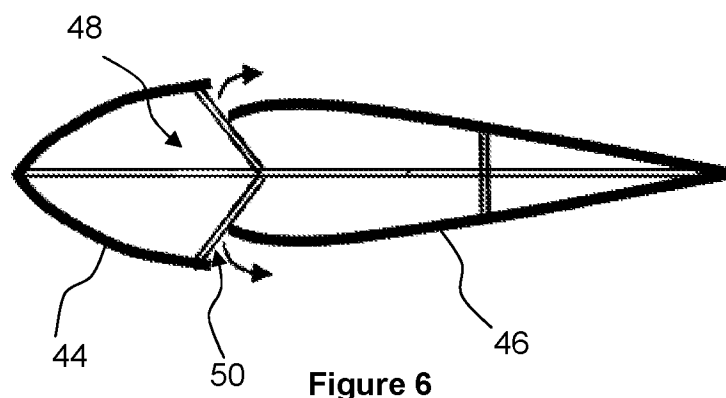


Figure 6

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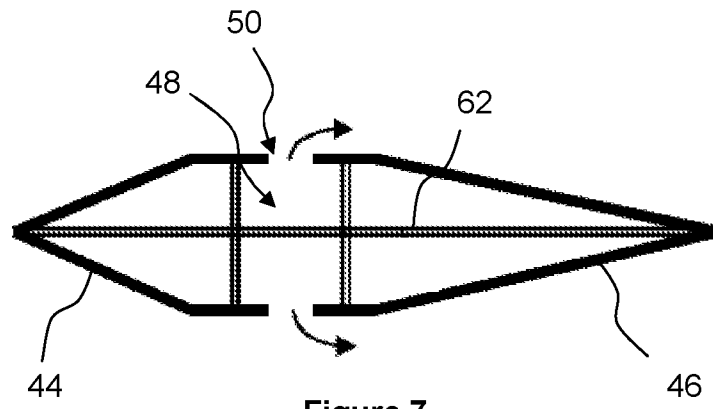


Figure 7

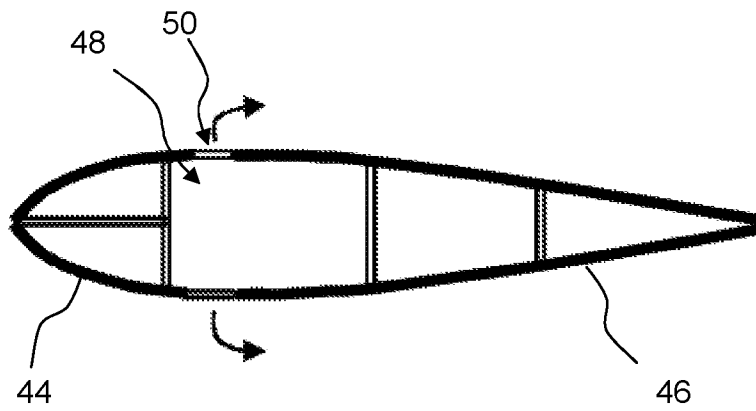


Figure 8

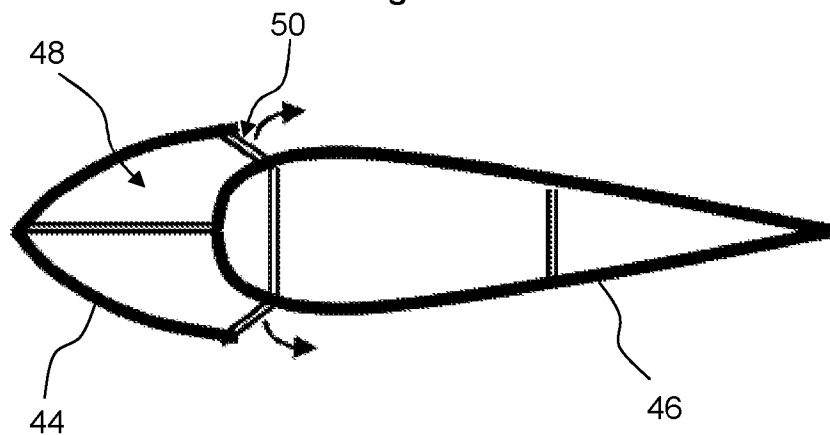


Figure 9

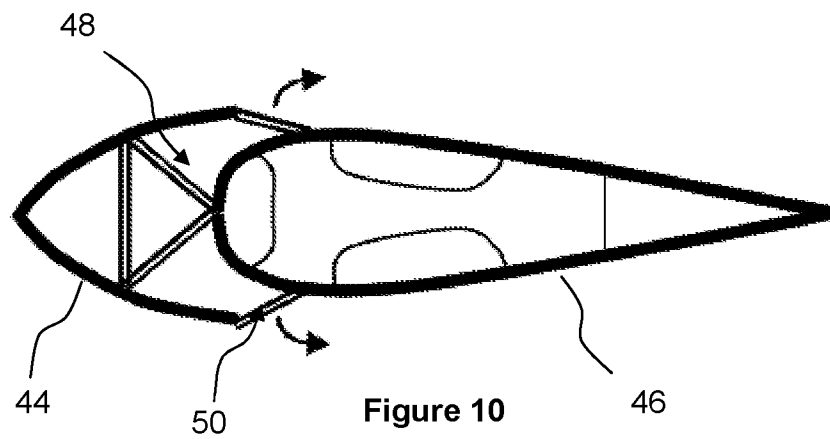
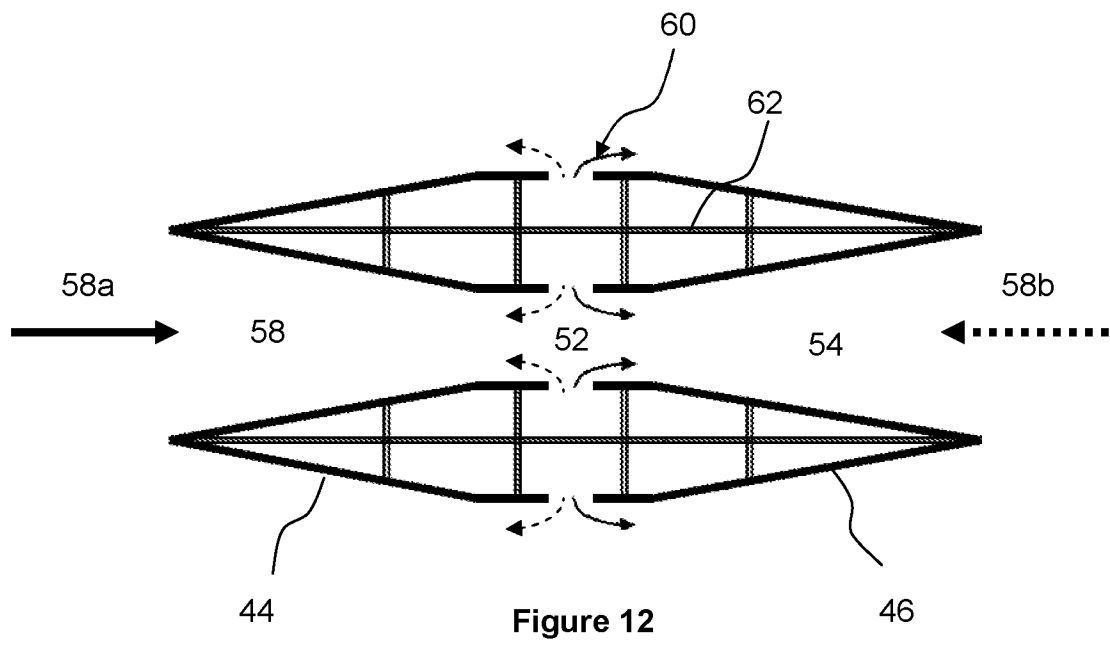
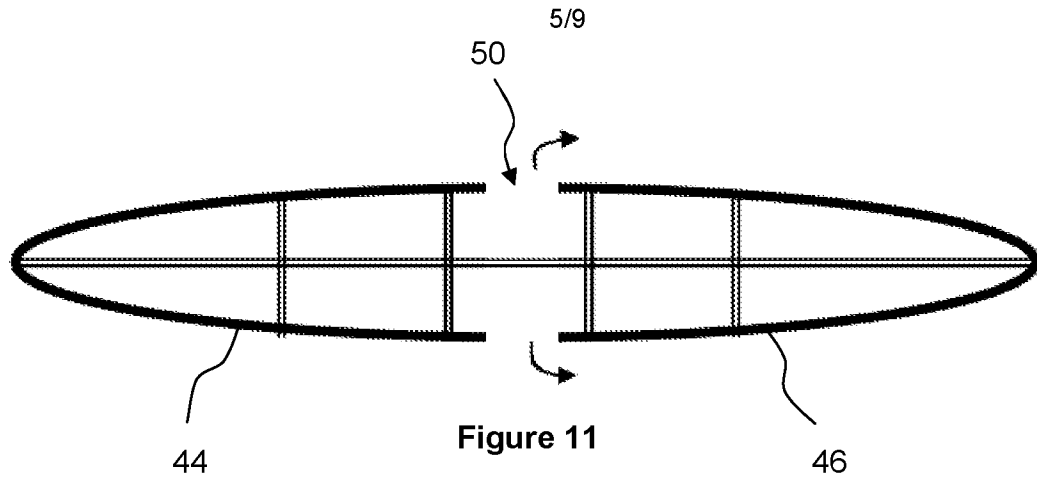


Figure 10



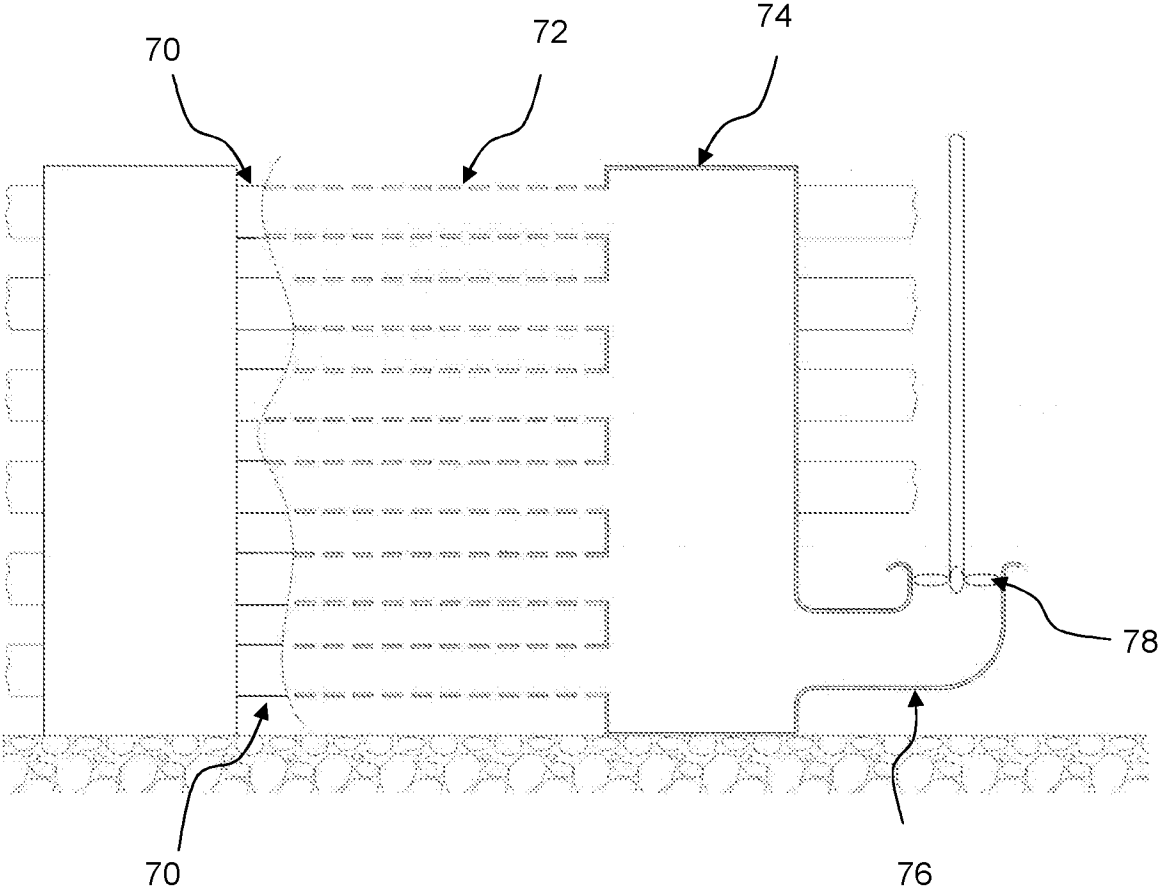


Figure 13

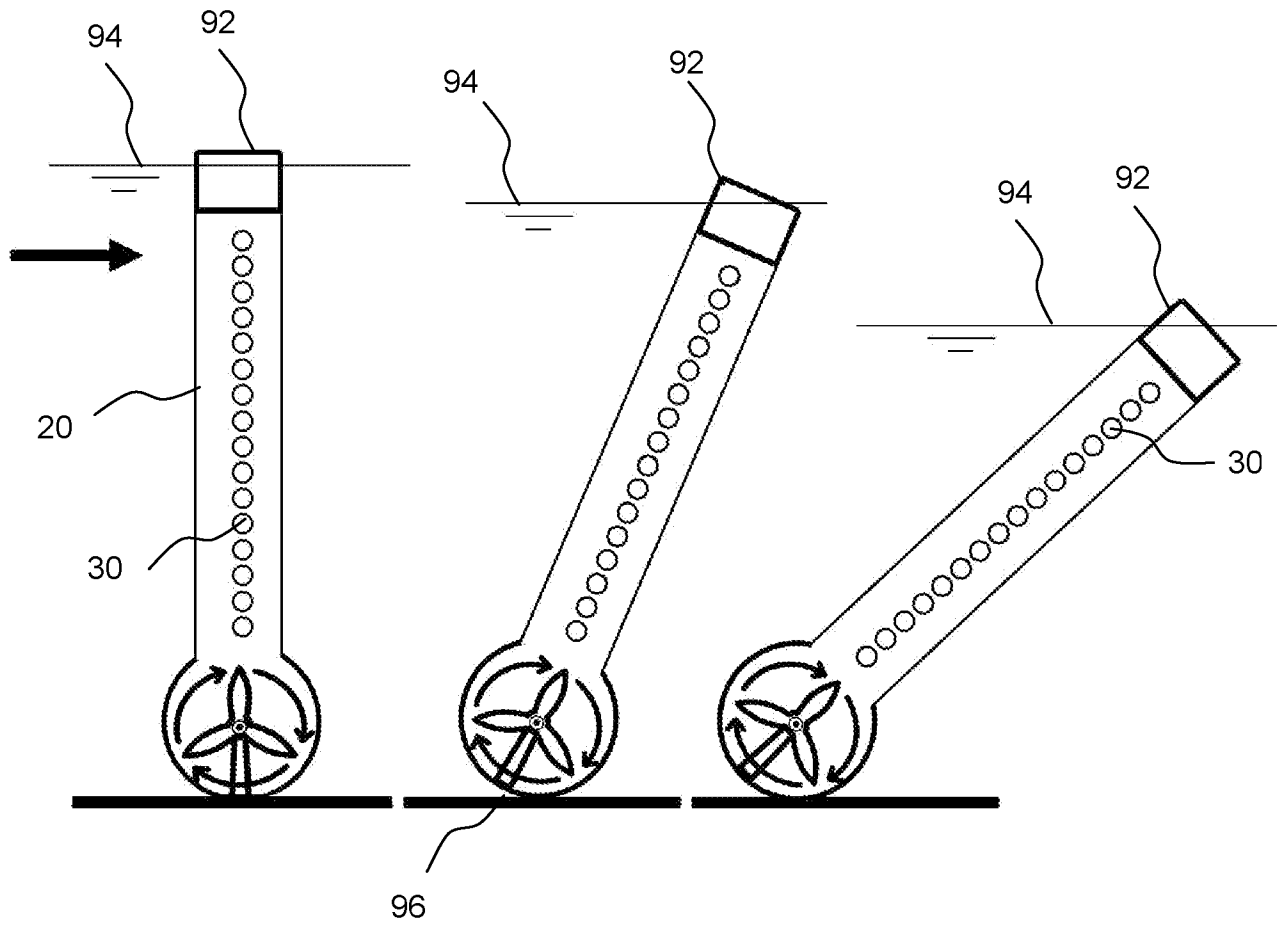


Figure 14

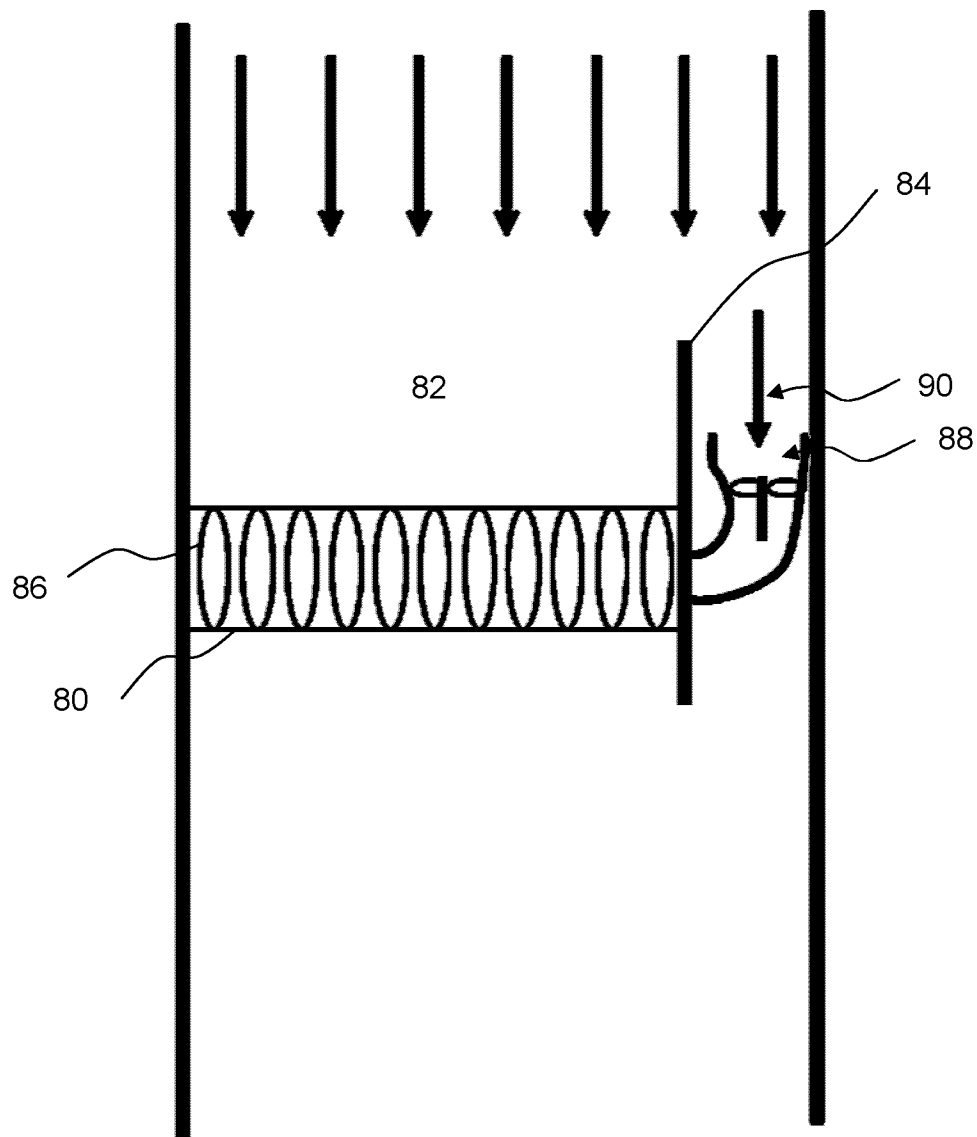


Figure 15

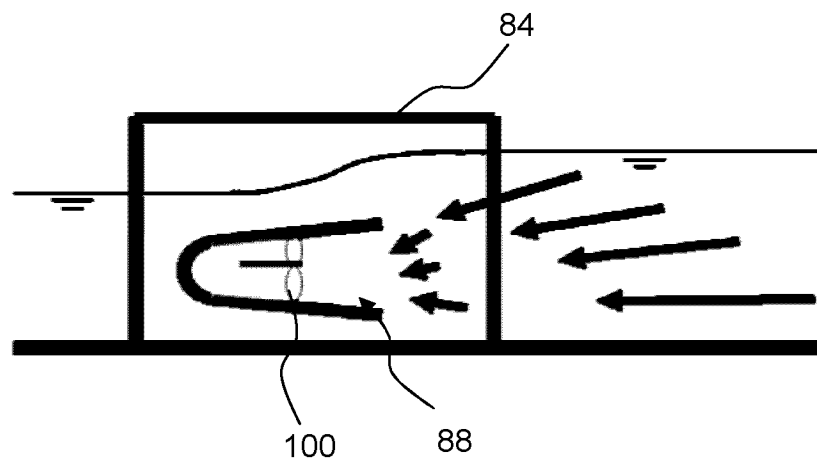


Figure 16

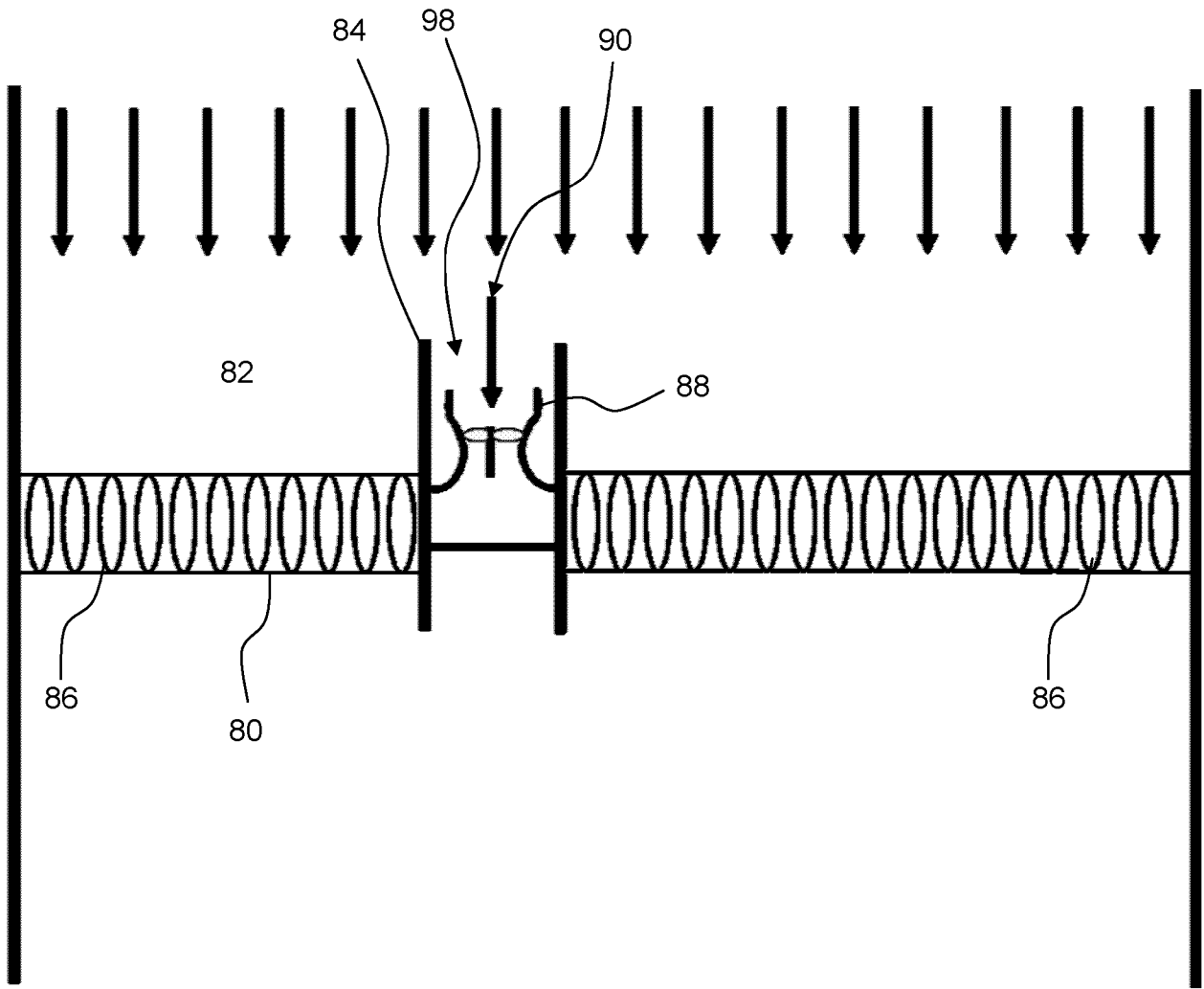


Figure 17