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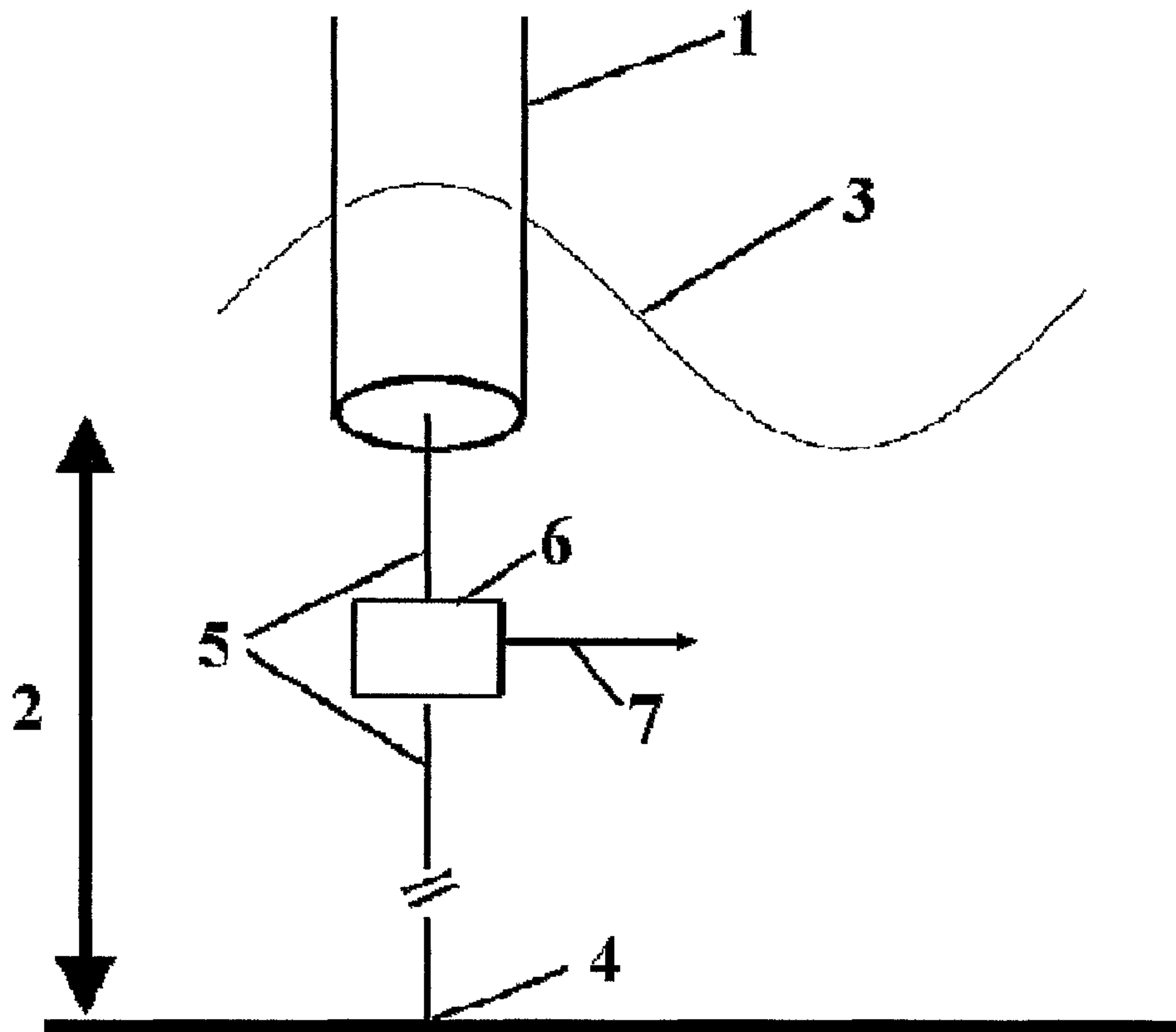
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(54) Titre : CONVERTISSEUR D'ENERGIE DE VAGUE OCEANIQUE (OWEC)

(54) Title: THE OCEAN WAVE ENERGY CONVERTER (OWEC)



(57) **Abrégé/Abstract:**

A device consisting of a container which is partially submerged in the sea which may be buoyant and connected to the seabed with cables or mounted on a platform and whose interior is connected to its exterior via pipes where in response to the passing of waves is filled and emptied through these pipes. The force of the water flowing through the pipes causes turbines to rotate thus generating electricity which may be transmitted to land. These turbines may be turbines which rotate in different directions depending on the direction of water flow or turbines which maintain the same direction of rotation irrespective of the direction of water flow.

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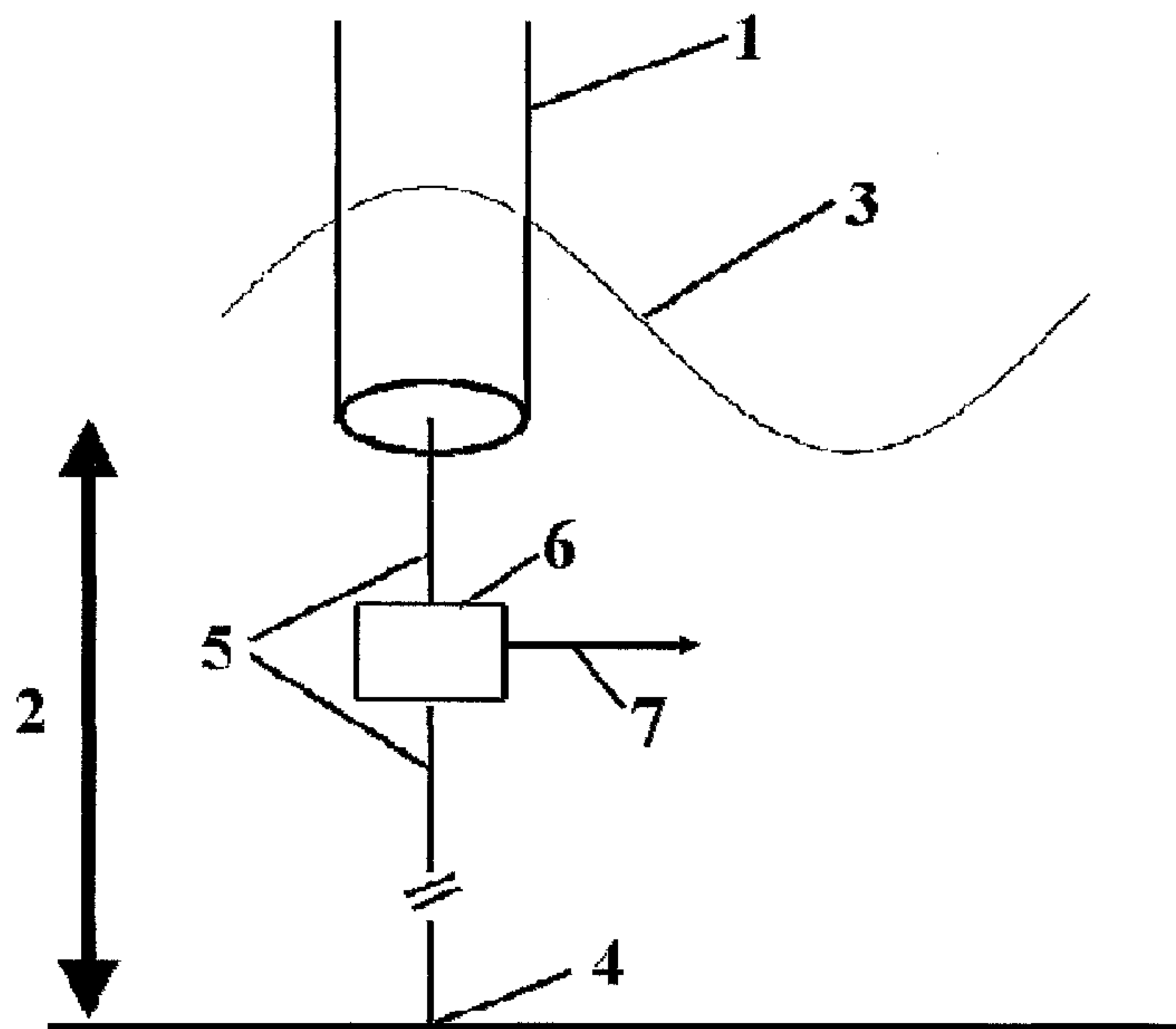
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(54) Title: THE OCEAN WAVE ENERGY CONVERTER (OWEC)



(57) Abstract: A device consisting of a container which is partially submerged in the sea which may be buoyant and connected to the seabed with cables or mounted on a platform and whose interior is connected to its exterior via pipes where in response to the passing of waves is filled and emptied through these pipes. The force of the water flowing through the pipes causes turbines to rotate thus generating electricity which may be transmitted to land. These turbines may be turbines which rotate in different directions depending on the direction of water flow or turbines which maintain the same direction of rotation irrespective of the direction of water flow.

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DescriptionThe Ocean Wave Energy Converter (OWEC)

The energy of ocean waves is immense and one of the largest renewable resources of energy that can be harvested by mankind. The US DOE estimate that the total power of waves breaking on the world's coastlines is 2 to 3 billion kW. Ocean wave energy is useful to mankind not only due to its energetic potential but also, unlike wind, is less intermittent as it is not reliant on local weather conditions and may travel thousands of miles with little energy dissipation.

There have been many attempts to harvest wave energy. The main problems being:

- 1) The energy of the waves is greatest in open sea far from shore, for example in some areas off the North Atlantic ridge swell heights can average about 8 metres. Closer to shore, wave energy is dissipated due to bottom friction and diffraction effects. Under deep-water conditions installation of wave energy converters can be difficult and expensive. Shore based wave energy converters are easier to install but have lower theoretical capacity and a greater environmental impact.
- 2) Many wave energy converters use floats that bob up and down on the wave with relation to the seabed, this movement may be used to generate electricity. However these type of energy converters intrinsically only harvest a small proportion of the wave's energy even if erected in open sea.
- 3) A wave's energy could be regarded as linear, perpendicular and/or parallel to the gravity of the earth. The energy that is parallel to the earth's gravity can be looked at as alternating in direction. Some of the most common electricity generating methods are based on force moving in one direction that creates a rotation of magnets or coils of wire about a central axis (a generator or turbine). Many methods for converting wave energy to electrical energy, particularly float based systems, have low efficiencies when attempting to convert alternating linear energy to the unidirectional rotation of a generator shaft.

A successful ocean wave energy converter could therefore comprise some or all of the following. It should function whatever the direction of the waves, it should harvest a large amount of the total energy of the wave, it should convert the force of the wave of alternating direction to unidirectional rotation of a generator shaft and it should be relatively simple to construct in open sea and deep water.

The ocean wave energy converter or OWEC (the device) described here fulfils all these criteria. It is estimated that, assuming 6 metre high waves, a 45 metre diameter device operating at 50% efficiency could be rated at 30MW of power.

Figure 1 is a not to scale schematic of an OWEC.

Figures 2 and 3 are schematic illustrations of the arrangement of the pipes in an OWEC and how water may flow in and out of the device.

Figures 4-7 are flow diagrams detailing the sequence of filling and emptying of an OWEC.

Figures 8-10 are schematic illustrations detailing the flow and turbine types available in an OWEC.

Figure 11 is a top view of a possible turbine (switching alternating flow turbine) in an OWEC.

Figures 12 and 13 are side views of two possible different blade orientations in a switching alternating flow turbine.

Figures 14 and 15 are side views of possible blade orientations in an alternating flow turbine.

Figure 16 is a top view of a possible turbine in an OWEC (alternating flow turbine)

Figure 17 is a schematic of spinning OWEC.

Figures 18-21 are schematics detailing different configurations of regulating the buoyancy of an OWEC.

Figures 22-24 are schematics detailing the use of a keel with an OWEC.

Figure 25 is a schematic detailing the use of a single buoy or platform with multiple OWECs.

There are many types of ocean wave energy converter. These may fall into several categories. These include devices that use the lateral movement of the waves such as the Pendulor and Tapchan; devices where a float moves relative to a fixed point or another float such as the Pelamis, the IPS Buoy and the Salter duck; devices which are submersed and respond to changes in water pressure to compress a gas or cause water flows such as the Powerbuoy and the Archimedes Wave Swing; and devices which are submersed or semi-submersed and use oscillating flows of water into and out of the device, such as the Oscillating Water Column. The conventional oscillating water column uses the inflow and outflow of water from the device to cause the changes in the pressure of a gas which in turn is used to power a gas turbine. The use of hydroturbines is rarely described, probably due to the low efficiency of these turbines under low pressure conditions. US2004/0217597 describes a stationary fully submersed cylinder whereby passing waves cause an oscillating flow of water powering a turbine. US6216455 describes a stationary semi-submersed cylinder whereby the inflow and outflow of water powers a turbine. US6216455 details a method of accelerating the water flows by using a float which is in phase with these water flows to change the pressure of the gas above the water. In this patent application (GB2005/003205) a process for accelerating the water flow is described whereby it is regulated so that head is formed. This is similar to 'latching' described for a float dependent device in US4203294. US4441316 also describes a form of latching in a free floating oscillating water column which bobs up and down in the water and uses air turbines. GB2005/003205 also details an alternating flow turbine which rotates the same direction independent of the direction of flow. Several other turbine designs have been described that achieve this. In US6216455 a turbine which has featherable blades is described. In US4271668 a turbine is described which uses guide vanes to direct air flow onto runners. The direction of the rotation of an output shaft staying the same by using a gear train. In US4286347 two sets of opposing guide vanes are used to direct airflow onto a runner which rotates the same direction independent on the direction of water flow.

The OWEC (Figure 1) essentially consists of a container (1) which in operation is partially submersed to a specific height from the seabed (2) such that the waterline (3) varies in height with the passing of waves. The device is connected to the seabed (4) using cables or supports (5). The device may be erected on a platform supported on the seabed or buoy (6). In Figure 2 and 3, the container is fitted with one or a number of pipes (8 or 9) that facilitate the inflow and outflow of seawater between the container's interior and the sea. As waves pass the container it is filled and emptied through these pipes. This is due to a differential created between the water on the inside of the device and the water on the outside of the device due to the device's buoyancy, that it is connected by cables to the seabed or that it is erected on a platform. Different pipes (8) could be used for the inflow and outflow (Figure 2) or the same pipe (9) could facilitate both the inflow and outflow (Figure 3), the arrows denoting the direction of flow. Due to the characteristics of ocean waves and that maximum differential is desirable, the pipes will primarily be located in the base of the container. Pipes may also be located in the devices sides which are more perpendicular to the plane of the sea. The pipe or pipes are fitted with a turbine or turbines. Each turbine rotates about a central axis as seawater flows through it. The flow of seawater could be regulated by valves. The rotation induces an electric current. The electricity may then be transmitted to land via cables (7). The emptying or filling of the container may be regulated using valves to allow a build up of head to drive the turbines, though regulation of flow is not necessary for all operation as a natural head may be created by the waterline variation and restriction of water flow as it passes through the pipes. The creation of a head by regulating flow to power the turbines may be considered as a four step process and may be considered to illustrate the general process by which the OWEC functions. In Figures 4-7 the arrow denotes the horizontal movement of a wave over time.

In Figure 4, the OWEC (10) is in a closed state with a lower amount of water (11) in its base. A head (12) is building up between the base of the container and the wave (3). At the optimum moment water is allowed to flow into the container.

In Figure 5, the water (13) has filled the container, it is then retained in there.

In Figure 6, a head (14) has been generated by the continuation of the wave past the container. At the optimum moment this water is released resulting in the situation in Figure 7. The cycle then starts again.

The flow into and out of the device is converted into electrical energy using turbines. These turbines may be of the propeller variety. There are four arrangements of turbines possible. In Figure 2, separate pipes may be used for the inflow and outflow of water and these pipes may be fitted with turbines which are designed for flow in only one direction. The disadvantage of this arrangement is that each turbine is only in operation for either the inflow or outflow of seawater.

In Figure 8, the same pipe may be used for both the inflow and outflow of water and may be fitted with a turbine that changes rotation direction dependent on the direction of water flow (15). This gives a greater surface area for the water to flow through, however, the disadvantage of this arrangement is that much of the energy of the water flow is used to change the direction of rotation of the propeller.

In Figure 9, the same pipe is used for inflow and outflow and uses a turbine whose blades switch orientation, by changing angle, dependent on flow direction (16). This also allows the turbine to maintain the same direction of rotation regardless of the direction of water flow. This type of turbine will be known as a switching alternating flow turbine or sAFT. In Figure 11 an example of a sAFT is shown where the turbine consists of blades (18) arranged about a central axis (19): Figure 12 illustrates the blade orientation (20) during the inflow stage, whilst Figure 13 illustrates the blade orientation (21) during the outflow stage. This allows the maximum surface area for the flow to pass through. As the orientation of blades is opposing dependent on the direction of flow, the inflow of water through the blades in one orientation and the outflow of water through the blades in another orientation results in rotation about the same axis, in the same direction.

These rotations can be used to generate electricity.

In Figure 10, the same pipe for both inflow and outflow and is fitted with a particular type of turbine that maintains the same direction of spin regardless of the direction of water flow (17). This consists of two sets of opposing blades arranged about a common axis. An example of this is shown in Figures 14-16. This type of turbine will be known as the alternating flow turbine or AFT. In this case the AFT consists of concentric bands of alternately opposing blades (22 and 23) about a single axis (24). However, sets of opposing blades may be arranged in any configuration. The flow through each set of blades is regulated by using valves. These valves may have an open and closed position. As water flows in one direction it is allowed to flow past one set of blades, the other set being closed. As water flows in the other direction it is allowed to flow past the opposing set of blades, the first set of blades being closed. In stages in which a build up of head is required, both sets of blades may be closed. As the orientation of each set of blades is opposing, the inflow of water through one set and the outflow of water through the other set results in rotation about the same axis, in the same direction. Only half the total flow is possible with the AFT than with the sAFT turbine. These rotations can be used to generate electricity.

Any number of pipes and/or combinations of turbines may be fitted as to allow flow into and out of the container and result in electricity generation. Alternatively a single turbine (25) may be fitted in the base of the cylinder which is composed of a circular section (26) (Figure 17). In this case, in operation, the entire device may rotate about a central axis (27). This subclass of OWEC is to be known as the spinning OWEC or sOWEC. In order for the OWEC to work at maximum efficiency its height in the waterline must be carefully regulated. The OWEC must have sufficient buoyancy to reduce the variation in the height the device sits in the waterline as a result of emptying or filling with water. As the device would normally be erected in deep water it may not be possible to erect it on top of a platform supported on the seabed. In these cases the container (1) will either use its own buoyancy (Figure 18) or be erected using a support (28) on top of a buoy (6) (Figure 19), whilst using a tense cable (5) connected to the seabed

(4) to allow the device to remain at an optimal, approximately constant distance to the seabed (2). The tension in the cable or the height of the support may be varied to attain the required height from the seabed. A platform or buoy may be used to house electrical generation and transmission equipment.

Horizontal forces from passing waves and wind as well as underwater currents may also effect the height that the device sits in the water. In Figures 20-24 these forces are denoted by an arrow. If horizontal forces are significant and/or variable such that they may effect the height of the OWEC in the water the device may be erected on a buoy (6) (Figure 20) which has sufficient buoyancy to counter much if these horizontal forces and the buoyancy of the container and tension in the cable (5) may be used to retain the desired height. If the device is erected on a buoy or platform a support (29) at an angle (30) to the normal (Figure 21) may be employed and height from the seabed regulated by varying this angle. The use of a keel (31) may be employed to keep the device upright (Figures 22-24). In operation many OWECs may be erected on a single buoy or platform (32) (Figure 25). The use of remote sensing of wave characteristics may allow more efficient regulation of wave inflow and outflow from an OWEC.

Claims

1. A wave energy converter which in use is partially submerged in open sea and maintained at an approximately constant distance to the seabed, the converter comprising:

a container whose interior is connected to its exterior via pipes primarily located in the container's base, whereby in response to a rise in water level relative to the container due to the passing of a wave peak, a differential in height between the water inside the container and the water on the outside of the container is created due to the device being connected to the seabed with a cable or that it is mounted on a platform such that water flows into the container through the pipes and is retained inside and in response to a drop in water level relative to the container due to the passing of a wave trough, a differential in height between the water inside the container and the water on the outside of the container is created due to the device being buoyant or that it is mounted on a platform such that water flows out of the container through the pipes;

wherein the pipes being fitted with fixed blade turbines being composed of two sets of opposing blades orientated around the same axis where water is only allowed to flow through either set of blades dependent on flow direction, the force of which being used to cause the rotation of an axis or axes resulting in the generation of electricity.

2. The wave energy converter as claimed in claim 1 whereby the flow of water through the pipes is regulated using valves such that an optimal head is created prior to the inflow or outflow of water into or out of the container

3. The wave energy converter as claimed in claim 1 or 2 where the water may flow in through one set of pipes and out through another set of pipes or in and out of the same set of pipes.

4. The wave energy converter as claimed in any one of claims 1 to 3 where the tension in the cables connecting the device to the seabed may be varied to adjust the height that the device sits in the water.

5. The wave energy converter as claimed in any one of claims 1 to 4 where the device is mounted on a buoy with a support such that varying the height of the support allows the height of the device to be adjusted.

6. The wave energy converter as claimed in any one of claims 1 to 5 where a keel is used to maintain the device in an upright position.

7. The wave energy converter as claimed in any one of claims 1 to 6 where multiple devices are mounted upon a single buoy or platform.

8. The wave energy converter as claimed in any one of claims 1 to 7 sensors are used to more efficiently regulate the water flow by determining wave characteristics.

9. A wave energy converter system being partially submerged in open sea and maintained at an approximately constant distance to the seabed, the wave energy converter system comprising:

a container having an interior, an exterior, an open top, and a base, the interior being connected to the exterior via at least one pipe primarily located in the base, the pipe being fitted with a turbine; and

a support attachable to the container and the seabed;

wherein in response to a rise in water level relative to the container due to the passing of a wave peak, a differential in height between the water inside the container and the water on the outside of the container is created due to the container being connected to the seabed with the support such that water flows into the container through the pipe and is retained inside, and in response to a drop in water level relative to the container due to the passing of a wave trough, a differential in height between the water inside the container and the water on the outside of the container is created due to the container being buoyant such that water flows out of the container through the pipe.

10. The wave energy converter as claimed in claim 9, wherein the pipe further comprising at least one valve for regulating the flow of water through the pipe such that an optimal head is created prior to the inflow or outflow of water into or out of the container.

11. The wave energy converter system as claimed in claim 9 or 10 further comprising a platform attachable to the container, the support being attachable to the platform.

12. The wave energy converter system as claimed in any one of claims 9 to 11, wherein the tension in the support connecting the container to the seabed is adjustable to adjust the height that the container sits in the water.

13. The wave energy converter system as claimed in any one of claims 9 to 12, wherein the container is mountable on a buoy with a support, the support being attachable to the container.

14. The wave energy converter system as claimed in any one of claims 9 to 13 further comprising a keel attachable to the container, the keel being adapted to maintain the container in an upright position.

15. The wave energy converter system as claimed in any one of claims 9 to 14, wherein multiple the containers are mountable on a support structure selected from the group consisting of a buoy, a platform, and a keel.

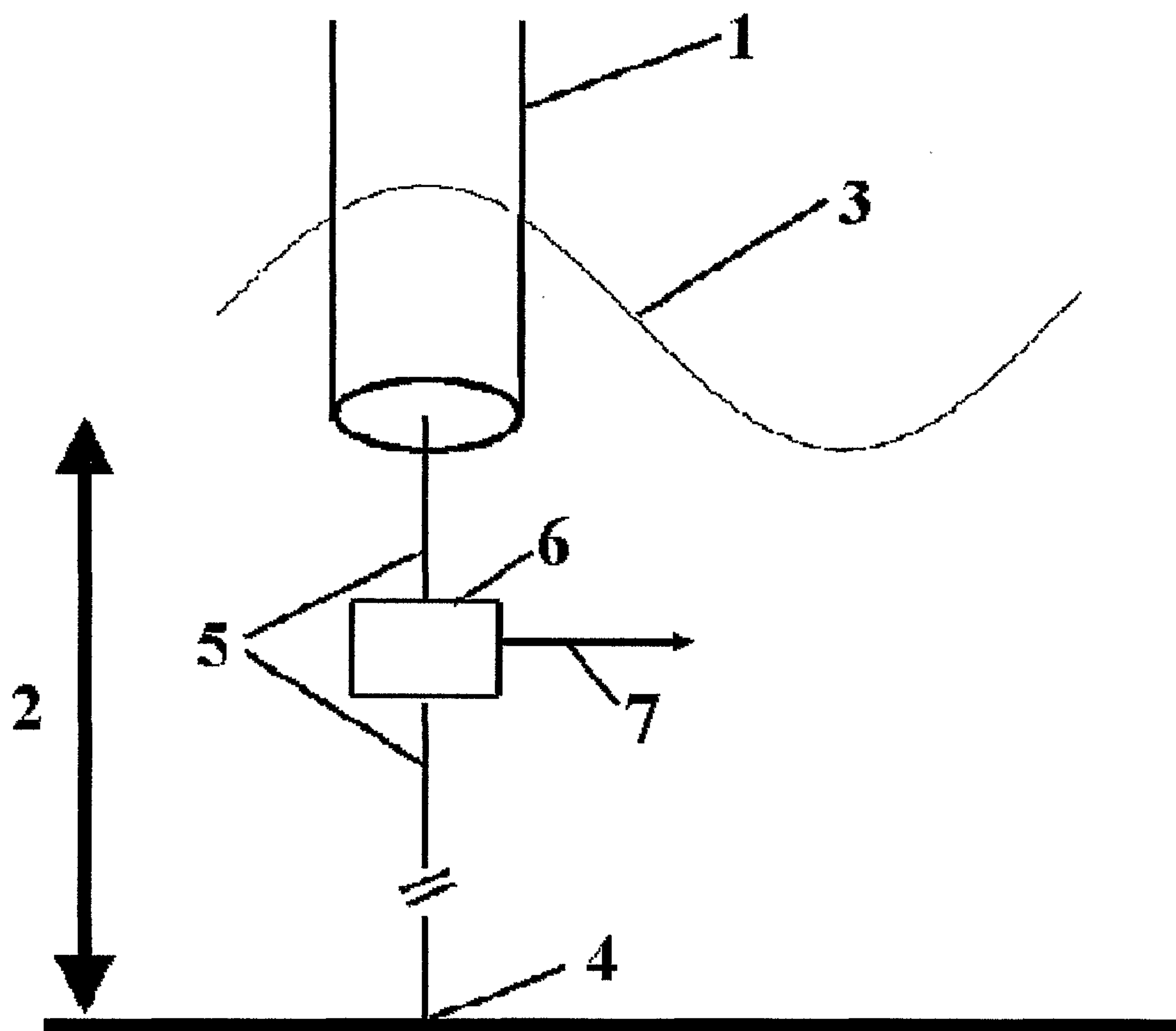
16. The wave energy converter system as claimed in any one of claims 9 to 15, wherein the pipe is a plurality of pipes arranged in at least two sets of plurality of pipes, one set of the pipes being adapted to allow the water to flow in to the interior of the container, and the other set of the pipes being adapted to allow the water to flow out from the interior of the container.

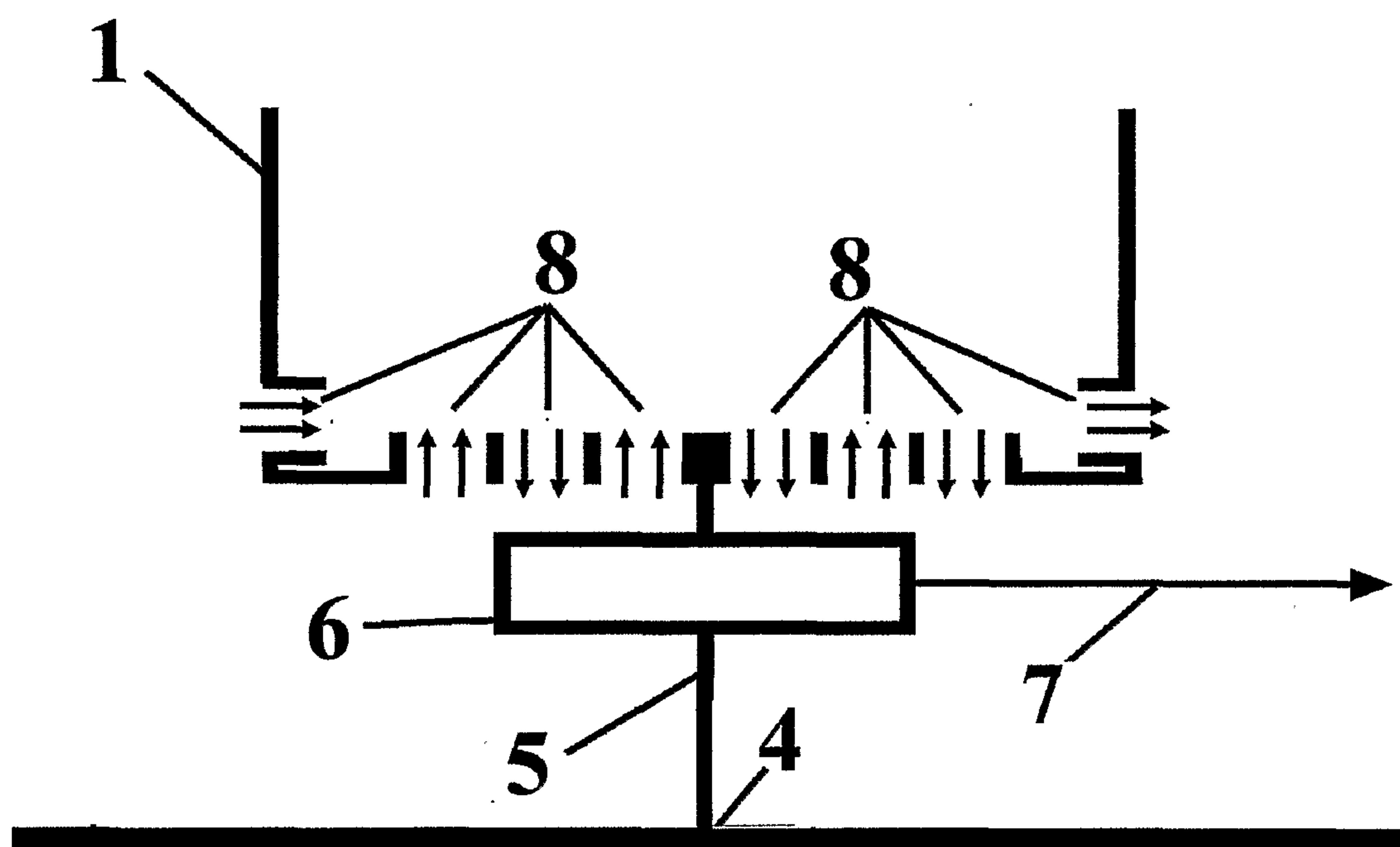
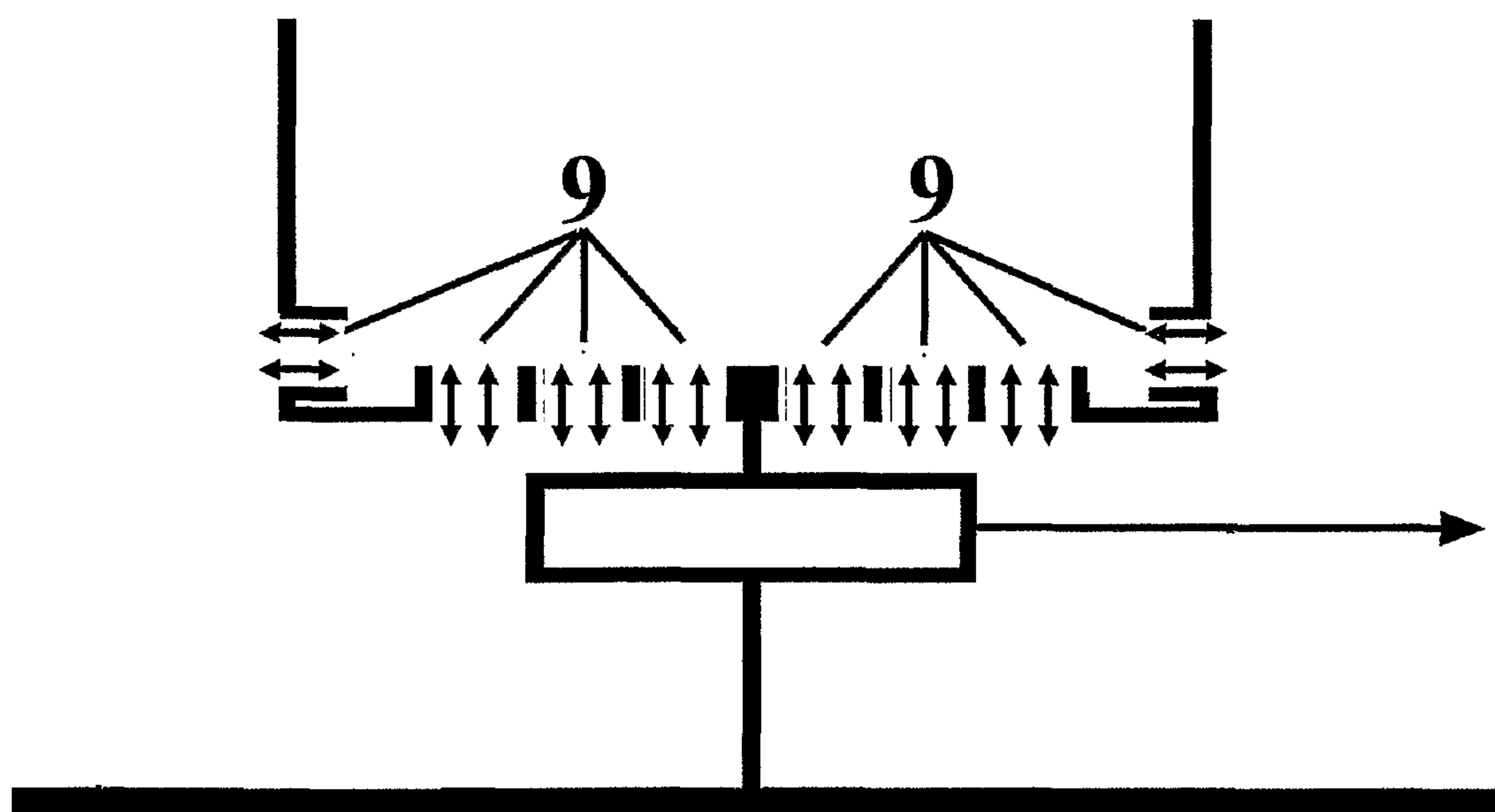
17. The wave energy converter system as claimed in any one of claims 9 to 16, wherein the turbine changes rotation direction dependent on the direction of water flow.

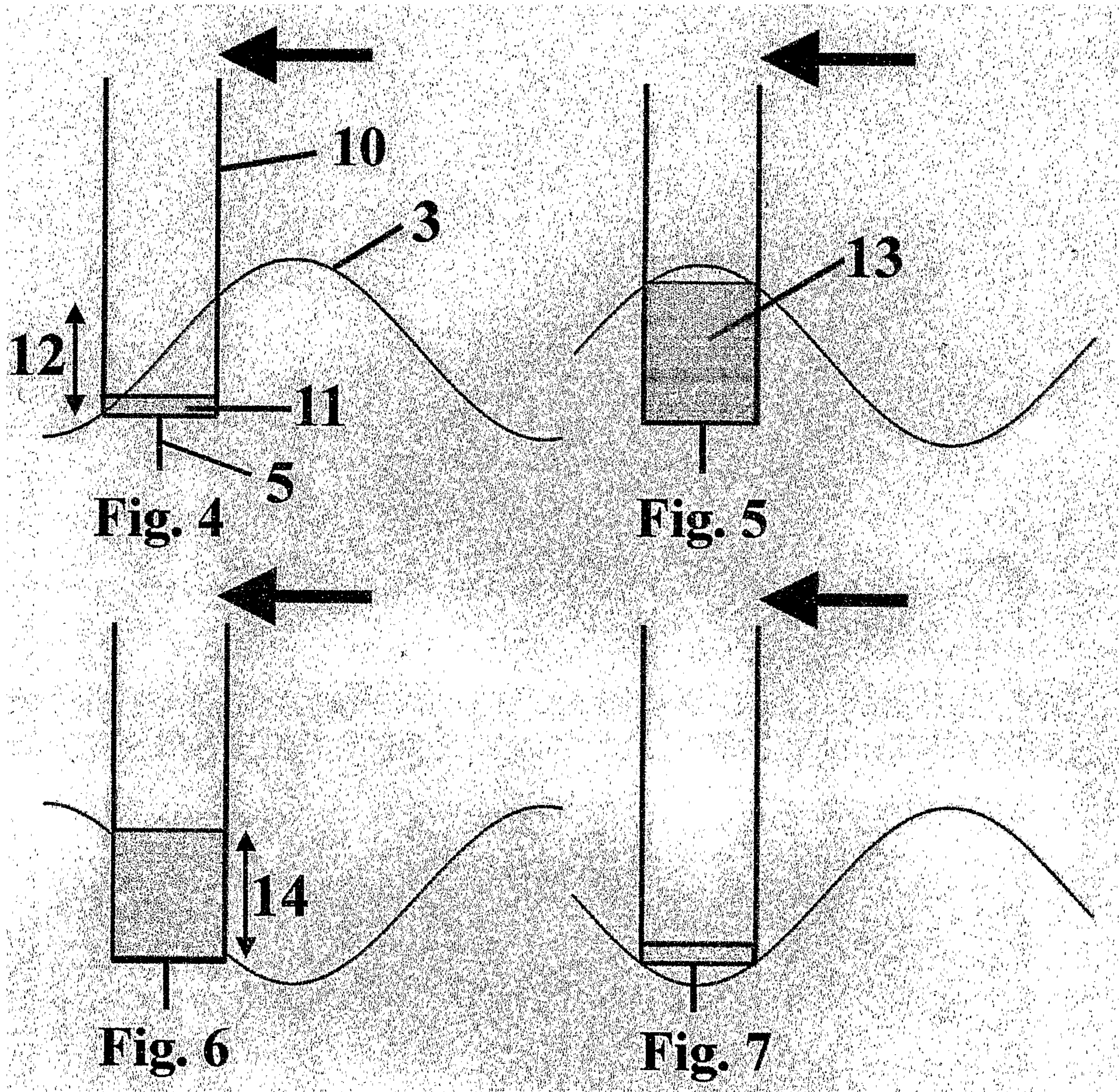
18. The wave energy converter system as claimed in any one of claims 9 to 16, wherein the turbine maintains the same direction of rotation regardless of the direction of water flow, the turbine being composed of blades arranged about a central axis and that are adapted to switch orientation, by changing angle, dependent on the direction of water flow.

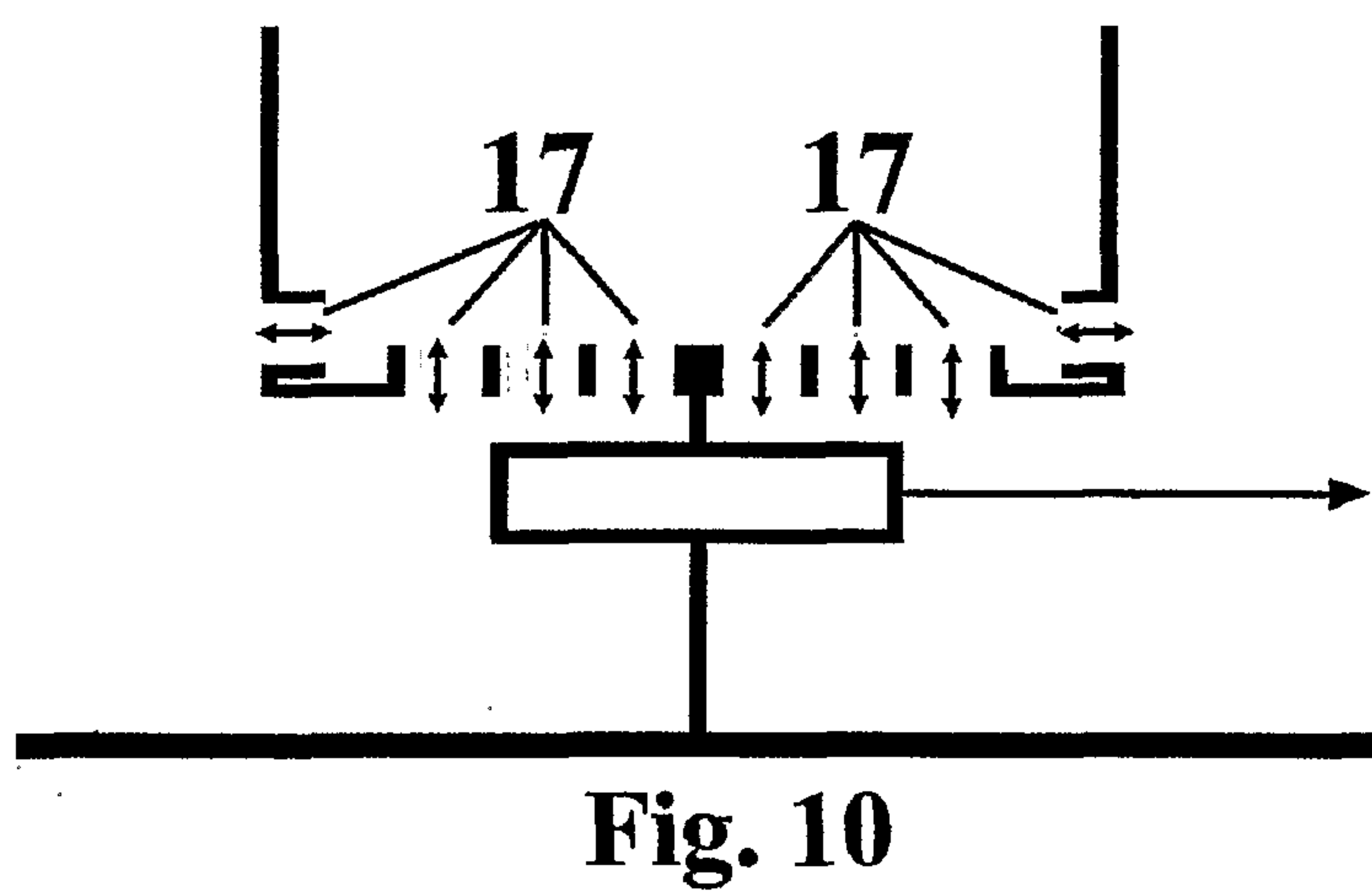
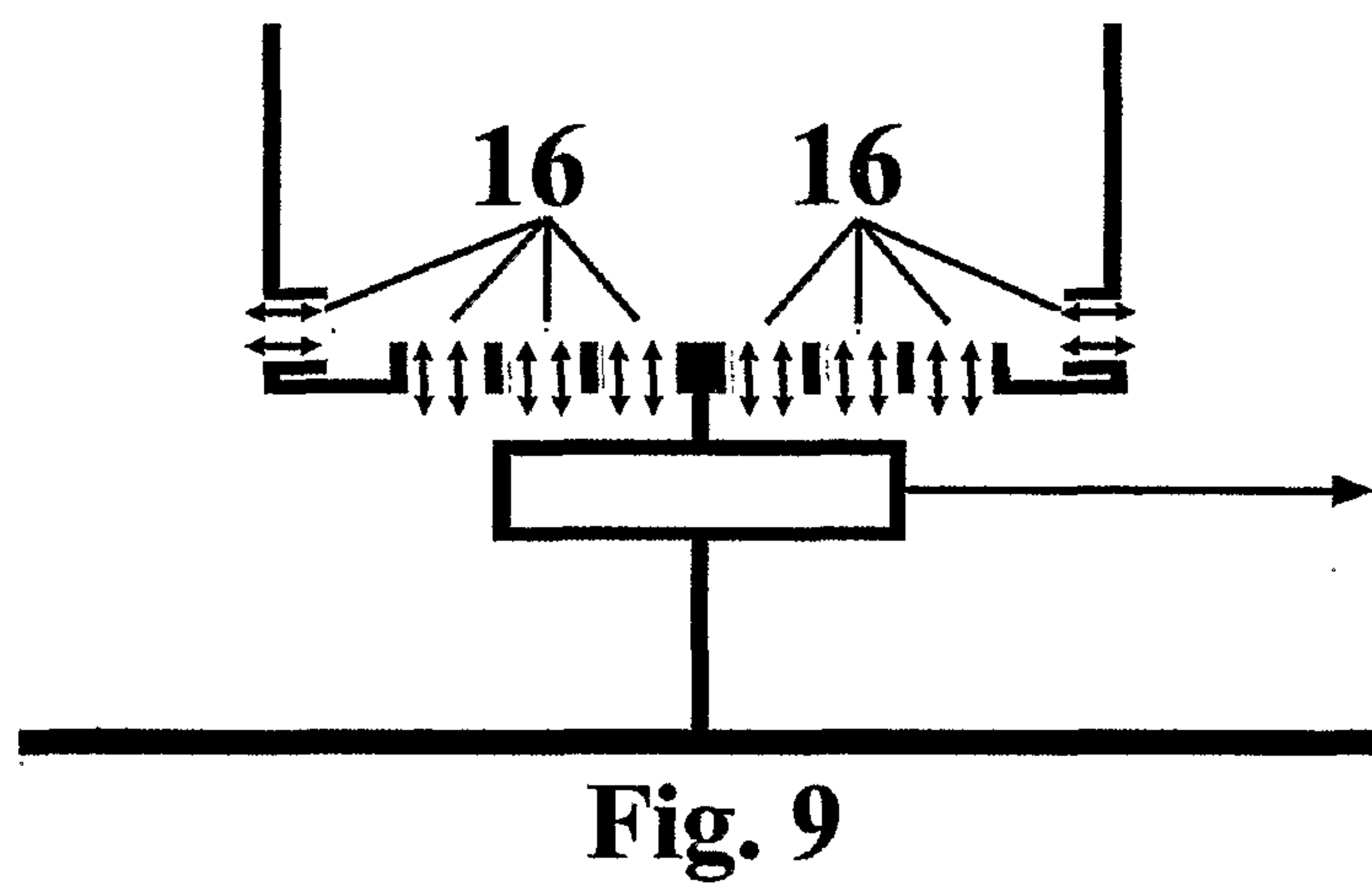
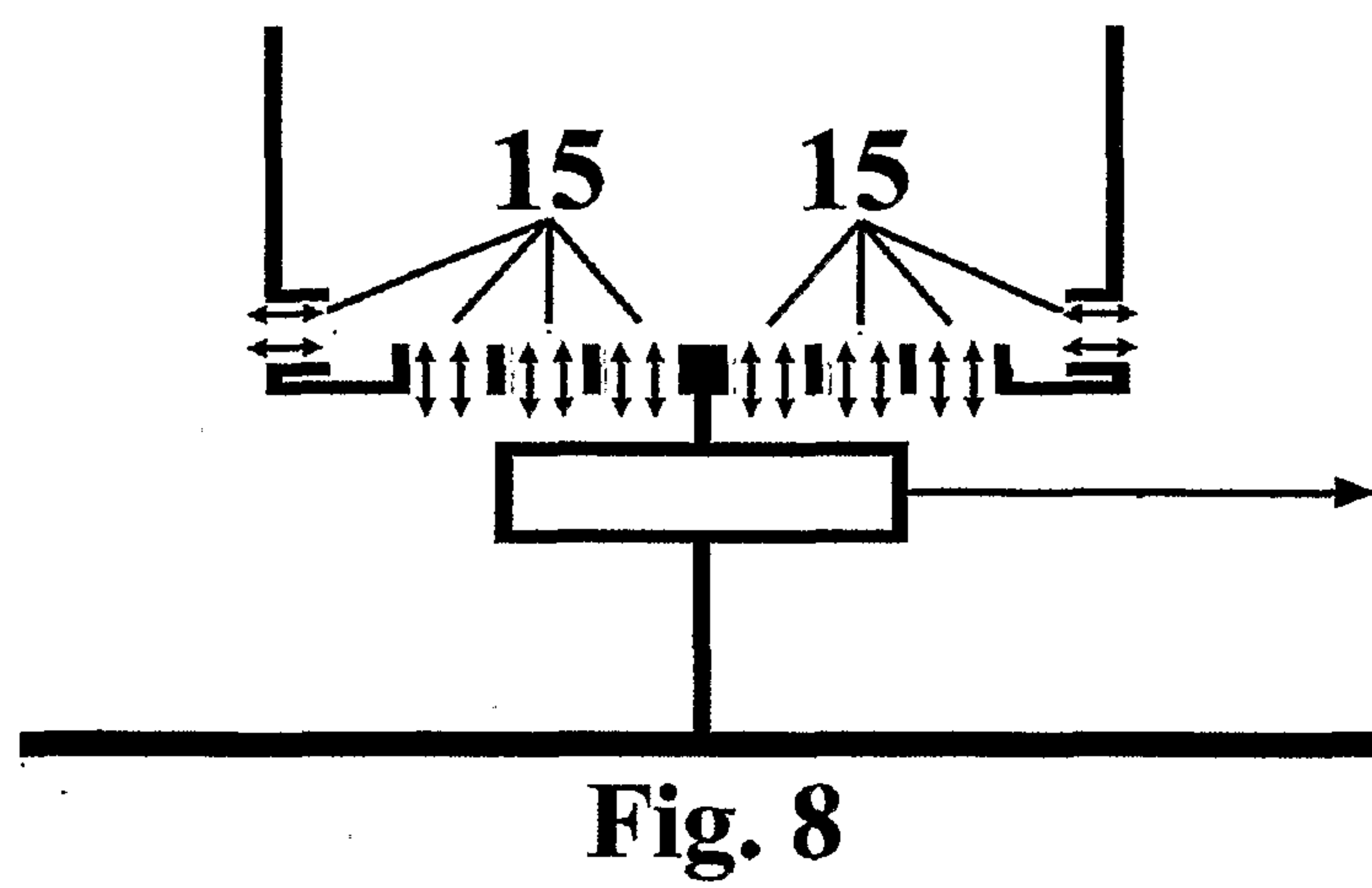
19. The wave energy converter system as claimed in any one of claims 9 to 16, wherein the turbine is a fixed blade turbine composed of two sets of opposing blades orientated around the same axis, and wherein the water is only allowed to flow through either set of blades dependent on flow direction, the force of which being used to cause the rotation of the turbine resulting in the generation of electricity.

20. The wave energy converter system as claimed in any one of claims 9 to 19, wherein the turbine is mountable to the base of the container having circular section, the container and the turbine being adapted to rotate about a central axis.

**Fig. 1**

**Fig. 2****Fig. 3**





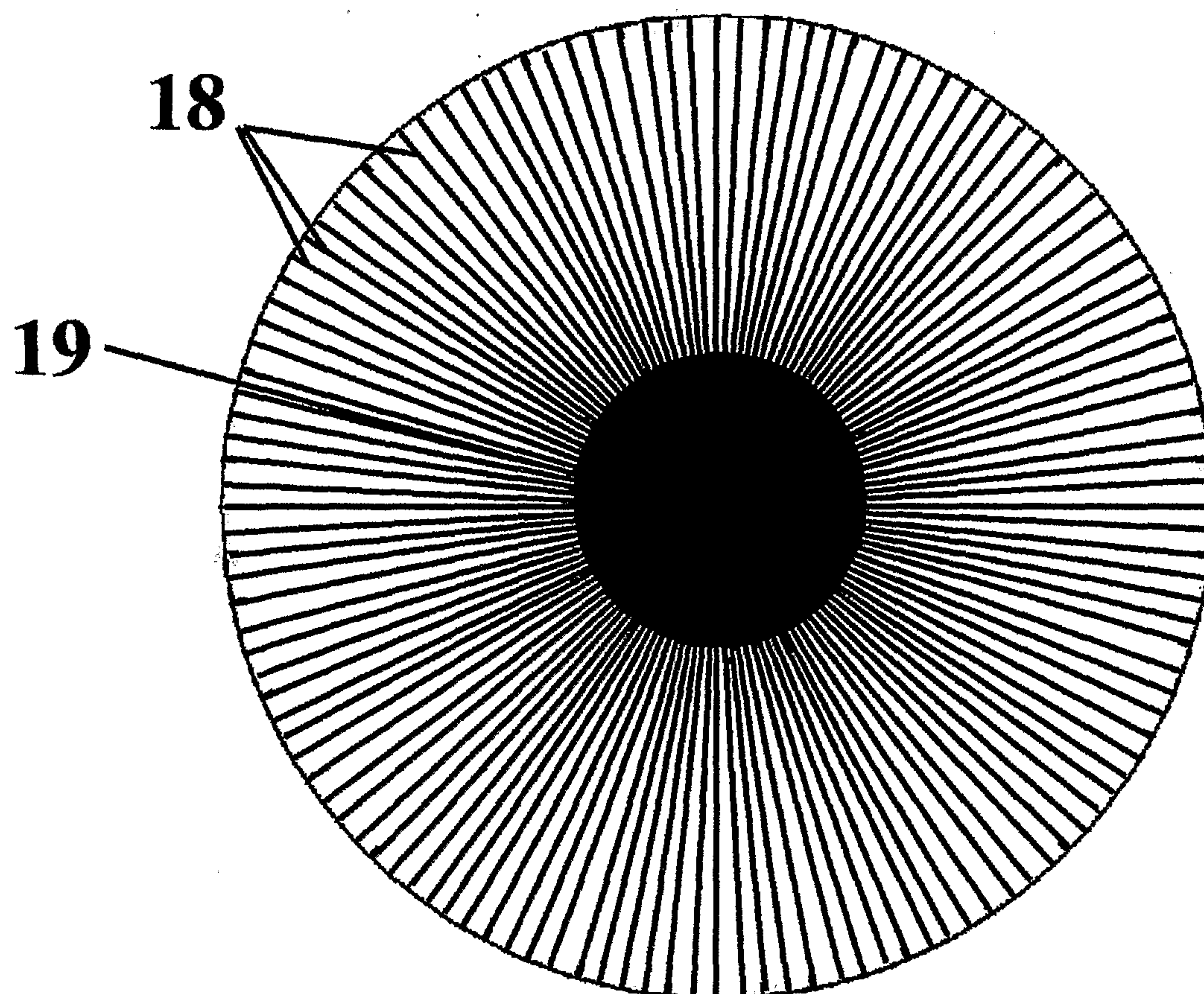
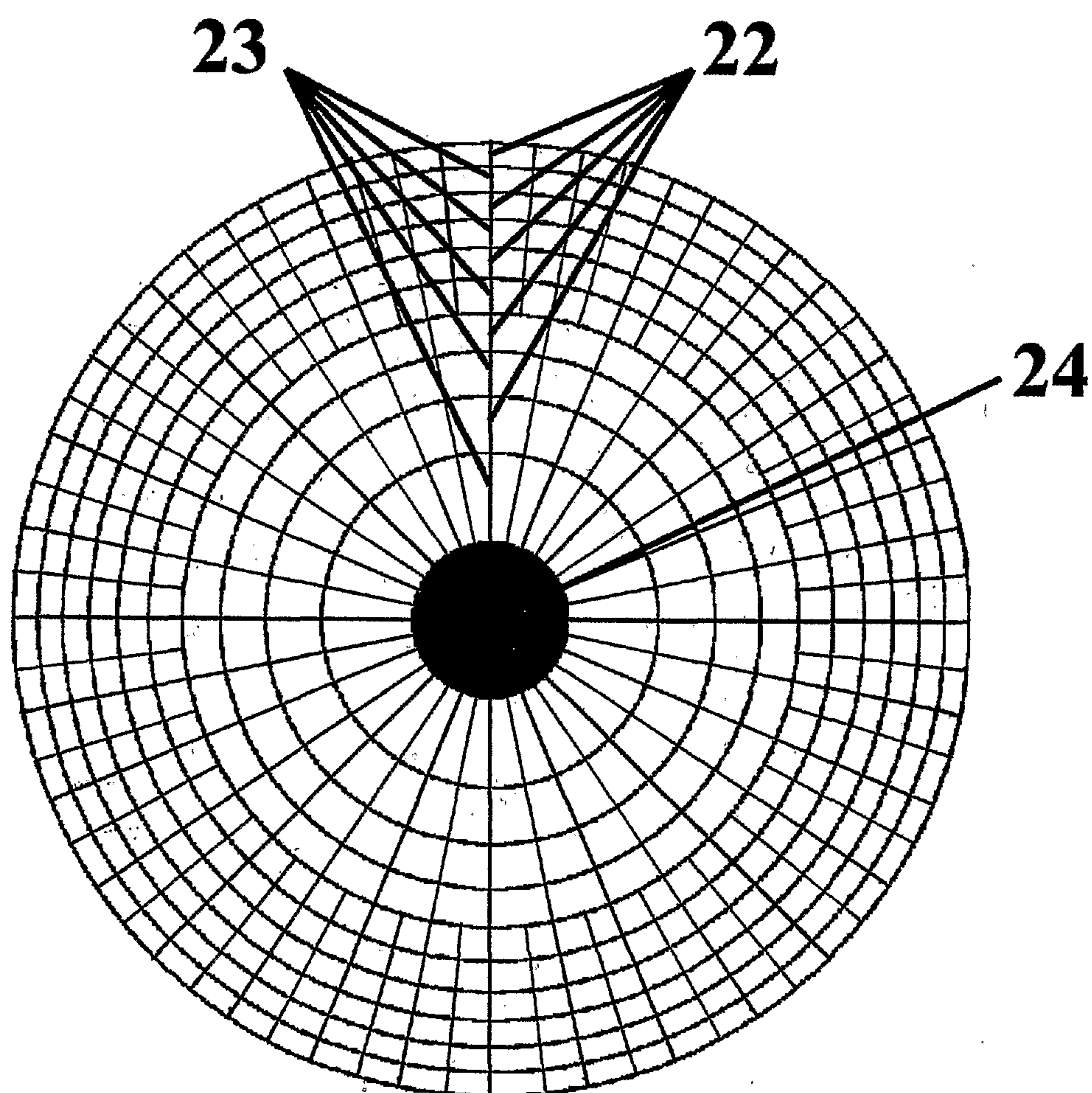
**Fig. 11****Fig. 12****Fig. 13**

**Fig. 14****Fig. 15****Fig. 16**

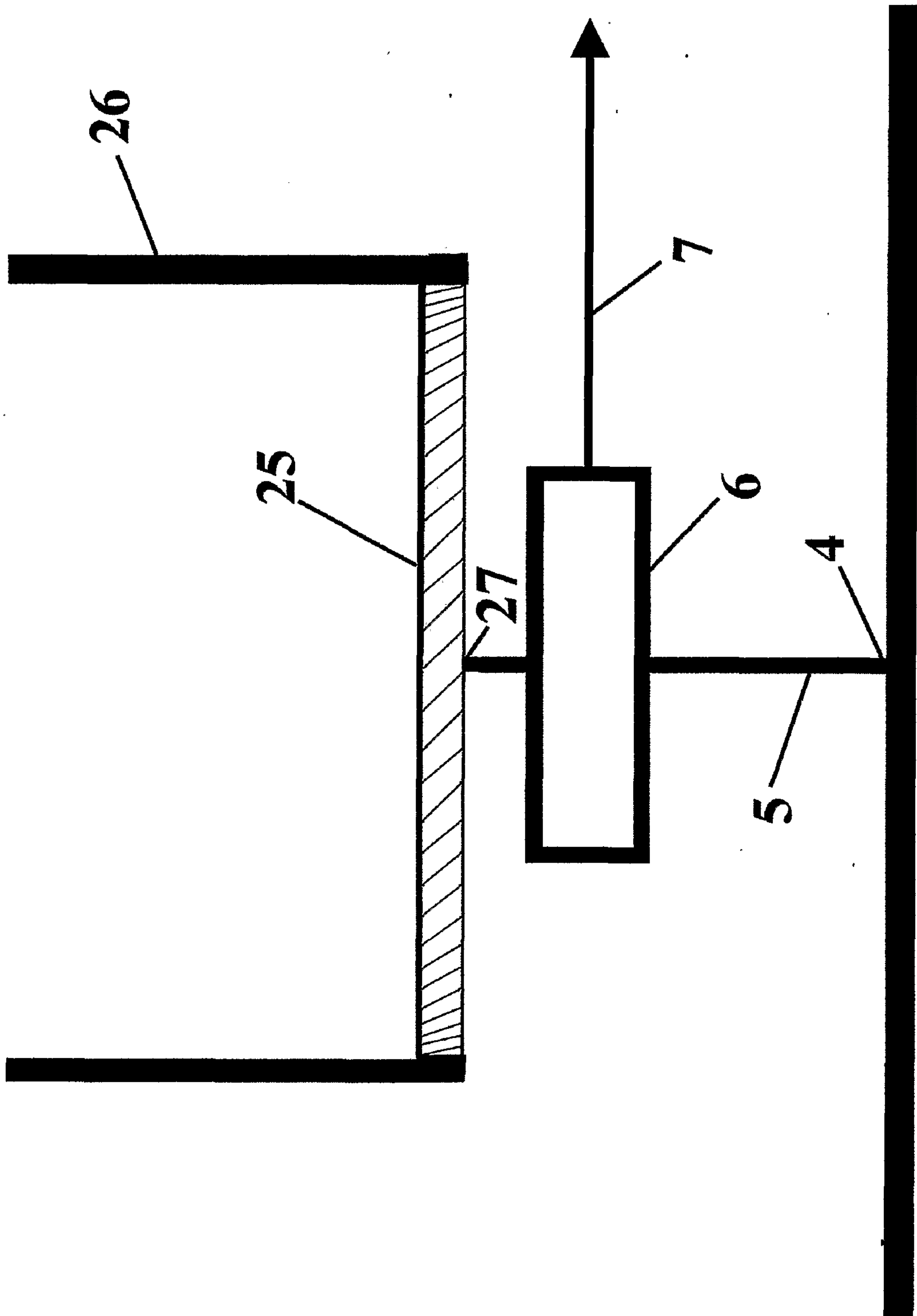
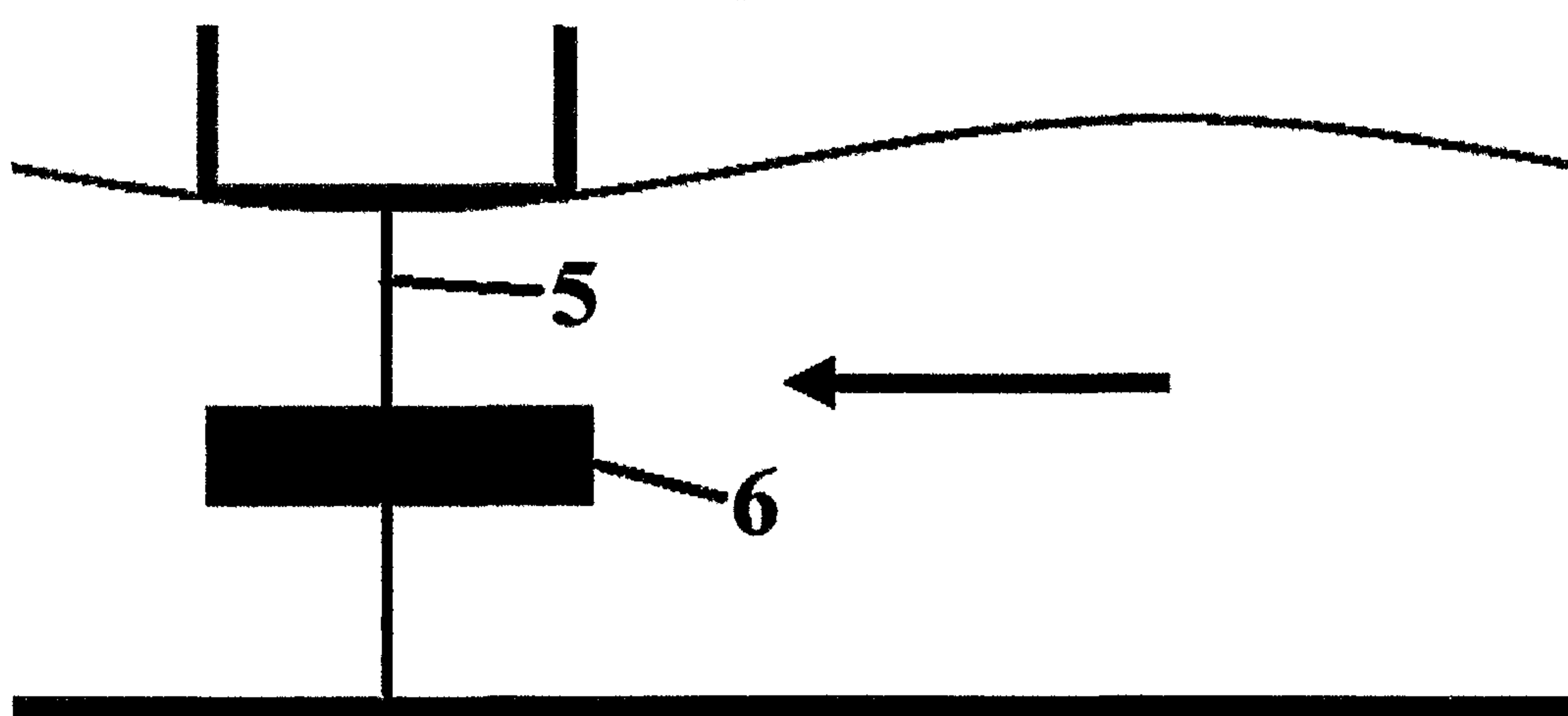
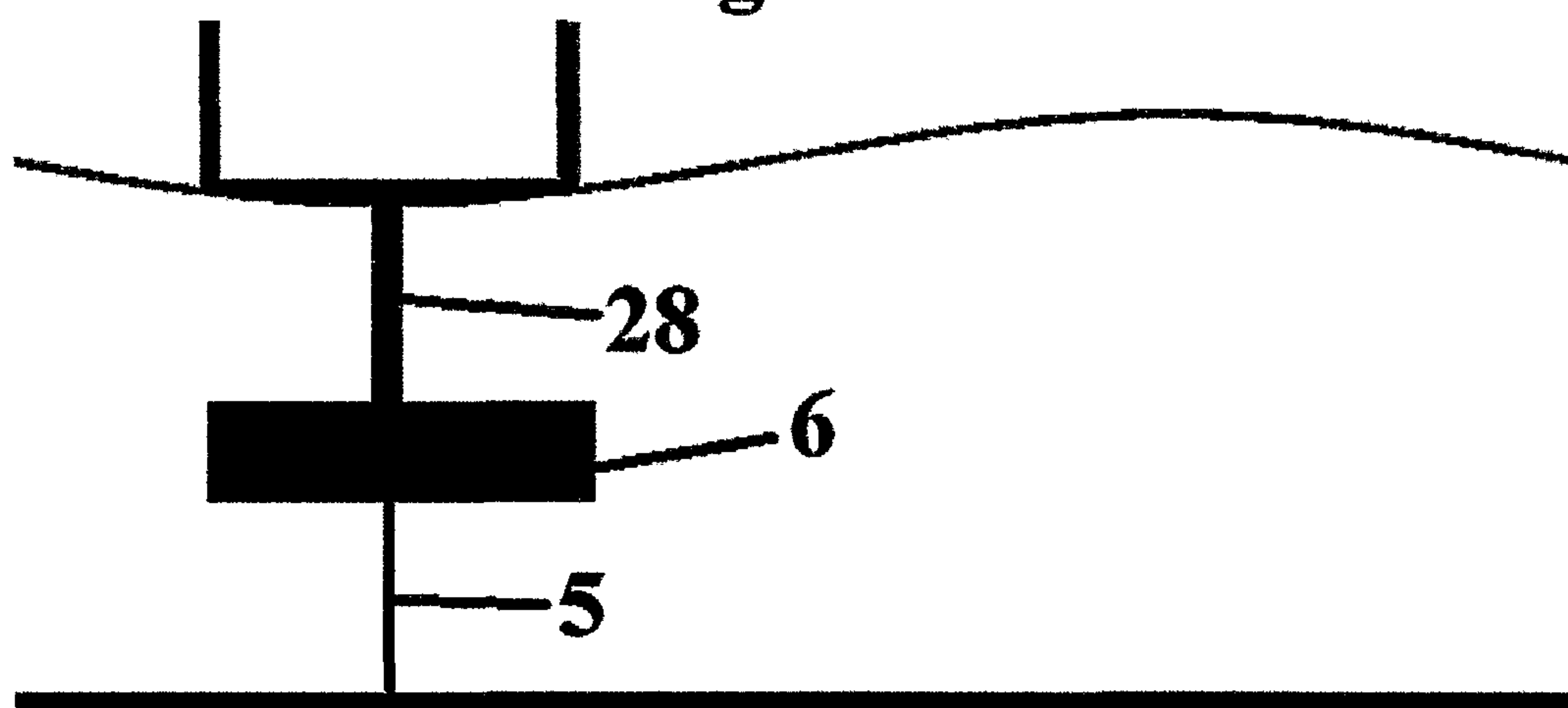
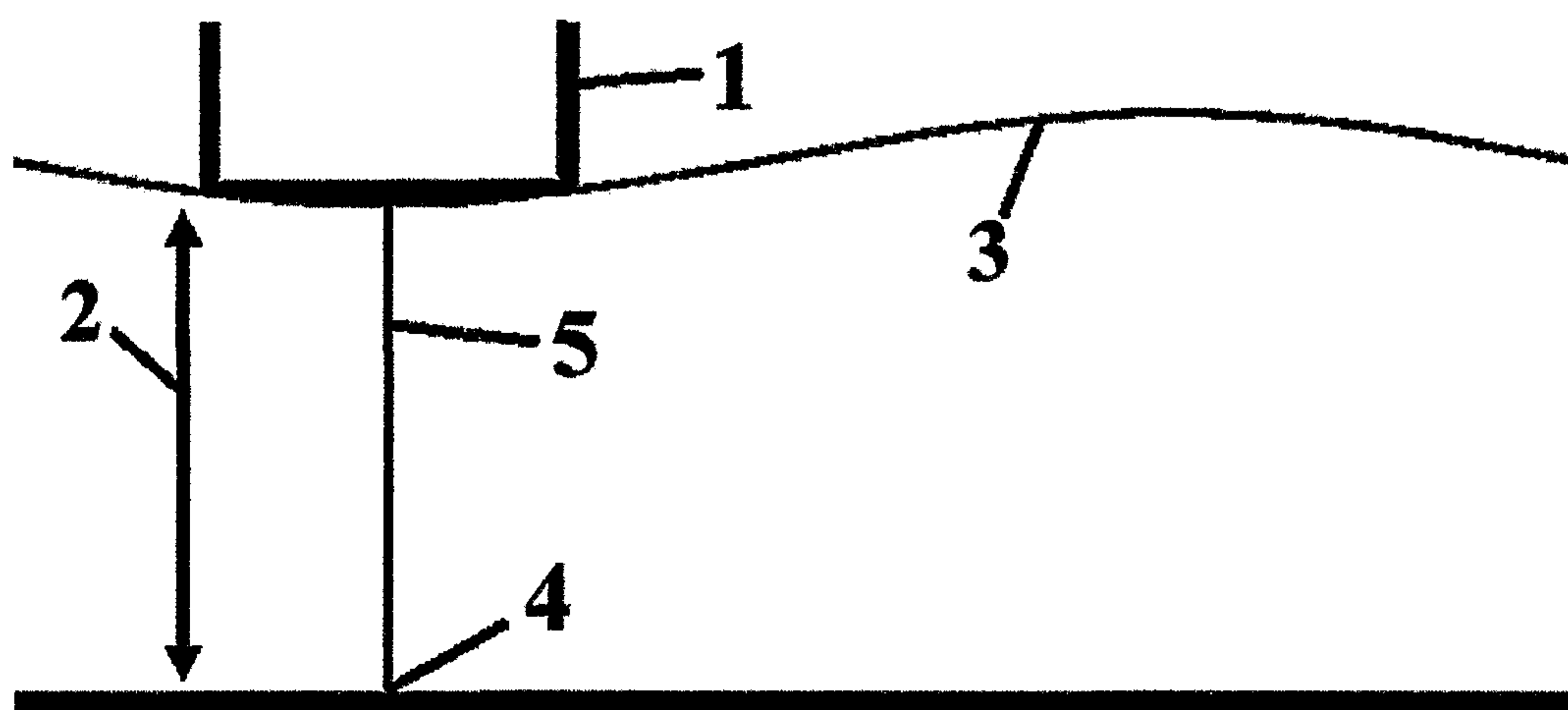
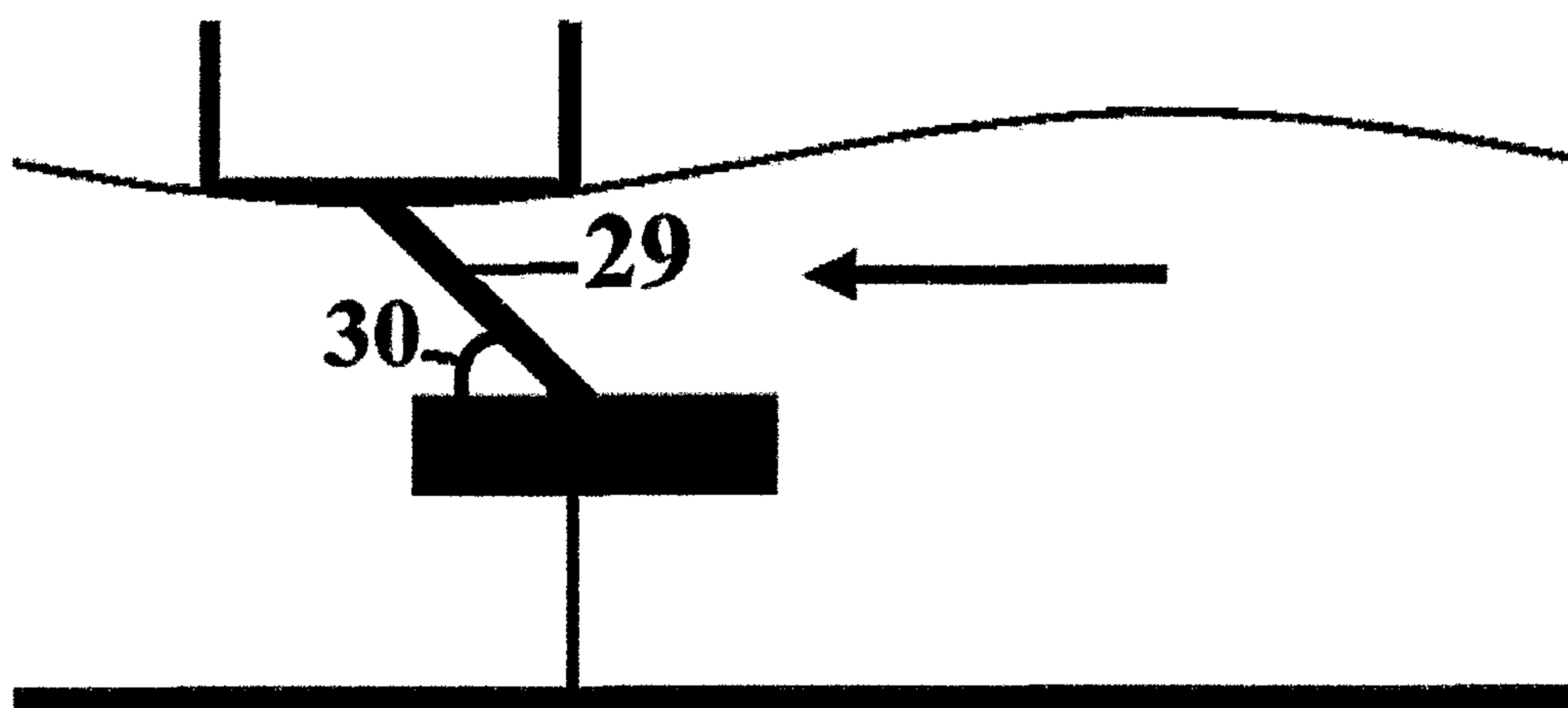
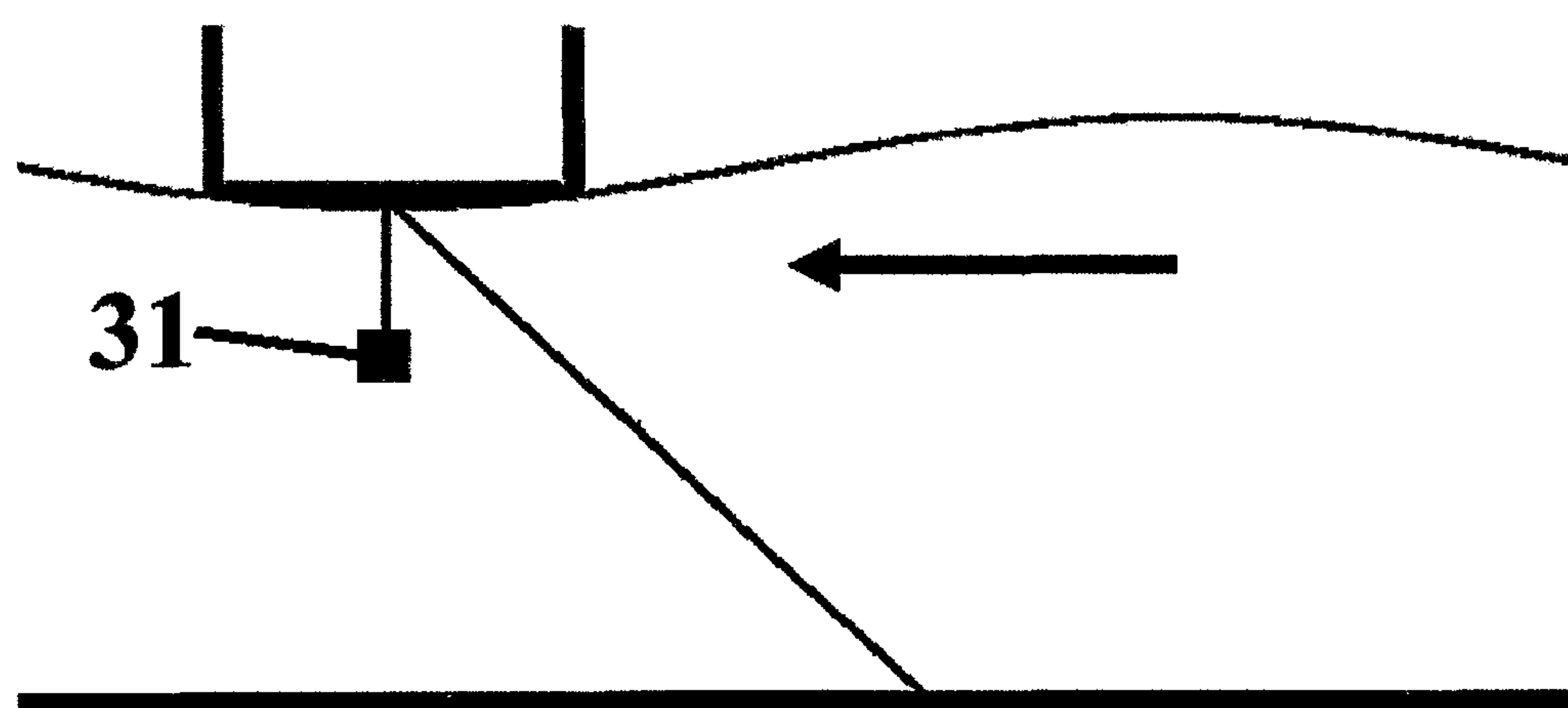
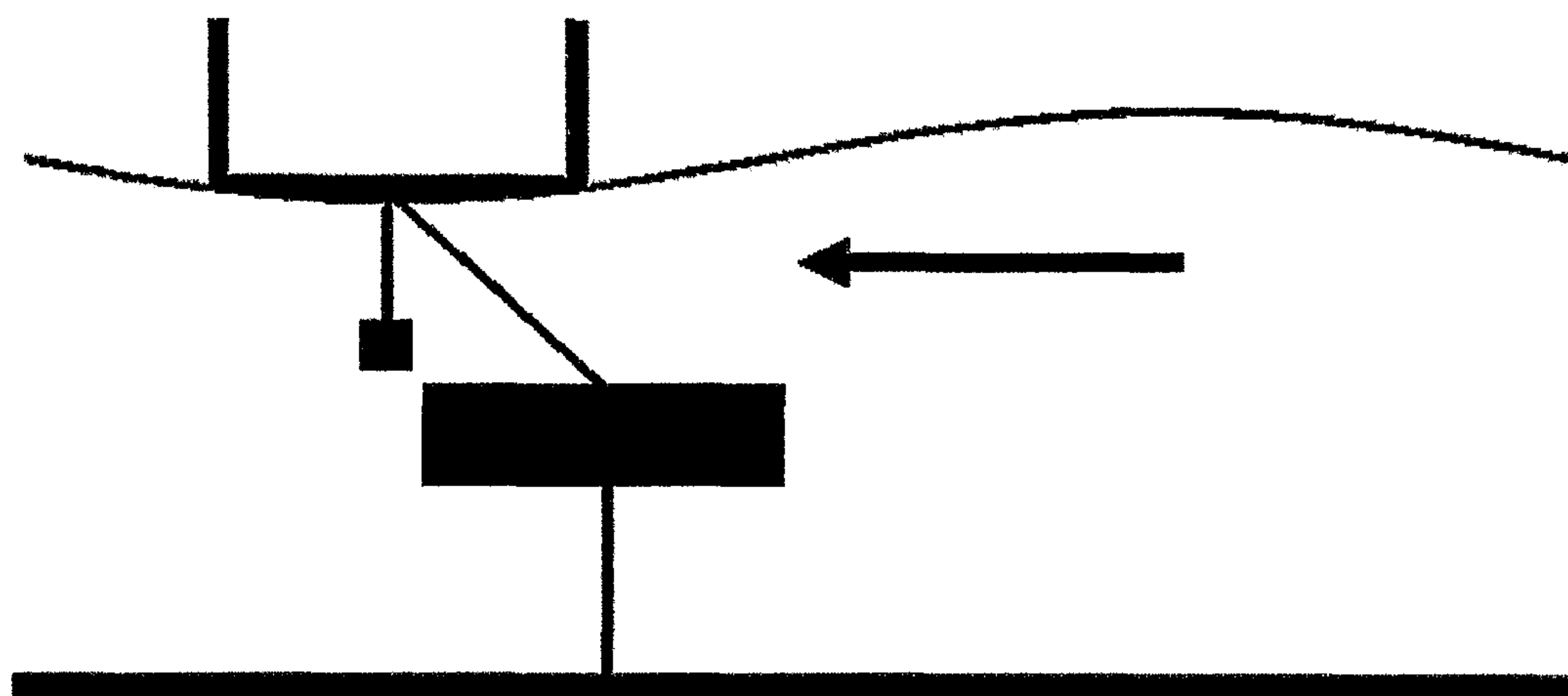
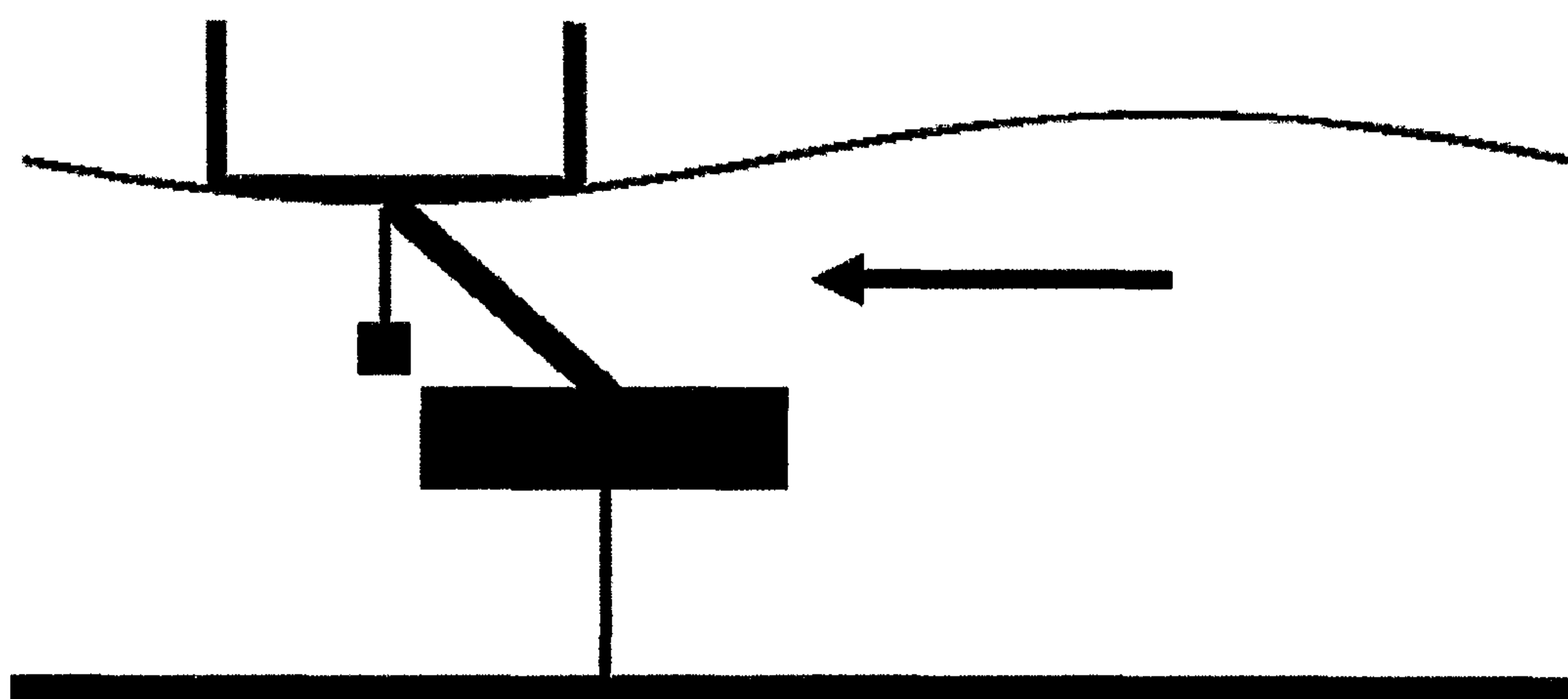


Fig. 17



**Fig. 21****Fig. 22**

**Fig. 23****Fig. 24**

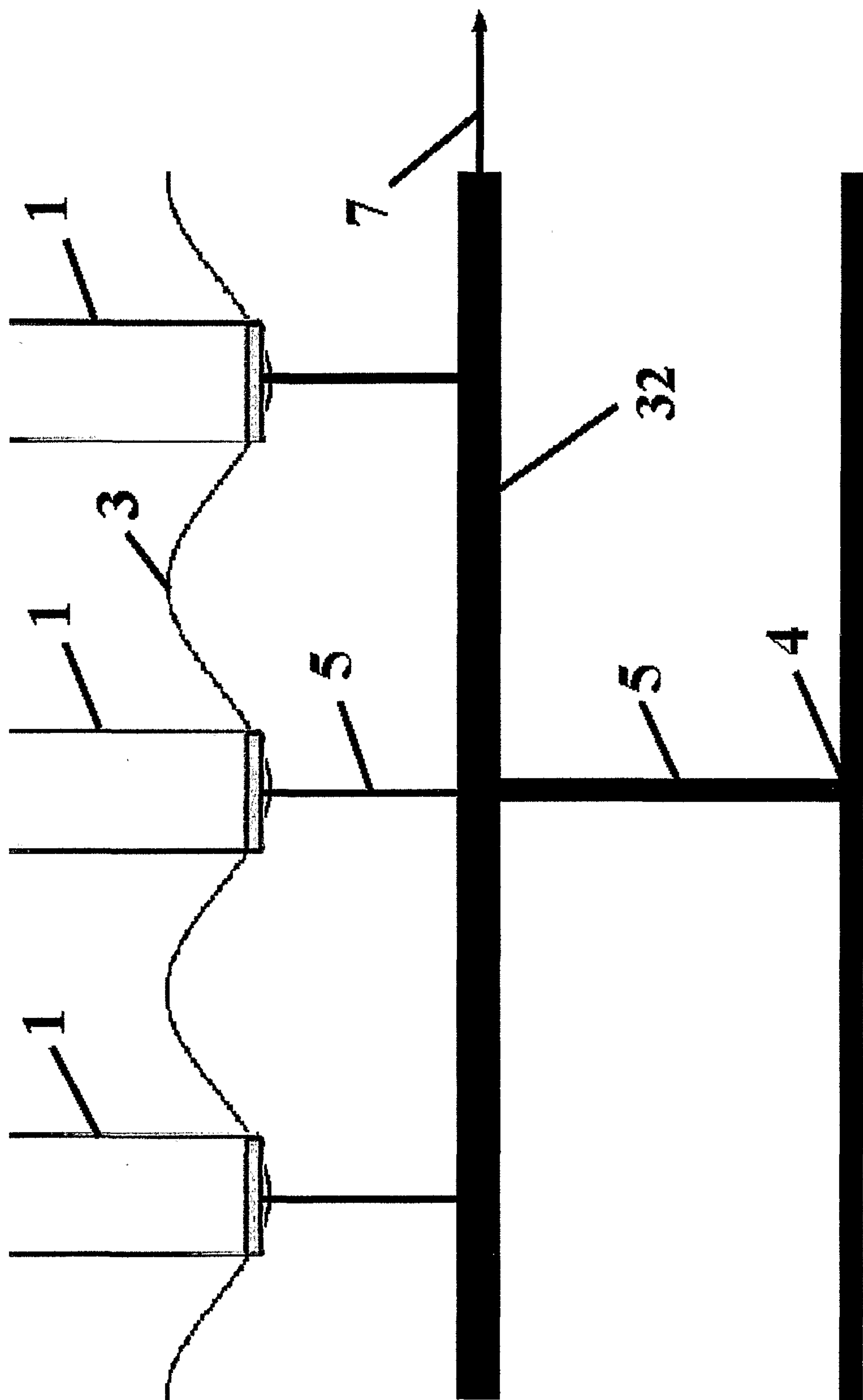


Fig. 25

