(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 748 084 A1**

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
09.12.2020 Bulletin 2020/50

(51) Int Cl.:
E02B 3/04 *(2006.01)* ***G01V 9/00*** *(2006.01)*
E02B 3/18 *(2006.01)*

(21) Application number: **20178851.0**

(22) Date of filing: **08.06.2020**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **08.06.2019 NL 2023282**

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(54) **METHOD AND DEVICE FOR TRANSPORTING SEDIMENT ALONG A BOTTOM OF A WATER MASS**

(57) The invention relates to a method for transporting sediment, particularly sand, along a bottom of a water mass, comprising the steps of:
- placing at least one obstacle at a starting position on the bottom at the position of a flow in the water mass, such that the flow sets a part of the bottom around the at least one obstacle into motion and urges it in a desired transport direction; and
- displacing the at least one obstacle to a subsequent position in the transport direction after some time.

The inventio further relates to a device for performing the method, comprising at least one obstacle placeable on the bottom and means for displacing the at least one obstacle in a desired transport direction.

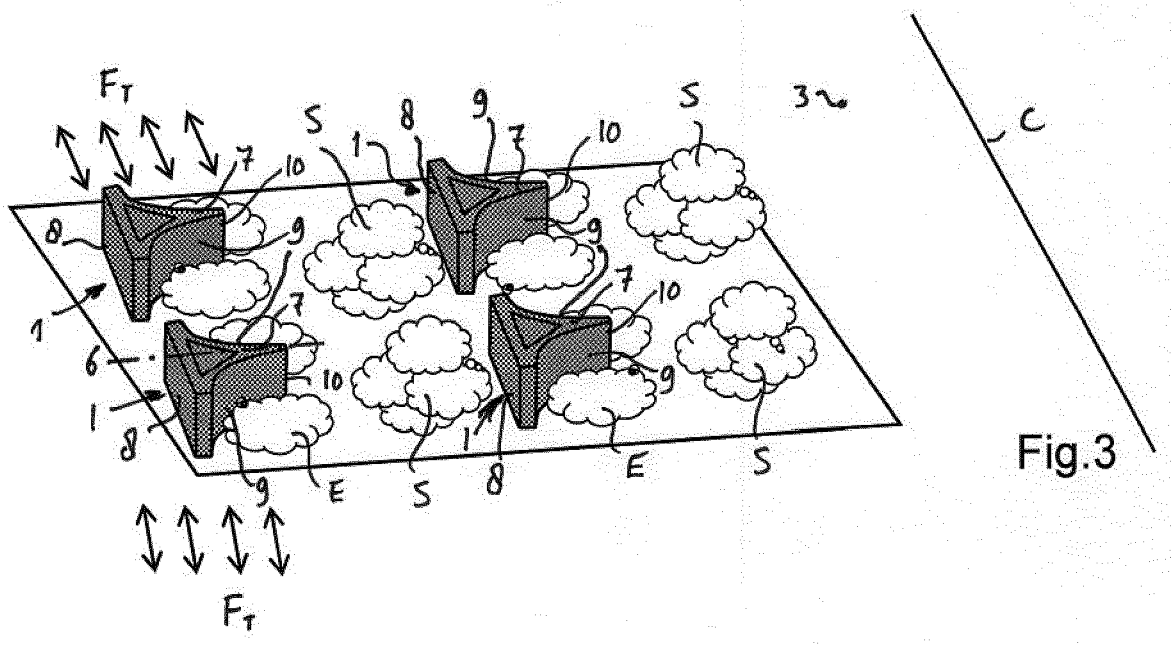

Fig.3

EP 3 748 084 A1

Description

[0001] The invention relates to a method and device for transporting sediment, particularly sand, along a bottom of a water mass. More specifically, the invention relates to a method and device for transporting sand from a deeper-lying part of a seabed to a coast for the purpose of forming a natural sea defence.

[0002] Dunes form a natural sea defence and protect coastal areas lying therebehind. In the past, dunes were created by waves transporting sand to the coast. The generally onshore wind blew the sand landward, where it was captured by vegetation. This is how the dunes were formed and fed for centuries.

[0003] This process gradually came to a standstill because the bottom became deeper as a result of the fact that the sand had been transported to the coast, while the sea level was rising at the same time. The waves were hereby no longer able to mobilize the sediment on the bottom. Sand was hereby no longer supplied from the deeper parts of the coastal foundation - the part of the coastal profile between the 20 m isobath and the 12 m isobath - to the nearshore coastal zone - the part of the coastal profile from the 8 m isobath to the beach.

[0004] The sea level did however continue to rise, whereby the waves above the deeper part were no longer able to set the bottom into motion and were no longer able to generate coastward transport. The supply of sand hereby came to a halt and the waves began attacking the coast rather than building it up. With each storm, sand was washed away, referred to as coastal erosion, but this sand was no longer supplied during calm periods. Over the years, this resulted in erosion of the coast; the phenomenon that, on average, more sand disappeared from a coast section than accumulated there.

[0005] Considering the importance of dunes for coastal protection, the government of the Netherlands decided in 1990 that the coast would be maintained as it was then by means of sand nourishments. The supply of sand which had ceased on the geologic time scale was hereby reinstated in artificial manner. Starting in the nineties, an average of 7 million m^3 of sand is replenished annually in coast sections along the Dutch coast. The sand is extracted in the deeper parts (deeper than -20 m) and brought to the coast.

[0006] The technique of sand nourishment (extraction, transport, nourishment) is an artificial alternative for the loss of a natural constant supply of sand from the shallow marginal sea to the coast. In beach nourishment the sand is pumped to the beach via a pipeline by a trailing suction hopper dredger. Bulldozers distribute the sand further over the beach.

[0007] During previous periods multiple studies have already been carried out into the way sand behaves in the dynamic coastal zone. The European project NOURTEC (NOURishment TEChnology), part of the European research programme MAST (Marine Science and Technology), has shown that underwater shoreface nourishment is highly effective: https://cordis.europa.eu/project/rcn/5620/factsheet/en. Sand which is deposited on the shallow foreshore (at a depth of around 6 m) lies within reach of the waves. The wave forces transport the sand in the direction of the coast. Active beach nourishment by means of pumping sucked-up sand via a pipeline is then not necessary.

[0008] At this point, climate change is intensifying. There is an urgent need to reduce CO_2 emissions. Replenishing the Dutch coast in conventional manner is accompanied by high CO_2 emission. The extraction and transport of the sand with dredging vessels requires a lot of energy, which in the case of dredging vessels is produced by combustion engines running on fuel oil.

[0009] The invention has for its object to provide a method and device with which sand can be replenished with lower CO_2 emission than can be achieved with the conventional nourishment techniques.

[0010] According to the invention, this is achieved in a method as described in the preamble by the steps of:

- placing at least one obstacle at a starting position on the bottom at the position of a flow in the water mass, such that the flow sets a part of the bottom around the at least one obstacle into motion and urges it in a desired transport direction; and
- displacing the at least one obstacle to a subsequent position in the transport direction after some time.

[0011] A sand transport in a determined direction can thus be initiated simply by suitable placing of the at least one obstacle, without using suction elements and pipelines.

[0012] In an application of the method the water mass can be a sea, the flow can be a tidal flow, and the sand can be transported from a deeper-lying part of the seabed in the direction of the coast. The obstacle placed on the bottom thus provides for sand being transported from the deeper parts of the coastal profile in the direction of the coast and thus coming into reach of wave forces which can move the sand further onto the coast. The invention can thus make use of the natural forces which are present in a marginal sea like e.g. the North Sea every day, i.e. tide and waves. The invention is based on the phenomenon of scouring; when an obstacle is placed in the coastal zone, a scour hole results. The tidal flow accelerates around the obstacle and entrains sediment. A scour hole is created at the foot of the obstacle until a determined equilibrium is reached. This principle thus forms the basis of the operation of the invention; placing an object in a coastal zone induces a temporary sand transport.

[0013] In order to accelerate the sand transport in the direction of the coast the step of displacing the at least one obstacle in the transport direction can be repeated multiple times.

[0014] In an embodiment of the method the at least one obstacle is profiled and the profile of the at least one obstacle determines the transport direction. The shape of the obstacle influences the size of this sand transport; a shape which brings about a great acceleration will result in a greater scour hole, and will thus cause a greater sand transport.

[0015] The bottom in the vicinity of the at least one obstacle can be monitored and on the basis of the monitoring it can be determined when the at least one obstacle will be displaced to a subsequent position. The sand transport toward the coast can thus be controlled.

[0016] In order to increase the output and ensure a uniform replenishment of sand a plurality of obstacles can be placed on the bottom in a pattern and be displaced, optionally synchronously.

[0017] The invention also relates to a device for transporting sediment, particularly sand, along a bottom of a water mass, whereby the above described method can be performed. Such a device is provided according to the invention with at least one obstacle placeable on the bottom and means for displacing the at least one obstacle in a desired transport direction. The displacing means can be driven electrically, hydraulically or pneumatically. The displacing means can for instance comprise driven wheels or caterpillars, whereby the obstacle can travel over the bottom. It is also possible to envisage the displacing means comprising displaceable suction anchors with electric pumps, pull rods and a control, whereby it is possible to have the obstacle "walk" over the bottom, as it were.

[0018] As discussed above, the at least one obstacle can be profiled for the purpose of determining the transport direction. The at least one obstacle can particularly have a protruding part which points in the transport direction.

[0019] In order to have the obstacle be effective in two substantially opposite flow directions of the water, for instance in tidal flow, the obstacle can be symmetrical relative to a line running transversely of the flow directions. The shape of the obstacle can thus for instance be substantially triangular, with a base running substantially parallel to the coastline and two oblique sides directed from the base to the coastline and converging in an angular point - or, seen three-dimensionally, an edge. The triangle is a shape which brings about a great acceleration and thus causes a great sand transport.

[0020] The at least one obstacle can have hollow parts on either side of the protruding part. The slightly hollow profile of the oblique sides ensures a uniform guiding of the flow from the base in the direction of the point.

[0021] In order to ensure that the obstacle/the obstacles is/are displaced only at a desired moment and in a desired direction, the device can further be provided with means for at least temporarily anchoring the at least one obstacle to the bottom. These optionally temporary anchoring means can comprise one or more suction anchors.

[0022] The device according to the invention can be provided with means for monitoring the bottom in the vicinity of the at least one obstacle. Such monitoring means can comprise sensors which detect the state of the bottom and on the basis thereof generate a signal that forms a measure of the effectiveness of the obstacle. The sensors can form part of a so-called multibeam echosounder.

[0023] In an embodiment the above described device is further provided with means, connected to the monitoring means, for determining when the at least one obstacle must be displaced to a subsequent position. These determining means can comprise a processor which receives and processes signals from the sensors and on the basis thereof determines that a state of equilibrium has been reached. This happens when the obstacle has been at a determined location for some time, and results in the sand transport coming to a standstill. At that moment the determining means indicate that the obstacle must be displaced.

[0024] As stated above, a uniform sand transport can be achieved when the device is further provided with a plurality of obstacles which can be placed on the bottom in a pattern and can be displaced, optionally synchronously.

[0025] The invention is now elucidated on the basis of an example, wherein reference is made to the accompanying drawings, in which:

Fig. 1 is a cross-section of a coastal profile with a wave-dominated zone and a portion affected by the invention;

Fig. 2 is a perspective view of a coast with an embodiment of the device according to the invention with a single obstacle and the associated sedimentation and erosion patterns;

Fig. 3 is a perspective view of the coast with another embodiment of the device according to the invention with a number of obstacles and the associated sedimentation and erosion patterns;

Fig. 4 is a schematic view of an obstacle on a bottom of a water mass and the deformation of the bottom under the influence of flow of the water mass; and

Fig. 5 is a schematic view of an embodiment of the method according to the invention.

[0026] When an obstacle 1 is placed on a bottom 2 of a water mass (Fig. 4), a flow F of the water mass is hereby in principle disrupted. This disruption of the water flow F results in an accelerated flow along the obstacle 1 and a turbulent wake Z downstream of obstacle 1, whereby sediment, for instance sand, is dislodged from bottom 2. This dislodged sand is entrained by the flowing water mass, and eventually settles at some distance downstream of obstacle 1 when the speed of the water flow becomes low. The dislodged sand can thus be transported over a determined distance. This eventually creates a cavity or scour hole 4 (shown in broken lines) in bottom 2 around obstacle 1, while an accumulation 5 of sand (likewise shown in broken lines) is created further downstream of obstacle 1. The form of the bottom around the obstacle is in equilibrium and corresponds to the flow profile. At positions where the water flows more quickly it is deeper and at sheltered positions it is more shallow.

[0027] This principle forms the basis of the operation of the invention. By placing the obstacle 1 at a different position after some time (shown with broken lines in Fig. 4) such a sand transport can also be caused there. By repeatedly displacing obstacle 1 in the direction of the flow a considerable amount of sand can thus eventually be transported in the flow direction.

[0028] When the flow direction changes however, the transport direction of the dislodged sand will also change. In the case of a tidal flow a full reversal of the flow direction takes place. In order to achieve the same transport direction T of the dislodged sand both in an outgoing tidal flow and an incoming tidal flow (shown with double arrows F_T in Fig. 2 and Fig. 3) obstacle 1 can take a substantially symmetrical form relative to a line of symmetry 6 running substantially transversely of the tidal flow F_T. Obstacle 1 can here have a protruding part 7 which points in the transport direction T.

[0029] In the shown embodiment obstacle 1 is substantially triangular in top view, with a base 8 which is substantially parallel to the incoming and outgoing tidal flows, and two sides 9 which converge in an apex, which is formed in three-dimensional obstacle 1 by an end edge 10. The basic shape of obstacle 1 is here thus an isosceles triangle, albeit that the equal sides are not straight but have a hollow profile. The flow which hits the side 9 lying upstream is hereby deflected evenly in the direction of end edge 10, so in transport direction T. The transport direction T is directed toward the coastline C, and is thus transverse to the tidal flow F_T which runs substantially parallel to the coastline C.

[0030] Owing to the even deflection by means of the side 9 with a hollow profile, the flow is accelerated there and the sand is washed away (erosion, shown schematically by the sand clouds E), after which this sand settles again at some distance coastward from obstacle 1 (sedimentation, designated by the sand clouds S). Due to the symmetrical form of obstacle 1 this phenomenon occurs both during the incoming tidal flow and during the outgoing tidal flow which is opposite thereto. A net sand transport in the desired direction, in this case in the direction of the coastline C, thus results over a full tidal cycle. In order to intensify this effect obstacle 1 can further be provided with flow guides, such as for instance twisted flow edges for setting water flowing past into a swirling motion.

[0031] As stated, an equilibrium will result around obstacle 1 after some time. The form of the bottom around obstacle 1 then corresponds to the flow profile, with deeper parts where the flow speed is higher and shallower parts in the area sheltered by obstacle 1. It is then time to adapt, and displace obstacle 1 over determined distance, for instance a few metres in the direction of the coastline C, so that the accumulated sand S2 is once again swirled up by the tidal flow and is transported further coastward again.

[0032] For the purpose of displacing obstacle 1 displacing means (not shown here) can be provided, for instance in the form of large wheels with which obstacle 1 can travel over bottom 2. Caterpillars can also be envisaged instead of wheels. The wheels or caterpillars can be driven electrically, hydraulically or even pneumatically, although in practice an electric drive is preferred. It is also possible to have obstacle 1 "walk" over bottom 2 by means of displaceable suction anchors with electric pumps, pull rods and a control, which together can form the displacing means. The electrical energy required for the displacement can be generated by solar panels or wind turbines and can be stored in batteries.

[0033] When obstacle 1 is placed at a determined position it must remain there until a state of equilibrium has been reached. For this purpose obstacle 1 takes a heavy form in the shown embodiment, for instance of stainless steel or composite material weighted with concrete. When the weight of obstacle 1 is insufficient to keep it in place, the obstacle can also be provided with anchoring means (not shown here either), for instance in the form of one or more suction anchors. These suction anchors can simultaneously play a part in the displacement of obstacle 1, as described above.

[0034] In order to determine when obstacle 1 must be displaced an electronic control system can be used (not shown here). This control system can co-act with sensors (not shown here either) that monitor the changes in bottom 2, and can determine on the basis of signals from these sensors when a situation of equilibrium of bottom 2 has resulted and how far obstacle 1 must then be shifted. As stated, use can for instance be made for this purpose of a multibeam echosounder.

[0035] With a view to safety, the device must have sufficient signalling for transiting shipping traffic and for fishery. For this purpose it is necessary for a part of obstacle 1 to protrude above water. This can however be a slender part, for instance masts or a frame, which experiences little resistance from the waves.

[0036] In order to be able to increase the transport capacity of the device a plurality of obstacles 1 can be placed in each other's vicinity in a pattern (Fig. 3). These obstacles 1 can be displaced either synchronously or in a determined order in the direction of the coast C, somewhat in the manner of a crab moving its legs. The device is therefore also referred to as "sand crab".

[0037] Depending on the sand nourishment requirement, such devices can be placed at multiple locations in the coastal zone, whereby coastward transport of sand occurs at multiple locations.

[0038] The steps of the method according to the invention are summarized in Fig. 5. Obstacle 1 is in the first instance placed at a determined position on the bottom 2 of a water mass 3, for instance the seabed close to the coast (step 100). The obstacle 1 can then be anchored at that position (step 101). The flow is affected as a result of the presence of obstacle 1, whereby sand is dislodged from bottom 2 in the desired direction, is for instance transported to the coast. The state of the bottom 2 around obstacle 1 is monitored continuously (step 102). On the basis of data from this monitoring it is determined whether a state of equilibrium has been reached (step 103). If this is not yet the case, the state is monitored further (step 102). If it is determined that an equilibrium has been reached, obstacle 1 is displaced over a determined distance (step 104). At the new position the obstacle 1 is anchored once again (step 101) and the transport of sand continues.

[0039] The device according to the invention is thus not a static apparatus; it is an apparatus that advances slowly. The speed of movement is determined by the speed at which the situation of equilibrium of the bottom is reached. In the case of turbulence due to high waves and in the case of spring tide the state of equilibrium will be reached sooner than in the case of low waves and slack water. The displacement of the obstacle must thus be determined by a mechanism which measures the changes in the bottom around the obstacle.

[0040] As stated, this technique provides for an integral transport of sand. Very strictly speaking, all three stages of conventional sand nourishment by means of suctioning, pumping and distributing sand are included;

1. Extraction; if extraction means mobilizing sand and readying it for transport, then the mechanism of scouring is the same as extraction.
2. Transport; the asymmetrical form of the obstacle results in transport of sand toward the coast.
3. Nourishment; scouring is local and the sand will automatically settle some distance from the obstacle.

[0041] The sequence "extraction-transport-nourishment" has hereby become a continuum.

[0042] The invention can be applied to any sandy coast that experiences tidal flow. It can be applied to the portion 11 of the coastal profile (Fig. 1) where the waves usually do not generate coastward sand transport because it is too deep there. The waves present will intensify the principle. Depending on how robustly the system is embodied and on the scale, the system can work continuously; it 'stands' (or actually crawls) in the coastal zone and, owing to the two flow-guiding sides, the device moves a volume of sand in the direction of the coastline C during every outgoing and incoming tidal flow. In the wave-dominated zone 12 of the coastal profile the waves take up the transport function.

[0043] The invention could also work in a situation in which water constantly flows in the same direction, for instance in a river. The obstacle would then not need to have a flow-favouring profile form on two sides, but only on one side.

[0044] The environmental impact of the method and device according to the invention is minimal. The device according to the invention is a large and heavy installation which advances, electrically driven, in the direction of the coast at a low speed determined by an electronic system. The device generates only minimal emissions here. The only environmental impact is the construction, placing and displacing of the device. Following a cycle of 'crawling towards the coast' the device must be displaced toward the sea again.

[0045] The method and device according to the invention are particularly cost-effective; the costs lie mainly in the construction of the device. The operational costs are limited; once it has been placed in the sea, the device can do its work almost passively, and so at minimal cost.

[0046] The invention makes it possible to bring about a coastward sand transport in a semi-passive manner. This sand transport is not large-scale, but is present continuously with every outgoing and incoming tidal flow. The device can be scaled up in simple manner. The ideal scale depends on the hydraulic regime and on the sand characteristics. The invention can in any case be scaled up per installation - for instance a device with 8 obstacles or with 20 obstacles - but also in number, by placing more devices per coast section. All this also depends on the influence of the obstacles on each other.

[0047] The device according to the invention is reliable since it is a relatively simple installation with few movable parts.

[0048] Robustness is a design requirement for the device. The device must be seaworthy in the coastal zone seaward of the surf zone in extreme conditions. The device is embodied with suction anchors which are activated at least in the event of extreme storms. The device does not enter the surf zone, but conversely ensures that the sand is transported from deeper-lying parts of the coast in the direction of the surf zone. There, the waves take over; the wave-driven sand transport which provides for the build-up of a coast.

[0049] Although the invention is described above on the basis of a number of embodiments, it will be apparent that it is not limited thereto and can be varied in many ways within the scope of the following claims.

Claims

1. Method for transporting sediment, particularly sand, along a bottom of a water mass, comprising the steps of:

- placing at least one obstacle at a starting position on the bottom at the position of a flow in the water mass, such that the flow sets a part of the bottom around the at least one obstacle into motion and urges it in a desired transport direction; and
- displacing the at least one obstacle to a subsequent position in the transport direction after some time.

2. Method according to claim 1, wherein the step of displacing the at least one obstacle in the transport direction is repeated multiple times.

3. Method according to claim 1 or 2, wherein the at least one obstacle is profiled and the profile of the at least one obstacle determines the transport direction.

4. Method according to any one of the foregoing claims, wherein the bottom in the vicinity of the at least one obstacle is monitored and it is determined on the basis of the monitoring when the at least one obstacle will be displaced to a subsequent position.

5. Method according to any one of the foregoing claims, wherein a plurality of obstacles are placed on the bottom in a pattern and are displaced, optionally synchronously.

6. Method according to any one of the foregoing claims, wherein the water mass is a sea, the flow is a tidal flow, and the sand is transported from a deeper-lying part of the seabed in the direction of the coast.

7. Method according to claims 3 and 6, wherein the at least one obstacle is profiled such that the transport direction in incoming tidal flow is substantially the same as the transport direction in outgoing tidal flow.

8. Device for transporting sediment, particularly sand, along a bottom of a water mass, comprising at least one obstacle placeable on the bottom and means for displacing the at least one obstacle in a desired transport direction.

9. Device according to claim 8, wherein the at least one obstacle is profiled for the purpose of determining the transport direction.

10. Device according to claim 9, wherein the at least one obstacle has a protruding part which points in the transport direction.

11. Device according to claim 9 or 10, wherein the obstacle is symmetrical relative to a line running transversely of two substantially opposite flow directions of the water mass.

12. Device according to claims 10 and 11, wherein the at least one obstacle has hollow parts on either side of the protruding part.

13. Device according to any one of the claims 8-12, further provided with means for at least temporarily anchoring the at least one obstacle to the bottom.

14. Device according to any one of the claims 8-13, further provided with means for monitoring the bottom in the vicinity of the at least one obstacle.

15. Device according to claim 14, further provided with means, connected to the monitoring means, for determining when the at least one obstacle will be displaced to a subsequent position.

16. Device according to any one of the claims 8-15, further provided with a plurality of obstacles which can be placed on the bottom in a pattern and can be displaced, optionally synchronously.

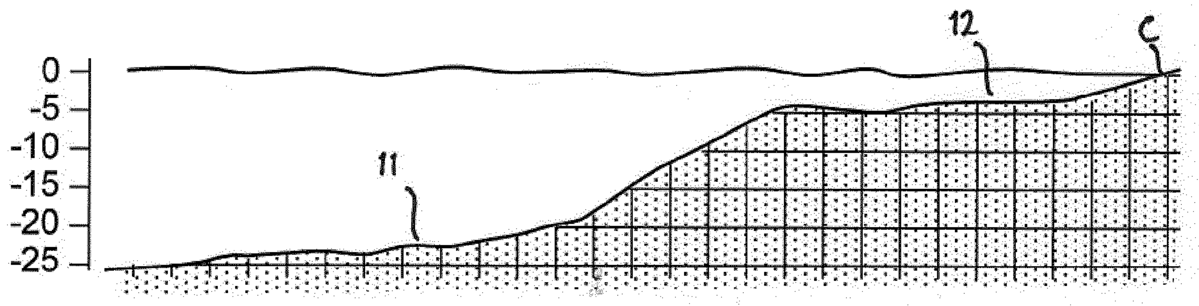

Fig.1

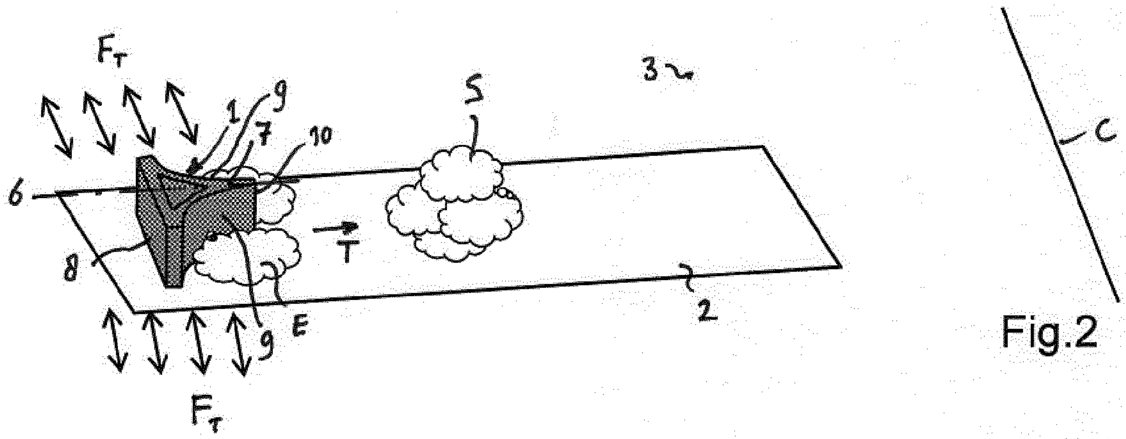

Fig.2

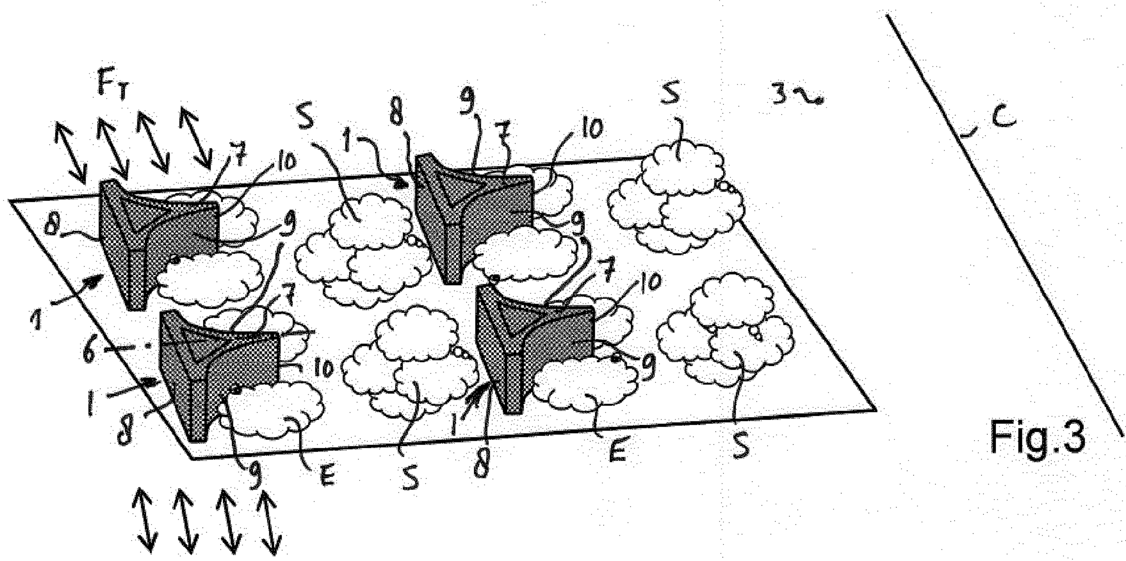

Fig.3

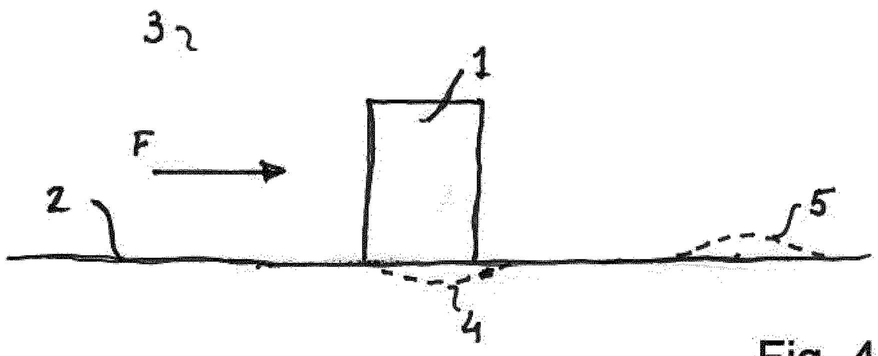

Fig. 4

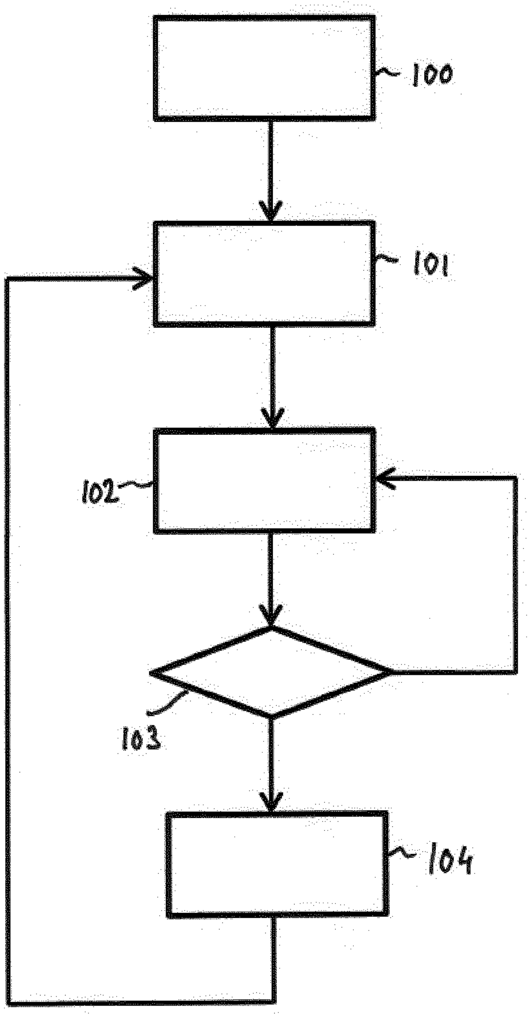

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 20 17 8851

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2012/315090 A1 (FARRELL JR JOSEPH EDWARD [US]) 13 December 2012 (2012-12-13) * paragraph [0023] - paragraph [0054]; figures *	1-16	INV. E02B3/04 G01V9/00 ADD. E02B3/18
X	US 9 151 008 B1 (CARSTENS HAZELTON W [US]) 6 October 2015 (2015-10-06)	8-16	
A	* column 2, line 4 - column 3, line 49; figures *	1-7	
X	US 3 892 075 A (TIBBETT MICHAEL EDWARD) 1 July 1975 (1975-07-01)	8-16	
A	* column 2, line 25 - column 4, line 16; figures *	1-7	
A	US 7 461 998 B1 (PARNELL WILLIAM C [US] ET AL) 9 December 2008 (2008-12-09) * abstract; figures *	1-16	

TECHNICAL FIELDS SEARCHED (IPC)

E02B
G01V

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	13 October 2020	Van Bost, Sonia

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 17 8851

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Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2012315090	A1	13-12-2012	NONE	
US 9151008	B1	06-10-2015	NONE	
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82