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(54) **A BARRIER COMPONENT AND A METHOD OF MANUFACTURING A BARRIER COMPONENT**

(57) The present disclosure relates to a barrier component (10) for a sonar system and a method of manufacturing a barrier component for a sonar system. At least a part of the outer surface (18) of the barrier component (10) comprises a repeating pattern, wherein the repeating pattern comprises surface features (16) formed in rows, wherein the surface features have a height of less than 10μm.

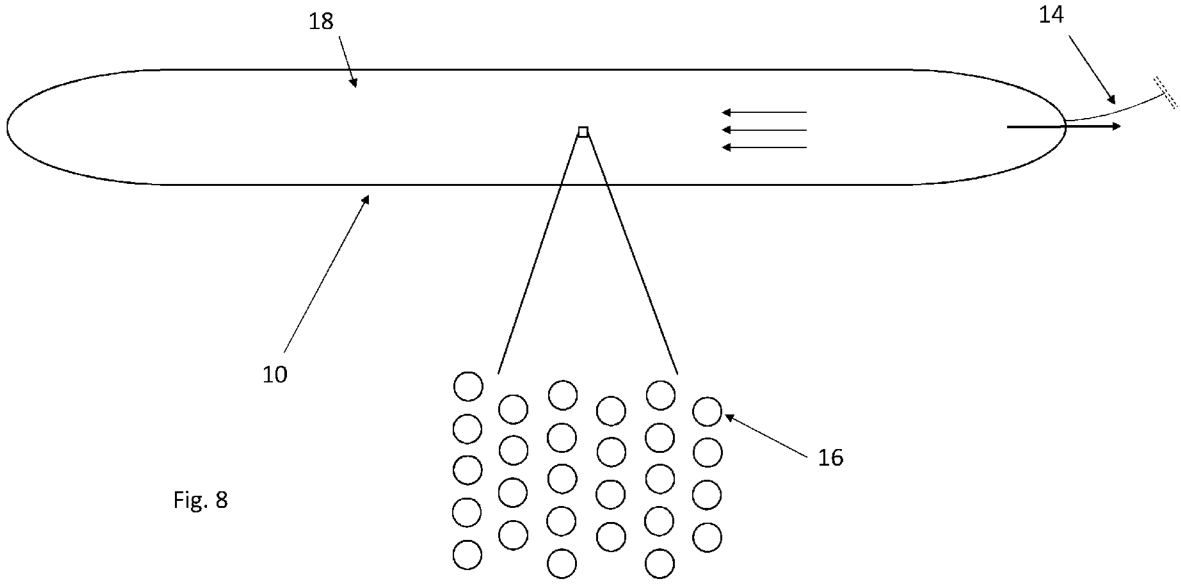

Fig. 8

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Description

FIELD

[0001] The present disclosure relates to a barrier component for a sonar system and a method of manufacturing a barrier component for a sonar system.

BACKGROUND

[0002] A sonar system uses sound propagation in water for purposes such as navigation, detection of objects, mapping or communication for example. A sonar system may comprise an array of acoustic transducers that generate an electrical signal in response to a received acoustic signal. In an active sonar system, the transducers both transmit and receive acoustic signals. In a towed array sonar system, a series of transducers are towed behind a vessel on a cable, which may be several kilometres in length. Alternatively, a sonar system may be directly mounted on a vessel, for example autonomous vehicles may have sonar systems mounted directly on their platform.

[0003] Movement of the sonar system through water can be a source of noise in the sonar system. There is a continuing need to reduce noise in sonar systems, in order to improve sensitivity.

SUMMARY

[0004] According to a first aspect there is provided a barrier component for a sonar system, wherein at least a part of the outer surface of the barrier component comprises a repeating pattern, wherein the repeating pattern comprises surface features formed in rows, wherein the surface features have a height of less than 10μm.

[0005] In an embodiment, the barrier component has a thickness of greater than 1mm.

[0006] The barrier component may be a tube for a towable sonar system.

[0007] The barrier component may be a barrier component for a sonar system mounted on a vessel.

[0008] In an embodiment, the surface features have a spacing of less than 5μm.

[0009] In an embodiment, surface features in alternate rows have a first height, and surface features in the remaining rows have a second height.

[0010] In an embodiment, at least some of the rows comprise a plurality of pillars.

[0011] The plurality of pillars may be equally spaced from each other within the rows.

[0012] The plurality of pillars may have a circular shape.

[0013] The pillars may be arranged in a regular hexagonal array.

[0014] At least some of the rows may comprise a ridge.

[0015] The rows may alternate between a ridge and a row of pillars.

[0016] The rows may be formed parallel to the direction of motion of the sonar system when deployed.

[0017] The rows may be formed in the longitudinal direction along the tube.

[0018] The barrier component may be polyurethane or polyvinyl chloride.

[0019] According to a second aspect, there is provided a sonar system comprising the barrier component described above.

[0020] According to a third aspect, there is provided a vessel, comprising the sonar system described above.

[0021] According to a fourth aspect, there is provided a method of manufacturing a barrier component for a sonar system, comprising:
applying a repeating pattern to at least a part of the outer surface of the barrier component, wherein the repeating pattern comprises surface features formed in rows, wherein the surface features have a height of less than 10μm.

[0022] In an embodiment, the barrier component is a tube for a towed sonar system, the method further comprising:

an extrusion step in which a material is formed into the tube using a die;
pulling the extruded tube away from the die, wherein the repeating pattern is applied to at least a part of the outer surface of the tube as the tube is pulled away from the die and before the tube is completely cooled.

[0023] In an embodiment, the outer surface of the tube is patterned by a one or more rollers comprising a plurality of depressions.

[0024] In an embodiment, the barrier component is a barrier component for a sonar system mounted on a vessel, the method further comprising: a moulding step in which a material is moulded to form the barrier component.

[0025] In an embodiment, the method further comprises:

an extrusion step, wherein the barrier component material is melted and forced through a die having an annular opening and forming a tube around a mandrel,
a step of pulling the extruded tube away from the die and cooling the tube,
a step of applying a pattern to at least a part of the outer surface of the tube prior to cooling to create surface features on the surface.

[0026] The outer surface of the tube may be patterned by a plurality of rollers.

[0027] The method of manufacture may include the outer surface of the tube being patterned by a plurality of rollers positioned at the exit of the die and around the circumference of the tube, wherein the outer surface of the tube may contact the rollers whilst the tube material is still soft.

[0028] The method of manufacture of may include the pattern on the outer surface of the tube being formed by a surface comprising a plurality of depressions.

[0029] The method of manufacture may include the outer surface of the tube being rolled across the surface comprising a plurality of depressions whilst the tube material is still soft.

[0030] The method of manufacture may include the outer surface of the tube being stamped by the surface having a pattern of depressions.

[0031] The method of manufacture may include the outer surface of the tube patterned by any combination of the steps described.

[0032] In an embodiment, the method comprises a moulding step wherein the barrier component material is moulded to form the barrier component geometry, a step of applying a pattern to at least a part of the barrier surface to create surface features on the surface and a cooling step.

[0033] The method of manufacture may include the pattern being applied during the moulding step or prior to cooling by a surface having a pattern of depressions, or a combination thereof.

[0034] The method may also comprise a curing step.

[0035] According to a fifth aspect, there is provided a computer program comprising computer executable instructions that, when executed by a processor, cause the processor to control an additive manufacturing apparatus to manufacture the barrier component described above.

[0036] According to a sixth aspect, there is provided a method of manufacturing a device via additive manufacturing, the method comprising:

obtaining an electronic file representing a geometry of a product wherein the product is a barrier component described; and

controlling an additive manufacturing apparatus to manufacture, over one or more additive manufacturing steps, the product according to the geometry specified in the electronic file.

BRIEF DESCRIPTION OF DRAWINGS

[0037] Embodiments of the invention will now be described by way of example only, with reference to the accompanying drawings in which:

FIG. 1A depicts an example of a towed sonar array system towed from a vessel;

FIG. 1B depicts an example of a sonar system directly mounted on a vessel;

FIG. 2 depicts an example of a towed sonar array system towed from a submarine;

FIG. 3A is a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component according to an embodiment;

FIG. 3B is a cross sectional view of the pattern of FIG. 3A, where the cross-section is taken in a direction parallel to the longitudinal direction;

FIG. 3C shows a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component according to an embodiment, in which the pattern is oriented differently with respect to the longitudinal direction;

FIG. 4A is a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component according to an embodiment;

FIG. 4B is a schematic illustration of a cross sectional view of the pattern of FIG. 4A, where the cross-section is taken in a direction parallel to the longitudinal direction;

FIG. 5A shows a portion of a barrier component according to an embodiment, having pillars having hexagonal cross sections with ridges positioned in between rows of pillars;

FIG. 5B shows a portion of a barrier component according to an embodiment, having no ridges and comprising pillars having hexagonal cross section;

Fig. 6A shows a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component according to an embodiment, in which pillars having triangular cross section which form pyramids on the surface;

FIG. 6B show a portion of a barrier component according to an embodiment, wherein the pillars have a uniform height;

FIG. 6C show a portion of a barrier component according to an embodiment, wherein the pillars have a first and second height;

FIG. 7A is a schematic illustration of a pattern applied to a barrier component according to an embodiment;

FIG. 7B shows a pattern applied to a barrier component according to an embodiment, in which the pillars are spaced apart evenly on the surface;

FIG. 8 shows a towable array according to an embodiment, with the surface features formed in the water-facing surface;

FIG. 9 shows a towable array according to an embodiment, with the surface features formed in the water-facing surface;

FIG. 10 shows a method of manufacturing a barrier component according to an embodiment;

FIG. 11 shows a schematic illustration of a process used in a method of manufacturing a barrier component according to an embodiment;

FIG. 12 shows a process of forming at least part of the pattern in the surface of the tube during the extrusion process used in a method of manufacturing a barrier component according to an embodiment;

FIG. 13 shows a towable array according to an embodiment, with surface features formed in the water-facing surface of the barrier component;

FIG. 14 shows a towable array according to an embodiment, with surface features formed in the water-facing surface of the barrier component.

DETAILED DESCRIPTION

[0038] FIG. 1A depicts an example of a towed sonar array system 10. The array 10 is attached to ship 12 via tether 14. The ship 12 tows the array 10 in the direction of the arrow in FIG. 1A. The array 10 comprises a series of acoustic transducers, or hydrophones (not shown), enclosed in a tube 18. The tube 18 is an example of a barrier component. The tube 18 may be a Polyvinyl chloride (PVC) or Polyurethane (PU) tube, which forms a barrier between the hydrophones and the water when the towed sonar array 10 is deployed. The array 10 may also be referred to as a towed line array, a seismic streamer or a linear array.

[0039] FIG. 1B depicts an example of a sonar system 50 directly mounted on a vessel 12, known as a hull mounted sonar. For example, the vessel 12 may be an autonomous vehicle having a sonar system 50 mounted directly on the platform. The vessel 12 moves in the direction of the arrow in FIG. 1B. The sonar system again comprises a series of acoustic transducers, or hydrophones (not shown), enclosed within a barrier component 60. The barrier component 60 may be a PU, PVC or carbon fibre surface, which forms a barrier between the hydrophones and the water when vessel 12 is deployed. For a hull mounted array, the barrier component 60 may comprise carbon fibre sonar domes for example.

[0040] The sonar system 100 may also be configured as a conformal array on a submarine or a towed array from a submarine as shown in FIG 2. Where the system 100 is a conformal array, the barrier component 60 may comprise PU. Where the system 100 is a towed array, the barrier component 60 may comprise PU or PVC.

[0041] In the systems described, movement of the sonar system through the water can be a source of noise. This noise may be referred to as flow noise. This noise can interfere with the operation of the sonar system, making detection of relevant acoustic signals by the sonar system more difficult. Flow noise increases with increasing drag on the sonar system. In particular, flow noise in a sonar system is proportional to drag to the power of 4, except at convective wavenumbers, where it is proportional to a power of 1.5. The outer surface of the barrier component, also referred to as the water-facing surface, affects the level of hydrodynamic drag which is generated.

[0042] Making the water-facing surface of the barrier component as smooth as possible may reduce flow turbulence. For example, chemically applied coatings could be applied to the outer surface of the barrier component 18 to reduce hydrodynamic drag. However, such coatings can have adhesive limitations due to the materials used and the environments in which sonar systems operate. For example, such coatings may be applied to streamer arrays used in seismic survey in the oil and gas industry. These coatings are intended to reduce the drag over the surface of the hose by exhibiting super-hydrophobic behaviour. However, these coatings may wear off with time, which may shorten the lifespan of the array and increase the frequency of required maintenance.

[0043] In the embodiments described herein, a repeating pattern of surface features in rows is formed into at least part of the outer surface of a barrier component for a sonar system. The rows are formed parallel to the direction of motion of the sonar system when deployed. Thus for a towed array such as shown in FIG. 1A or FIG. 2, the rows are formed along the longitudinal direction of the tube 18. For the mounted array shown in FIG. 1B, the rows are formed along the longitudinal direction of the vessel, indicated by the direction of the arrow in FIG. 1B. The spacing and heights of the rows can cause vortices in turbulent flow to be lifted away from the surface, reducing drag on the surface.

[0044] As the barrier component travels through fluid, the fluid moves through the rows. Furthermore, the surface features forming the rows may have a non-uniform geometry - for example, alternating rows may be formed from pillars and ribs. Oscillation of the fluid velocity around the mean velocity can also therefore be reduced. In particular, momentum transfer, in which slow moving fluid near the surface exchanges with higher velocity fluid, is reduced, leading to further reduction in drag. Thus, the surface pattern results in the flow of water across the surface while the platform travels through water being less turbulent. This lowers the hydrodynamic drag of the vessel and hence flow noise.

[0045] All of the rows of surface features may be the same height. Alternatively the surface features may have different heights. The surface features may have two different heights or a plurality of heights. In particular, the heights may alternate between the adjacent rows. The surface features in one row have same height and are adjacent a row having surface features of a different height. This may further reduce the drag on the surface, since the rows with alternating heights efficiently direct the water in the direction of motion.

[0046] Patterning the outer surface of the barrier component of the sonar system reduces hydrodynamic drag, lowers the generation of flow-noise and hence enhances the performance of the sonar system by reducing the noise floor of the system. The surface features are formed directly in the outer surface, either during, or after, manufacturing of the barrier component. Resistance to wear is therefore improved.

[0047] A reduction in drag produced by forming the pattern in the outer surface of the barrier component of a towed line array may also allow longer sonars to be deployed from unmanned or small platforms without increasing the fuel or energy consumption for example. For a given length of array the reduction in drag may allow the fuel or energy consumption to be decreased, thus extending the platform mission duration or reducing the volume required for fuel or battery storage.

[0048] A sonar system may be used in the water for extended periods, for example several weeks or months. Such conditions permit growth of marine life on the surface of the sonar system. This is referred to as 'bio-fouling'. This may be a particular problem for sonar systems operating in tropical environments for example. Bio-fouling on the surface of the sonar system may further increase the hydrodynamic drag, and thus increase the noise and impact the sonar performance. Removal of such growth may require periodic maintenance of the array. By forming a repeating pattern of surface features in rows into at least part of the outer surface of a barrier component for a sonar system, growth of marine life on the surface of the sonar system can also be reduced. The spacing between the surface features is less than a bio-fouling organism size and, as such, the surface features discourage organisms from attaching to the surface in the first place while promoting the easier release of any attached organisms from the surface. For example, the spacing between the surface features may be less than 5μm.

[0049] Drag reduction of the sonar system outer surface may enhance the mission life of autonomous vehicles which have sonar systems mounted directly on their platform or towed behind them. In particular, reduction in drag produced by forming the pattern in the outer surface of the barrier component of a sonar system may allow the fuel or energy consumption to be decreased, thus extending the platform mission duration.

[0050] FIG. 3A is a schematic illustration of a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component for a sonar system in accordance with an embodiment. The longitudinal direction, corresponding to the direction of travel through the water when deployed, is indicated by an arrow. FIG. 3B is a schematic illustration of a cross sectional view of the pattern, where the cross-section is taken in a direction parallel to the longitudinal direction. The longitudinal direction is the out of the page direction here.

[0051] The repeating pattern of surface features comprises a plurality of pillars 16. The pillars are formed in a regular hexagonal pattern. The pillars 16 are spaced apart evenly on the surface 18. The distance between the centres of adjacent pillars P is between 5-10μm. In an embodiment the distance between the centres of adjacent pillars P is 7μm. The gap between the adjacent pillars at the closest point is 2μm. The pillars 16 have a circular cross-section in the plane of the surface. The diameter D, or maximum width D, of each pillar 16 is 5μm. The pillars 10 have flat tops.

[0052] The pillars 16 form parallel rows, R1, R2, R3, R4, R5, R6, etc. As depicted in FIG. 3B the pillars 16 in alternate rows have a first height, H1, corresponding to R2, R4, R6. The pillars in the remaining rows have a second height, H2, corresponding to R1, R3, R5. The rows form dual height features. The first height is 2μm and the second height is 4μm.

[0053] Although a pattern having specific dimensions is described in relation to FIG. 3, it will be understood that variations to the pattern may be made. Generally the pattern may be formed with pillars 16 having heights of less than 10μm. Optionally, the pillars have heights of less than 5μm. It will be also be understood that although the pillars described in relation to FIG. 3 are circular, alternatively square or hexagonal pillars may be formed for example. Although pillars having flat tops are shown, alternatively the pillars may have rounded tops, for example. The pillars may have a size of less than 10μm. The gap between the adjacent pillars at the closest point may be less than 5μm.

[0054] FIG. 3C shows a variation according to an embodiment in which the pattern is oriented differently with respect to the longitudinal direction. Dashed lines are added in the figure to more clearly illustrate the rows.

[0055] FIG. 4A is a schematic illustration of a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component for a sonar system in accordance with another embodiment. The longitudinal direction, corresponding to the direction of travel through the water when deployed, is indicated by an arrow. FIG. 4B is a schematic illustration of a cross sectional view of the pattern, where the cross-section is taken in a direction parallel to the longitudinal direction. The longitudinal direction is the out of the page direction.

[0056] The repeating pattern of surface features comprises a plurality of pillars 16 and a plurality of ribs or ridges 20. The pillars are formed in parallel rows, R1, R3 and R5. The pillars 16 within each row are spaced apart evenly on the surface 18. The distance between the centres of adjacent pillars in a row is 7μm. The gap between the adjacent pillars in a row at the closest point is 2μm. The pillars 16 have a circular cross-section in the plane of the surface. The diameter D, or maximum width, of each pillar 16 is 5μm. The pillars 16 have a first height, H1, corresponding to R1, R3, R5. The first height is 2μm.

[0057] In between each row of pillars 16 is formed a rib or ridge 20. The width W of the ridge 20 is 5μm. The distance between the centre of the ridge 20 and the centre of the pillar 16 in an adjacent row in a direction parallel to the surface and the longitudinal direction P is 7μm. The gap between the ridge 20 and a pillar 16 in an adjacent row at the closest point is 2μm. The ridges 20 have a second height H2 of 4μm.

[0058] Again, although a pattern having specific dimensions is described in relation to FIG. 4, it will be understood that variations to the pattern may be made. Generally the pattern may be formed with pillars 16 having heights of less than 10μm and with ridges 20 having heights of less than 10μm. Optionally, the pillars 16 and ridges 20 have heights of less than 5μm. It will also be understood that although the pillars described in relation to FIG. 4 are circular, alternatively square or hexagonal pillars may be formed. Although pillars having flat tops are shown, alternatively the pillars may have rounded tops for example. The pillars may have size of less than 10μm. The gap between the adjacent pillars at the closest point may be less than 5μm. Furthermore, although the ridges 20 are shown having a rectangular cross-section in FIG. 4B, ridges 20 having a curved or triangular cross-section may be formed for example. The ridges 20 may have a width of less than 10μm. The gap between the ridge 20 and the adjacent pillars 16 at the closest point may be less than 5μm.

[0059] FIG. 5A is a schematic illustration of a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component for a sonar system in accordance with another embodiment. The pattern comprises pillars 16 having hexagonal cross sections, with ridges 20 positioned in between rows of pillars 16. The pillars 16 are formed in parallel rows, R1, R3 and R5. The pillars 16 within each row are spaced apart evenly on the surface 18. The distance between the centres of adjacent pillars in a row is 7μm. The gap between the adjacent pillars in a row at the closest point is 2μm. The maximum width of each pillar 16 is 5μm. The pillars 10 have flat tops. The pillars 16 have a first height, H1, corresponding to R1, R3, R5. The first height is 2μm. The width W of the ridge 20 is 5μm. The distance between the centre of the ridge 20 and the centre of the pillar 16 in an adjacent row in a direction parallel to the surface and the longitudinal direction P is 7μm. The gap between the ridge 20 and a pillar 16 in an adjacent row at the closest point is 2μm. The ridges 20 have a second height H2 of 4μm. Again, although a pattern having specific dimensions is described, it will be understood that variations to the pattern may be made.

[0060] FIG. 5B is a schematic illustration of a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component for a sonar system in accordance with another embodiment. There are no ridges and the surface comprises pillars 16 having hexagonal cross sections. The pillars are formed in parallel rows. The pillars 16 within each row are spaced apart evenly on the surface 18. The distance between the centres of adjacent pillars in a row is 7μm. The gap between the adjacent pillars at the closest point is 2μm. The diameter maximum width of each pillar 16 is 5μm. The pillars 16 have a first height of 4μm. Again, although a pattern having specific dimensions is described, it will be understood that variations to the pattern may be made.

[0061] Fig. 6A is a schematic illustration of a top view of a repeating pattern of surface features in rows formed into at least part of the outer surface of a barrier component for a sonar system in accordance with another embodiment. The pattern comprises rows of pillars 16 having triangular cross section which form square based pyramids on the barrier surface. As illustrated in FIG. 6B and FIG. 6C the pillars may have a uniform height or have a first and second height as previously described. The pillars are formed in parallel rows. The pillars 16 within each row are spaced apart evenly on the surface 18. The distance between the centres of adjacent pillars in a row is 7μm. The gap between the adjacent pillars at the closest point is 2μm. The diameter maximum width of each pillar 16 is 5μm. The pillars 16 have a first height of 4μm. Again, although a pattern having specific dimensions is described, it will be understood that variations to the pattern may be made.

[0062] The patterns presented in FIG. 3 to FIG. 6 also exhibit hydrophobic properties. The patterns presented in FIG. 3 to FIG. 6 are inspired by those stemming from nature. Bioinspired surfaces have been demonstrated to exhibit low stick, hydrophobic and self-cleaning properties. Surfaces in which patterns are formed which are similar to those found in nature which exhibit high wetting, such as those inspired by the lotus leaf, provide lower drag for use in sonar systems. Hydrophobic surfaces also reduce surface frictional drag and turbulent boundary layer flow, by trapping a thin layer of air in the spacing between the features. In particular, air can be trapped between the pillars, which increases the hydrophobicity, and in turn further reduces drag.

[0063] The patterned surfaces shown in FIG. 3 to FIG. 6 can exhibit 'self-cleaning' properties, which prevent the growth of organisms on the surface. This could result in reduced platform downtime required for antifouling activities, especially for those operating in tropical environments for example. In particular, the spacing between the surface features is less than a bio-fouling organism size and, as such, the surface features discourage organisms from attaching to the surface in the first place while promoting the easier release of any attached organisms from the surface. For example, the spacing between the surface features may be less than 5μm.

[0064] FIG. 7 illustrates various examples of repeating patterns formed into a surface. FIG. 7A is a schematic illustration of a pattern applied to a barrier component according to an embodiment, wherein the pattern of surface features comprises a plurality of pillars 16. The plurality of pillars 16 have a height of less than 10 μm. The pillars 16 shown in FIG. 7 have a height of 2μm. The pillars shown have a circular cross-section. The diameter of each pillar 16 is less than 10μm. It will be understood that although the pillars described herein are circular, triangular, square or hexagonal pillars may also be used and the diameter in those cases is the maximum width. Various different pillar and rib geometries are possible. In the pattern shown in FIG. 7A and FIG. 7B, the pillars 16 are spaced apart evenly on the surface 18.

[0065] The pattern may be pseudo random, in other words the pattern may not exhibit a short range order, for example over scales of 0.1mm, but may repeat over a longer range order, for example over scales of between 1mm and 100mm. In some embodiments the pattern may repeat over a scale of greater than 100mm. The scale of the order is linked to the manufacturing process, for example depending on the manufacturing process used there may be a longer range order. Use of a roller and/or a die could vary the geometry locally but would repeat the pattern over the barrier component depending on the size of the roller/die/barrier surface. A longer range order is also possible using a surface to stamp the pattern onto the barrier component.

[0066] FIG. 7C shows an alternative surface pattern comprising surface features of ribs 16 and pillars 20. The ribs 20 have a height of 4μm and the ribs have a height of 2μm as shown in FIG.7D. As shown in FIG. 7C and D the pillars 16 are arranged in rows and are spaced apart equally. The ribs 20 are positioned between rows of pillars 16.

[0067] The patterns described in relation to the above figures may be formed in the outer surface of the barrier component, i.e. the tube 18, of a towed array such as is illustrated in FIG. 1A or FIG. 2. FIG. 8 and FIG. 9 show the towed array 10, 100 of FIG. 1A or FIG. 2 with the surface features formed in the water-facing surface of the tube 18. The pillars 16 shown in FIG. 3 above are shown formed in the surface of the tube 18 in FIG. 8. The combination of ribs 20 and pillars 16 in FIG. 4 are shown formed in the surface of the tube 18 in FIG. 9. The pattern can cover substantially all of or only a part of the tube 18 surface. The patterns specifically texture the surface of the towed array tube 18.

[0068] A towed array tube 18 may be formed using an extrusion process as set out in FIG. 10. A schematic illustration of a process used in a method of manufacturing a barrier component in accordance with an embodiment is shown in FIG. 11.

[0069] As shown in FIG. 10 the extrusion process comprises the steps of extrusion, pulling the extruded tube away from a die, and application of a pattern to at least a part of the outer surface of the tube. In more detail, in step 1 of the extrusion process, the tube material is melted and forced through a die 41 which forms it into a tube shape. The material may be polyvinyl chloride (PVC). The die 41 comprises an annular opening 45. Various types of die may be used to form the tube. For example, a spider die may comprise a mandrel 43 within the annular opening 45. The mandrel 43 is a cylindrical rod. The melted PVC flows through the annular opening 45 and around the mandrel 43 forming a hollow tube. Once extruded from the die 41, the tube is pulled away by one or more rollers 51 and cooled in step 2. The material gradually hardens as it cools.

[0070] The outer surface of the tube 18 is patterned during manufacture i.e. during the extrusion process, through the use of a plurality of rollers 47. For example, to form the pattern shown in FIG. 3 into the outer surface of the tube 18, a number of rollers 47 are positioned at the exit of the die 41 around the circumference of the tube 18, such that the outer surface of the tube passes over the rollers 47 whilst the PVC material is still soft in step 3. The rollers 47 are applied whilst the tube is at the correct temperature, before the hose cools too much. The rollers 47 comprise circular depressions 49 in the surface, which when the surface of the tube 18 is pressed against the roller 47 form the pillars in the surface of the tube 18. The depressions have the dimension corresponding to the desired dimensions of the pillars. The surface of the roller 47 is also shown in the figure. The roller 47 itself may be fabricated using stereolithography techniques to form the depressions. The roller 47 may be silicon or sapphire glass for example.

[0071] Although circular depressions are shown in FIG. 11, different shape depressions may be used, for example to form the surface features shown in FIGs 5 and 6 above.

[0072] To form the pattern shown in FIG. 4 or FIG. 5A, the surface of alternating rollers is modified to comprise a depression in the form of a strip instead of the circular depressions 49. When the surface of the tube 18 is pressed against the roller 47, the strip shaped depression forms a ridge in the surface of the tube 18.

[0073] Additionally or alternatively, a surface 55 having depressions 49 may be used to form at least part of the pattern in the surface of the tube 18 during the extrusion process, for example as shown in FIG. 12. Once the tube is extruded, the surface 55 is pressed against the outer surface of the tube 18 while the material is still soft. The tube 18 can then be rotated to allow the circumference of the tube 18 to contact the patterned surface 55. The tube 18 can be stamped by the surface 55 to impart the desired pattern into the tube surface 18. The surface 55 itself may be fabricated using stereolithography techniques to form the depressions 49. The surface 55 may be silicon or sapphire glass.

[0074] Additionally or alternatively, the die 41 through which the hose is extruded could be modified to create at least part of the pattern. For example, the surface of the annular opening 45 corresponding to the outer surface of the tube 18 may comprise a series of strip-like depressions, which when the tube material is extruded through the die, form the longitudinal ridges 20 shown in FIG. 4.

[0075] Alternatively, or additionally, the patterning is created by modifying selected parts of the surface of the tube 18 using rollers, stamping, lithography using a suitable mask and etching into the surface, or some combination thereof to the tube 18 after the manufacture process.

[0076] Once the towed array is installed on the vessel, rollers or stamps could be used on the vessel to produce or refresh the pattern upon deployment or recovery of the towed array.

[0077] PU surfaces or PVC tubing used in towed array sonar systems tend to be smooth, and the surface is determined by the die used during extrusion of the material during manufacture. In the process described in relation to FIG. 10, FIG. 11 and FIG. 12, further surface modifications are made to the hose. By applying the patterning to the PU/PVC towed array hose, reduction of the drag created by the towed array as it is pulled through the water is achieved, lowering the generation of flow-noise and hence enhancing the performance of the sonar system. For a conformal array or a hull mounted sonar, the barrier component 60 is formed by a moulding step wherein the barrier component material is moulded to form the desired barrier component geometry. The pattern of surface features is applied to at least a part of the barrier surface. The pattern of surface features may be applied using the mould for the barrier array during the moulding step. In this case, the mould comprises depressions for forming surface features during the moulding step.

[0078] Alternatively, the application of the pattern of surface features is a separate step performed after the moulding step. The surface features may be formed using a roller or a stamp applied to the barrier component surface. For example, a roller comprising depressions corresponding to the surface is used. The surface of the barrier component 60 is pressed against the roller to form the surface features in the surface of the barrier components. The depressions have the dimensions corresponding to the desired dimensions of the pattern of surface features. Instead of a roller, a stamp may be used. The roller or stamp may be fabricated using stereolithography techniques to form the depressions. The roller or stamp may be silicon or sapphire glass for example. For a conformal array formed from PU, the roller or stamp is applied when the PU is fully cured or cooled, or close to being cooled or cured.

[0079] The patterns described in relation to the above figures may be formed in the outer surface of the barrier component 60 of a mounted array such as is illustrated in FIG. 1B. FIG. 13 and FIG. 14 show the towed array 10 of FIG. 1B with the surface features formed in the water-facing surface of the barrier component 60. The pillars 16 shown in FIG. 3 above are shown formed in the surface of the barrier component 60 in FIG. 13. The combination of ribs 20 and pillars 16 in FIG. 4 are shown formed in the surface of the barrier component 60 in FIG. 14. The pattern can cover substantially all of or only a part of the barrier component 60 outer surface. By forming the pattern in the surface of a conformal array such as that shown in FIG. 1B, drag and therefore self-noise are reduced.

[0080] FIG. 8 to FIG. 14 describe the application of a pattern to a PU surface or PVC tubing which is a barrier component for a sonar system. Modifying the surface through patterning reduces hydrodynamic drag and hence flow noise. PU surfaces or PVC tubing are widely utilised in sonar systems.

[0081] In the above described embodiments, a pattern is formed in the outer surface of the sonar system. The surface of the barrier component of the sonar system is modified such that surface features are formed in the surface in a repeating pattern. The surface may be modified by use of rollers, stamping on to the surface, moulding into the barrier component during manufacture or etching into the surface.

[0082] Although specific configurations of sonar systems are described, the pattern could be formed on the surface of a barrier component for any sonar array system.

[0083] Examples according to the disclosure may be formed using an additive manufacturing process. A common example of additive manufacturing is 3D printing; however, other methods of additive manufacturing are available. Rapid prototyping or rapid manufacturing are also terms which may be used to describe additive manufacturing processes.

[0084] As used herein, "additive manufacturing" refers generally to manufacturing processes wherein successive layers of material(s) are provided on each other to "build-up" layer-by-layer or "additively fabricate", a three-dimensional component. This is compared to some subtractive manufacturing methods (such as milling or drilling), wherein material is successively removed to fabricate the part. The successive layers generally fuse together to form a monolithic component which may have a variety of integral subcomponents. In particular, the manufacturing process may allow an example of the disclosure to be integrally formed and include a variety of features not possible when using prior manufacturing methods.

[0085] Additive manufacturing methods described herein enable manufacture to any suitable size and shape with various features which may not have been possible using prior manufacturing methods. Additive manufacturing can create complex geometries without the use of any sort of tools, molds or fixtures, and with little or no waste material. Instead of machining components from solid billets of plastic or metal, much of which is cut away and discarded, the only material used in additive manufacturing is what is required to shape the part.

[0086] Suitable additive manufacturing techniques in accordance with the present disclosure include, for example, Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), 3D printing such as by inkjets and laserjets, Sterolithography (SLA), Direct Selective Laser Sintering (DSLS), Electron Beam Sintering (EBS), Electron Beam Melting (EBM), Laser Engineered Net Shaping (LENS), Electron Beam Additive Manufacturing (EBAM), Laser Net Shape Manufacturing (LNSM), Direct Metal Deposition (DMD), Digital Light Processing (DLP), Continuous Digital Light Processing (CDLP), Direct Selective Laser Melting (DSLM), Selective Laser Melting (SLM), Direct Metal Laser Melting (DMLM), Direct Metal Laser Sintering (DMLS), Material Jetting (MJ), NanoParticle Jetting (NPJ), Drop On Demand (DOD), Binder Jetting (BJ), Multi Jet Fusion (MJF), Laminated Object Manufacturing (LOM) and other known processes.

[0087] The additive manufacturing processes described herein may be used for forming components using any suitable material. For example, the material may be plastic, metal, composite, concrete, ceramic, polymer, epoxy, photopolymer resin, or any other suitable material that may be in solid, liquid, powder, sheet material, wire, or any other suitable form or combinations thereof. More specifically, according to exemplary embodiments of the present subject matter, the additively manufactured components described herein may be formed in part, in whole, or in some combination of materials including but not limited to pure metals, nickel alloys, chrome alloys, titanium, titanium alloys, magnesium, magnesium alloys, aluminum, aluminum alloys, iron, iron alloys, stainless steel, and nickel or cobalt based superalloys (e.g., those available under the name Inconel® available from Special Metals Corporation). These materials are examples of materials suitable for use in additive manufacturing processes which may be suitable for the fabrication of examples described herein.

[0088] As noted above, the additive manufacturing process disclosed herein allows a single component to be formed from multiple materials. Thus, the examples described herein may be formed from any suitable mixtures of the above materials. For example, a component may include multiple layers, segments, or parts that are formed using different materials, processes, and/or on different additive manufacturing machines. In this manner, components may be constructed which have different materials and material properties for meeting the demands of any particular application. In addition, although the components described herein are constructed entirely by additive manufacturing processes, it should be appreciated that in alternate embodiments, all or a portion of these components may be formed via casting, machining, and/or any other suitable manufacturing process. Indeed, any suitable combination of materials and manufacturing methods may be used to form these components.

[0089] Additive manufacturing processes typically fabricate components based on three-dimensional (3D) information, for example a three-dimensional computer model (or design file), of the component.

[0090] Accordingly, examples described herein not only include products or components as described herein, but also methods of manufacturing such products or components via additive manufacturing and computer software, firmware or hardware for controlling the manufacture of such products via additive manufacturing.

[0091] The structure of one or more parts of the product may be represented digitally in the form of a design file. A design file, or computer aided design (CAD) file, is a configuration file that encodes one or more of the surface or volumetric configuration of the shape of the product. That is, a design file represents the geometrical arrangement or shape of the product.

[0092] Design files can take any now known or later developed file format. For example, design files may be in the Stereolithography or "Standard Tessellation Language" (.stl) format which was created for stereolithography CAD programs of 3D Systems, or the Additive Manufacturing File (.amf) format, which is an American Society of Mechanical Engineers (ASME) standard that is an extensible markup-language (XML) based format designed to allow any CAD software to describe the shape and composition of any three-dimensional object to be fabricated on any additive manufacturing printer.

[0093] Further examples of design file formats include AutoCAD (.dwg) files, Blender (.blend) files, Parasolid (.x_t) files, 3D Manufacturing Format (.3mf) files, Autodesk (3ds) files, Collada (.dae) files and Wavefront (.obj) files, although many other file formats exist.

[0094] Design files can be produced using modelling (e.g. CAD modelling) software and/or through scanning the surface of a product to measure the surface configuration of the product.

[0095] Once obtained, a design file may be converted into a set of computer executable instructions that, once executed by a processer, cause the processor to control an additive manufacturing apparatus to produce a product according to the geometrical arrangement specified in the design file. The conversion may convert the design file into slices or layers that are to be formed sequentially by the additive manufacturing apparatus. The instructions (otherwise known as geometric code or "G-code") may be calibrated to the specific additive manufacturing apparatus and may specify the precise location and amount of material that is to be formed at each stage in the manufacturing process. As discussed above, the formation may be through deposition, through sintering, or through any other form of additive manufacturing method.

[0096] The code or instructions may be translated between different formats, converted into a set of data signals and transmitted, received as a set of data signals and converted to code, stored, etc., as necessary. The instructions may be an input to the additive manufacturing system and may come from a part designer, an intellectual property (IP) provider, a design company, the operator or owner of the additive manufacturing system, or from other sources. An additive manufacturing system may execute the instructions to fabricate the product using any of the technologies or methods disclosed herein.

[0097] Design files or computer executable instructions may be stored in a (transitory or nontransitory) computer readable storage medium (e.g., memory, storage system, etc.) storing code, or computer readable instructions, representative of the product to be produced. As noted, the code or computer readable instructions defining the product that can be used to physically generate the object, upon execution of the code or instructions by an additive manufacturing system. For example, the instructions may include a precisely defined 3D model of the product and can be generated from any of a large variety of well-known computer aided design (CAD) software systems such as AutoCAD®, TurboCAD®, DesignCAD 3D Max, etc. Alternatively, a model or prototype of the component may be scanned to determine the three-dimensional information of the component.

[0098] Accordingly, by controlling an additive manufacturing apparatus according to the computer executable instructions, the additive manufacturing apparatus can be instructed to print out one or more parts of the product. These can be printed either in assembled or unassembled form. For instance, different sections of the product may be printed separately (as a kit of unassembled parts) and then subsequently assembled. Alternatively, the different parts may be printed in assembled form.

[0099] In light of the above, embodiments include methods of manufacture via additive manufacturing. This includes the steps of obtaining a design file representing the product and instructing an additive manufacturing apparatus to manufacture the product in assembled or unassembled form according to the design file. The additive manufacturing apparatus may include a processor that is configured to automatically convert the design file into computer executable instructions for controlling the manufacture of the product. In these embodiments, the design file itself can automatically cause the production of the product once input into the additive manufacturing device. Accordingly, in this embodiment, the design file itself may be considered computer executable instructions that cause the additive manufacturing apparatus to manufacture the product. Alternatively, the design file may be converted into instructions by an external computing system, with the resulting computer executable instructions being provided to the additive manufacturing device.

[0100] Given the above, the design and manufacture of implementations of the subject matter and the operations described in this specification can be realized using digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. For instance, hardware may include processors, microprocessors, electronic circuitry, electronic components, integrated circuits, etc. Implementations of the subject matter described in this specification can be realized using one or more computer programs, i.e., one or more modules of computer program instructions, encoded on computer storage medium for execution by, or to control the operation of, data processing apparatus. Alternatively or in addition, the program instructions can be encoded on an artificially-generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. A computer storage medium can be, or be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, or a combination of one or more of them. Moreover, while a computer storage medium is not a propagated signal, a computer storage medium can be a source or destination of computer program instructions encoded in an artificially-generated propagated signal. The computer storage medium can also be, or be included in, one or more separate physical components or media (e.g., multiple CDs, disks, or other storage devices).

[0101] Although additive manufacturing technology is described herein as enabling fabrication of complex objects by building objects point-by-point, layer-by-layer, typically in a vertical direction, other methods of fabrication are possible and within the scope of the present subject matter. For example, although the discussion herein refers to the addition of material to form successive layers, one skilled in the art will appreciate that the methods and structures disclosed herein may be practiced with any additive manufacturing technique or other manufacturing technology.

[0102] Further embodiments are set out in the following clauses:

1. A barrier component for a sonar system, wherein at least a part of the outer surface of the barrier component comprises a repeating pattern, wherein the repeating pattern comprises surface features formed in rows, wherein the surface features have a height of less than 10μm.

2. The barrier component of clause 1, wherein the barrier component has a thickness of greater than 1mm.

3. The barrier component of clause 1 or 2, wherein the barrier component is a tube for a towable sonar system.

4. The barrier component of clause 1 or 2, wherein the barrier component is a barrier component for a sonar system mounted on a vessel.

5. The barrier component of any preceding clause, wherein the surface features have a spacing of less than 5μm.

6. The barrier component of any preceding clause, wherein surface features in alternate rows have a first height, and surface features in the remaining rows have a second height.

7. The barrier component of any preceding clause, wherein at least some of the rows comprise a plurality of pillars.

8. The barrier component of clause 7, wherein the plurality of pillars are equally spaced from each other within the rows.

9. The barrier component of clause 7 or 8, wherein the plurality of pillars have a circular shape.

10. The barrier component of any of clauses 7 to 9, wherein the pillars are arranged in a regular hexagonal array.

11. The barrier component of any preceding clause,

wherein at least some of the rows comprise a ridge.

12. The barrier component of any preceding clause, wherein the rows alternate between a ridge and a row of pillars.

13. The barrier component of any preceding clause, wherein the rows are formed parallel to the direction of motion of the sonar system when deployed.

14. The barrier component of clause 3, wherein the rows are formed in the longitudinal direction along the tube.

15. The barrier component of any preceding clause, wherein the barrier component is polyurethane or polyvinyl chloride.

16. A sonar system comprising the barrier component of any preceding clause.

17. A vessel, comprising the sonar system of clause 16.

18. A method of manufacturing a barrier component for a sonar system, comprising:
applying a repeating pattern to at least a part of the outer surface of the barrier component, wherein the repeating pattern comprises surface features formed in rows, wherein the surface features have a height of less than 10μm.

19. The method of clause 18, wherein the barrier component is a tube for a towed sonar system, the method further comprising:

an extrusion step in which a material is formed into the tube using a die;
pulling the extruded tube away from the die, wherein the repeating pattern is applied to at least a part of the outer surface of the tube as the tube is pulled away from the die and before the tube is completely cooled.

20. The method of clause 19, wherein the outer surface of the tube is patterned by a one or more rollers comprising a plurality of depressions.

21. The method of clause 18, wherein the barrier component is a barrier component for a sonar system mounted on a vessel, the method further comprising: a moulding step in which a material is moulded to form the barrier component.

22. A computer program comprising computer executable instructions that, when executed by a processor, cause the processor to control an additive manufacturing apparatus to manufacture the barrier component of any of clauses 1 to 15.

23. A method of manufacturing a device via additive manufacturing, the method comprising:

obtaining an electronic file representing a geometry of a product, wherein the product is a barrier component of any one of clauses 1 to 15; and
controlling an additive manufacturing apparatus to manufacture, over one or more additive manufacturing steps, the product according to the geometry specified in the electronic file.

[0103] The present invention has been described above purely by way of example. Modifications in detail may be made to the present invention within the scope of the claims as appended hereto. Furthermore, it will be understood that the invention is in no way to be limited to the combination of features shown in the examples described herein. Features disclosed in relation to one example can be combined with features disclosed in relation to a further example.

Claims

1. A barrier component for a sonar system, wherein at least a part of the outer surface of the barrier component comprises a repeating pattern, wherein the repeating pattern comprises surface features formed in rows, wherein the surface features have a height of less than 10μm.

2. The barrier component of claim 1, wherein the barrier component has a thickness of greater than 1mm.

3. The barrier component of claim 1 or 2, wherein the barrier component is a tube for a towable sonar system.

4. The barrier component of claim 1 or 2, wherein the barrier component is a barrier component for a sonar system mounted on a vessel.

5. The barrier component of any preceding claim, wherein the surface features have a spacing of less than 5μm; and/or wherein surface features in alternate rows have a first height, and surface features in the remaining rows have a second height.

6. The barrier component of any preceding claim, wherein at least some of the rows comprise a plurality of pillars; optionally wherein at least one of:

(i) the plurality of pillars are equally spaced from each other within the rows;
(ii) the plurality of pillars have a circular shape;
(iii) wherein the pillars are arranged in a regular

hexagonal array.

7. The barrier component of any preceding claim, wherein at least one of:

   (i) at least some of the rows comprise a ridge;
   (ii) the rows alternate between a ridge and a row of pillars;
   (iii) the rows are formed parallel to the direction of motion of the sonar system when deployed.

8. The barrier component of claim 3, wherein the rows are formed in the longitudinal direction along the tube.

9. The barrier component of any preceding claim, wherein the barrier component is polyurethane or polyvinyl chloride.

10. A sonar system comprising the barrier component of any preceding claim.

11. A vessel, comprising the sonar system of claim 10.

12. A method of manufacturing a barrier component for a sonar system, comprising:
applying a repeating pattern to at least a part of the outer surface of the barrier component, wherein the repeating pattern comprises surface features formed in rows, wherein the surface features have a height of less than 10μm.

13. The method of claim 12, wherein:

   (i) the barrier component is a tube for a towed sonar system, the method further comprising:

      an extrusion step in which a material is formed into the tube using a die;
      pulling the extruded tube away from the die, wherein the repeating pattern is applied to at least a part of the outer surface of the tube as the tube is pulled away from the die and before the tube is completely cooled, optionally
      wherein the outer surface of the tube is patterned by a one or more rollers comprising a plurality of depressions; or

   (ii) the barrier component is a barrier component for a sonar system mounted on a vessel, the method further comprising: a moulding step in which a material is moulded to form the barrier component.

14. A computer program comprising computer executable instructions that, when executed by a processor, cause the processor to control an additive manufacturing apparatus to manufacture the barrier component of any of claims 1 to 9.

15. A method of manufacturing a device via additive manufacturing, the method comprising:

   obtaining an electronic file representing a geometry of a product, wherein the product is a barrier component of any one of claims 1 to 9; and
   controlling an additive manufacturing apparatus to manufacture, over one or more additive manufacturing steps, the product according to the geometry specified in the electronic file.

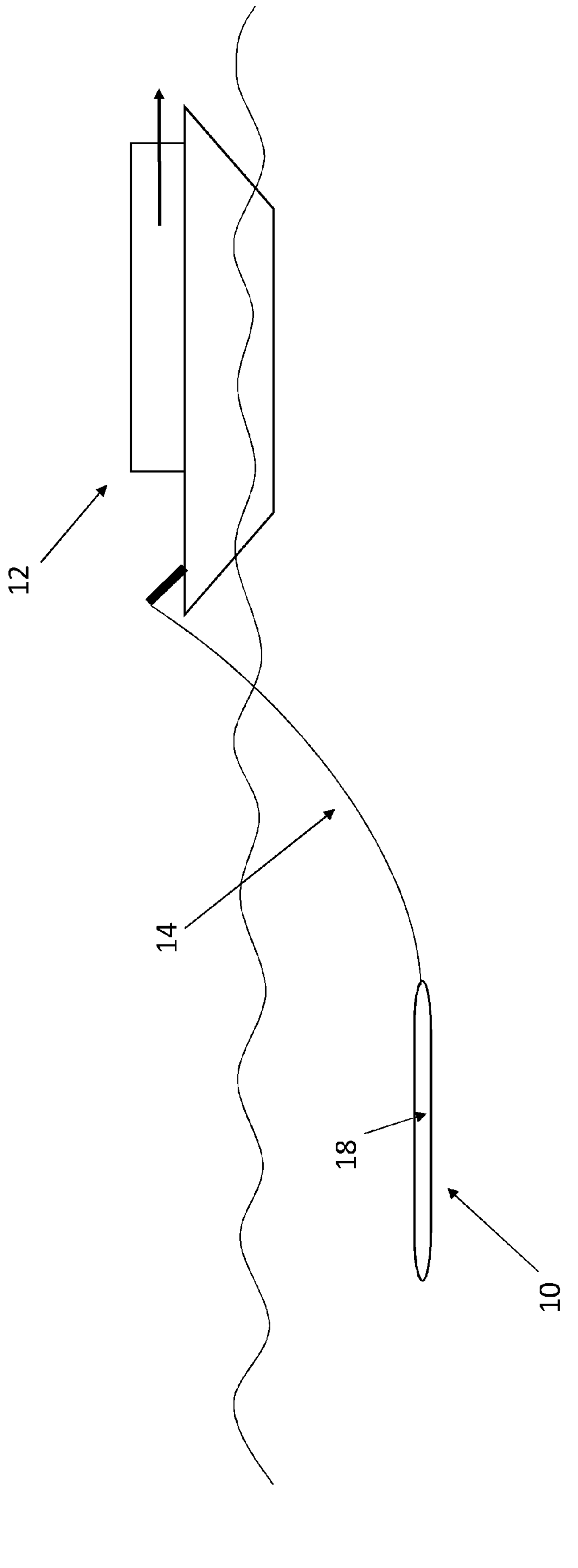


Fig. 1A

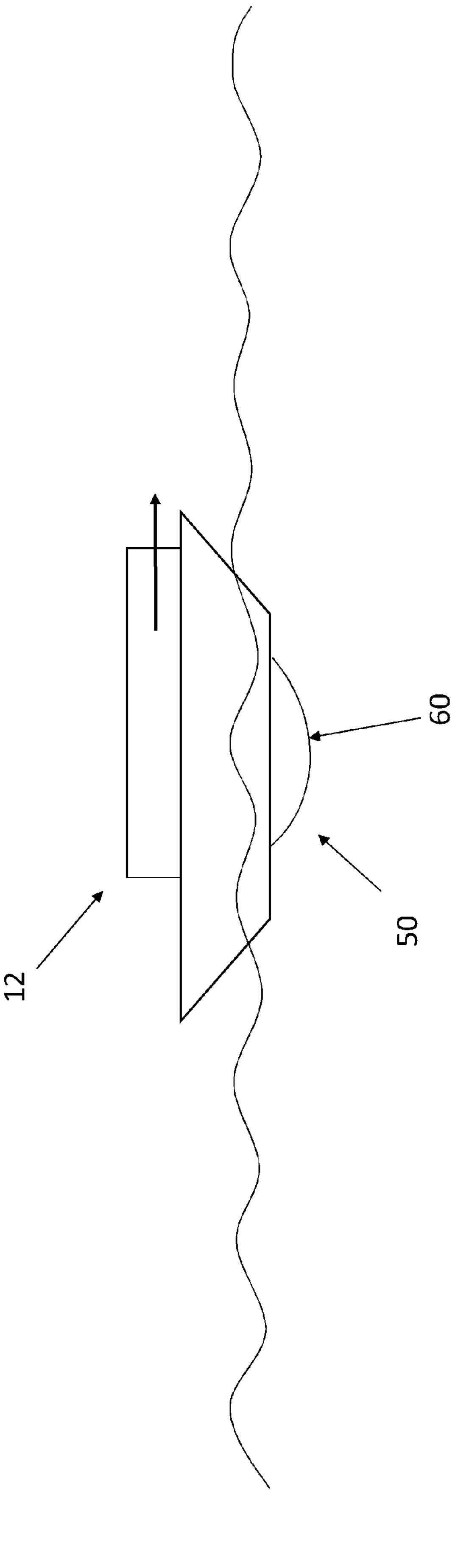


Fig. 1B

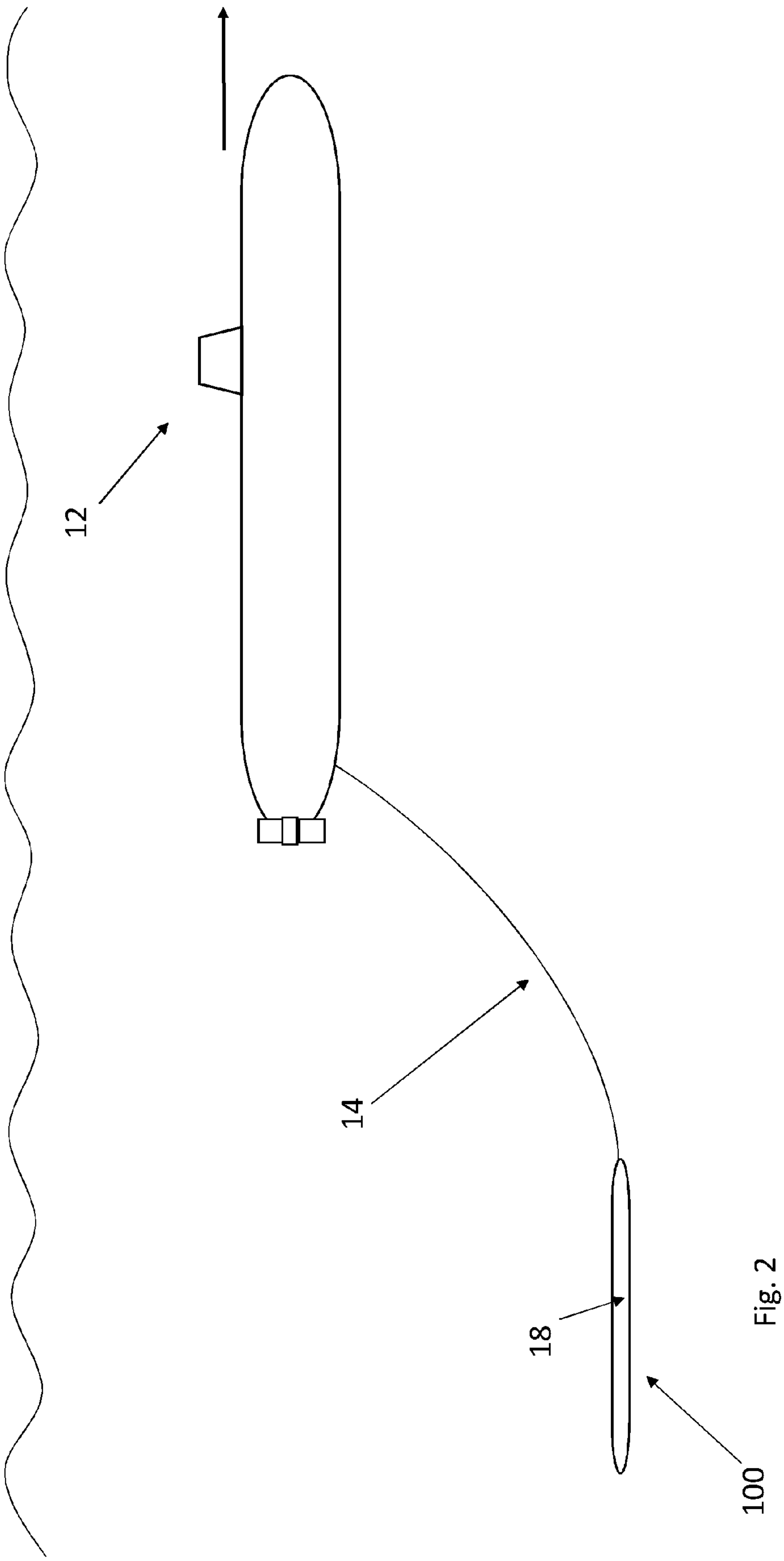


Fig. 2

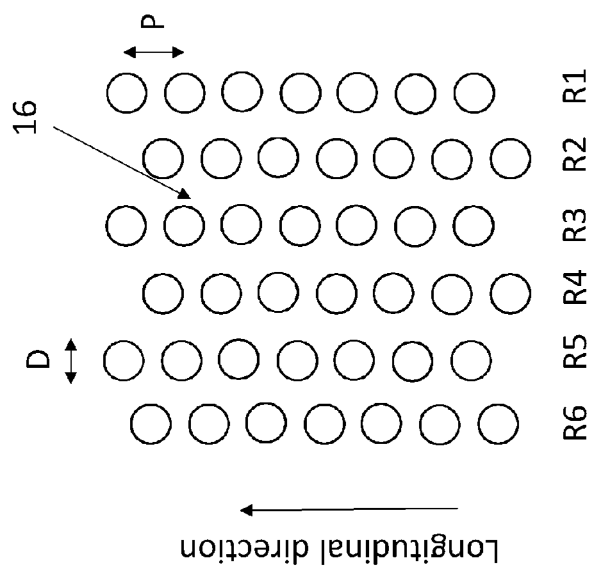

16
P
D
R1
R2
R3
R4
R5
R6
Longitudinal direction

Fig. 3A

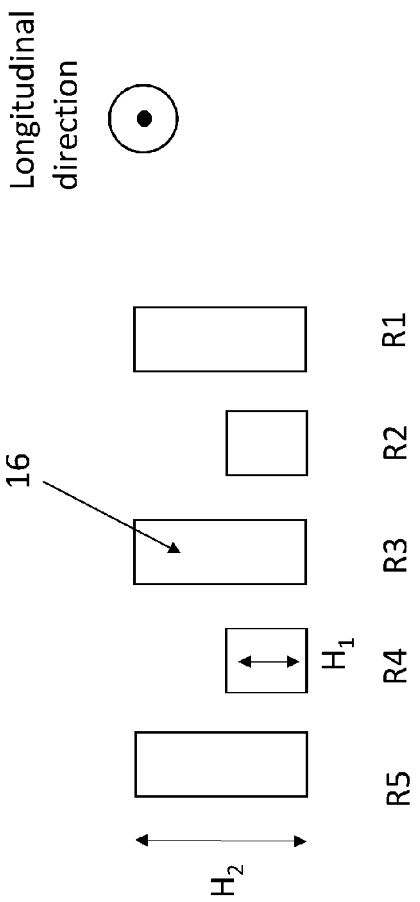

Longitudinal direction
16
R1
R2
R3
R4
R5
H_1
H_2

Fig. 3B

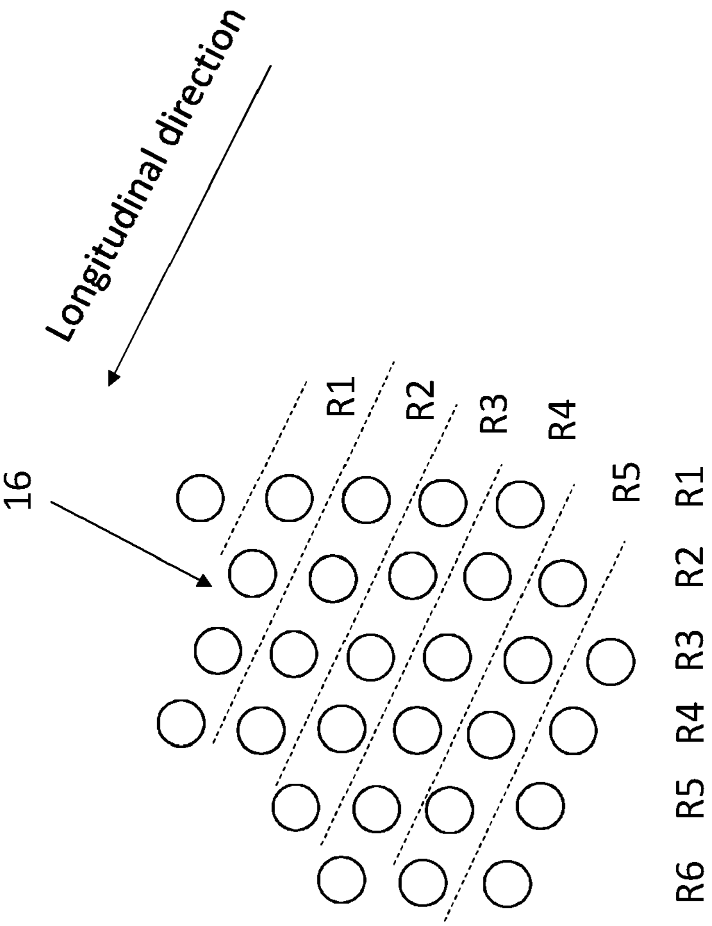


Fig. 3C

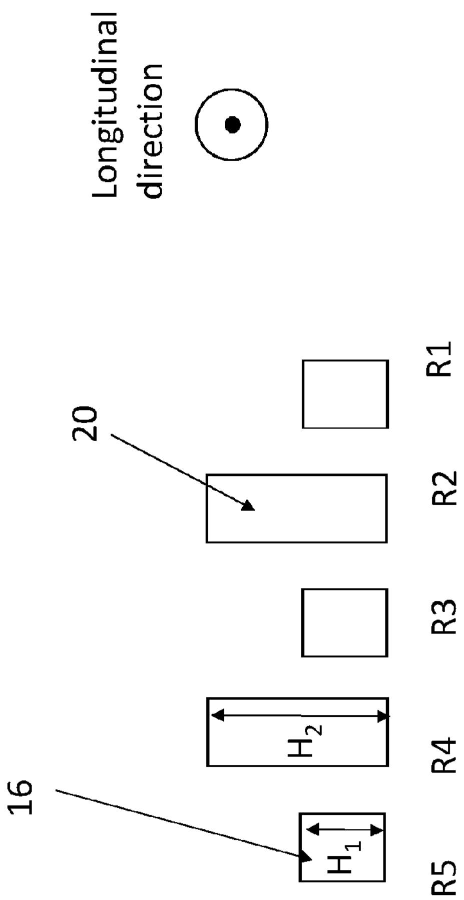

Longitudinal direction
20
16
H$_2$
H$_1$
R1
R2
R3
R4
R5

Fig. 4B

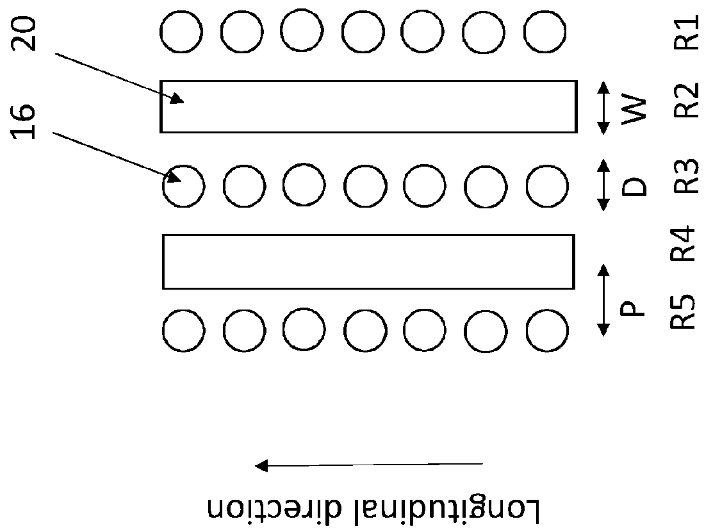

20
16
W
D
P
R1
R2
R3
R4
R5
Longitudinal direction

Fig. 4A

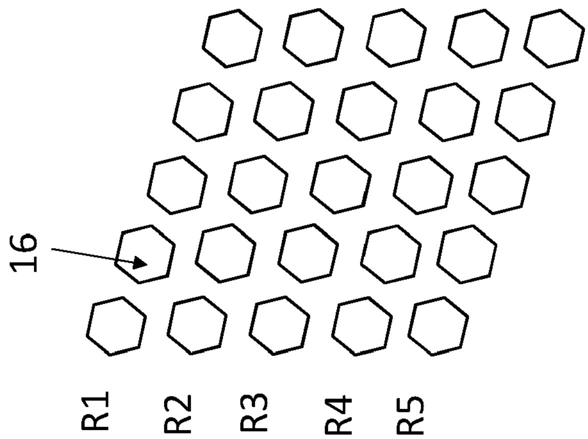

16
R1
R2
R3
R4
R5

Fig. 5B

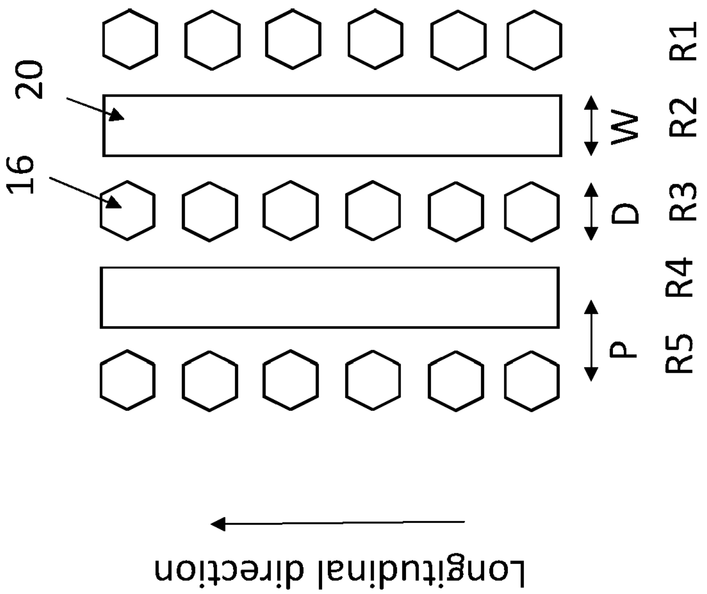

20
16
W
D
P
R1
R2
R3
R4
R5
Longitudinal direction

Fig. 5A

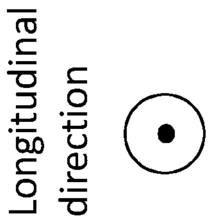


Fig. 6B

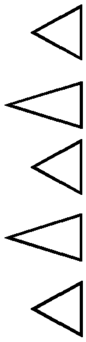


Fig. 6C

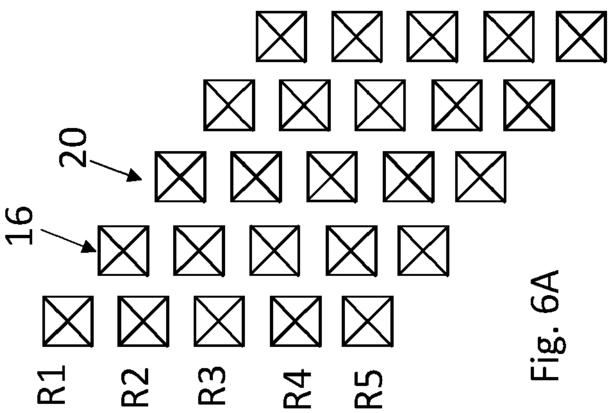
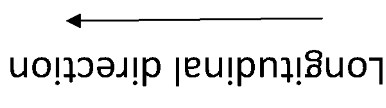


Fig. 6A



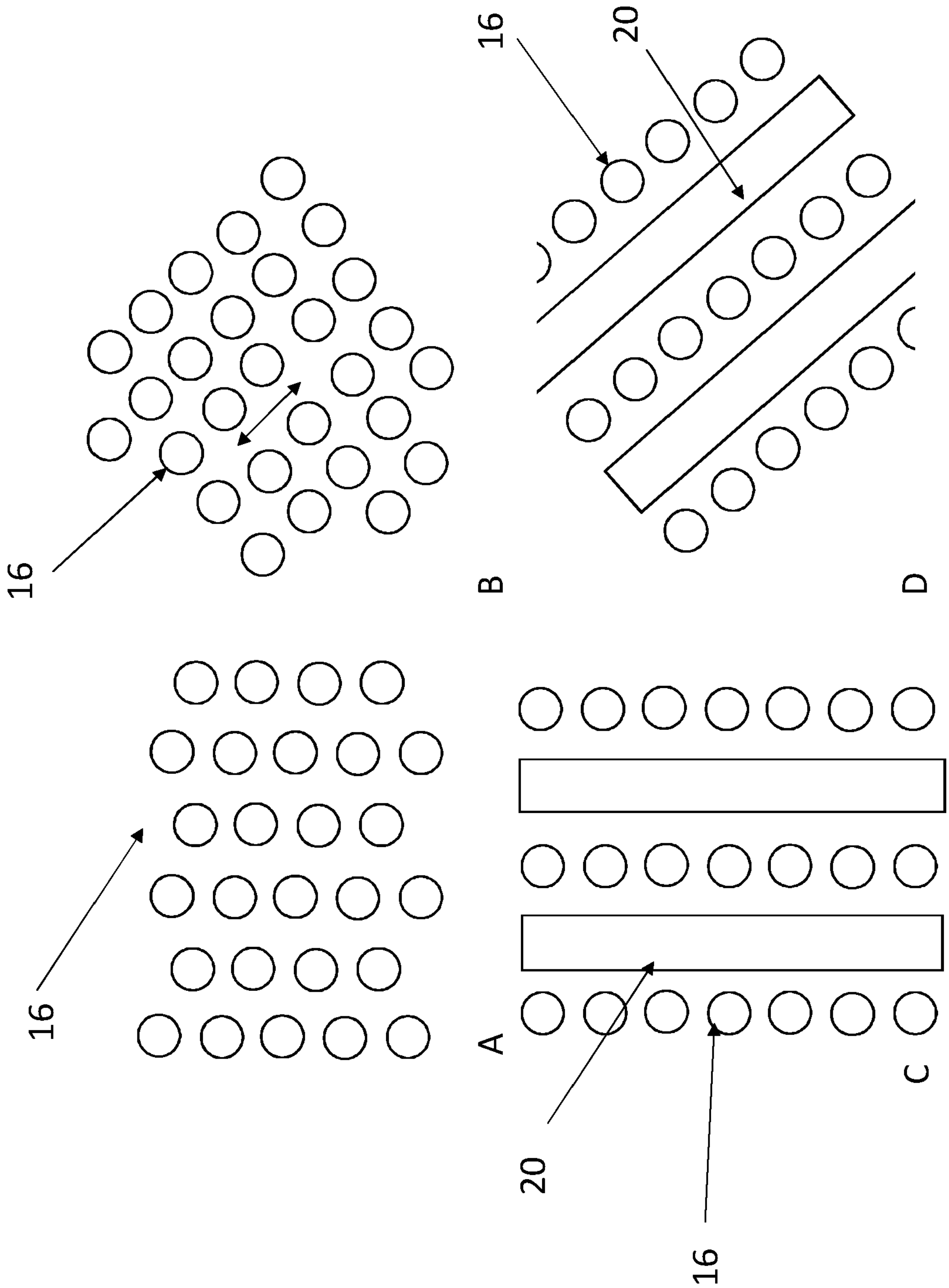


Fig. 7

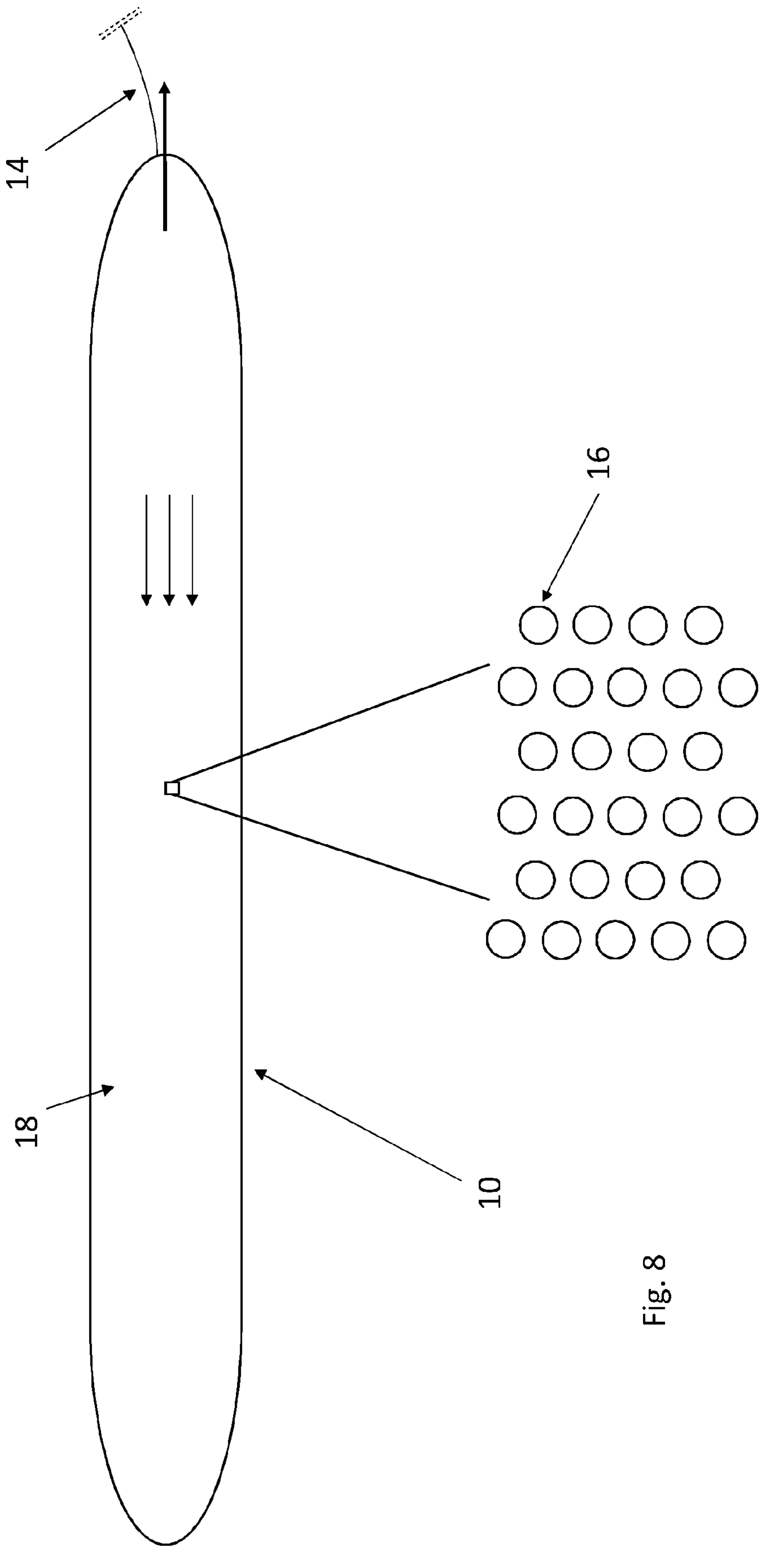


Fig. 8

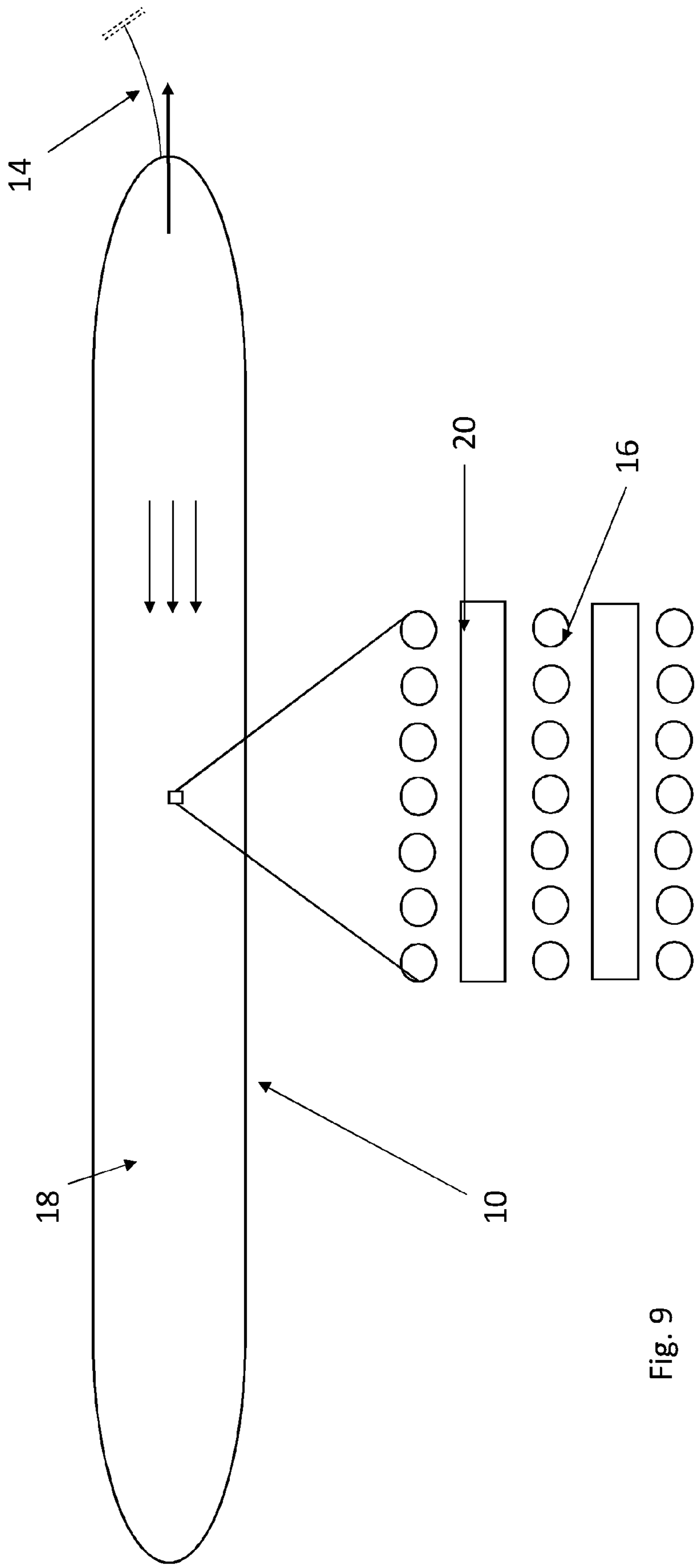


Fig. 9

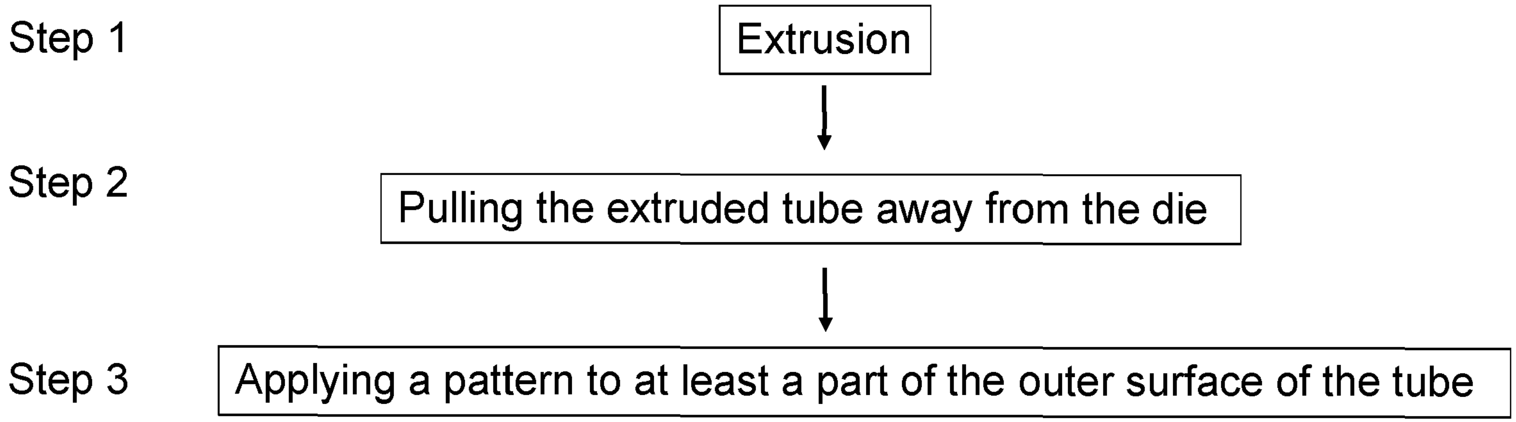

Step 1
Extrusion
Step 2
Pulling the extruded tube away from the die
Step 3
Applying a pattern to at least a part of the outer surface of the tube

Fig. 10

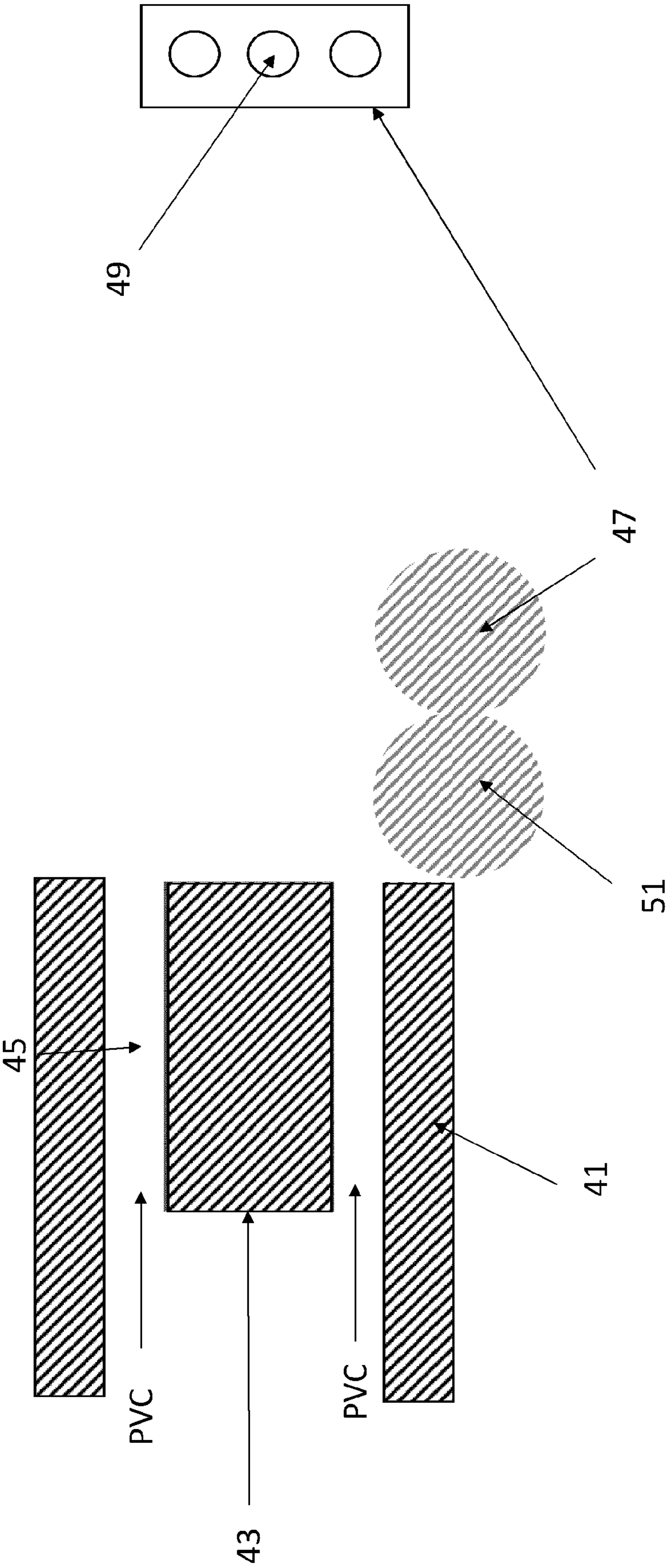


Fig. 11

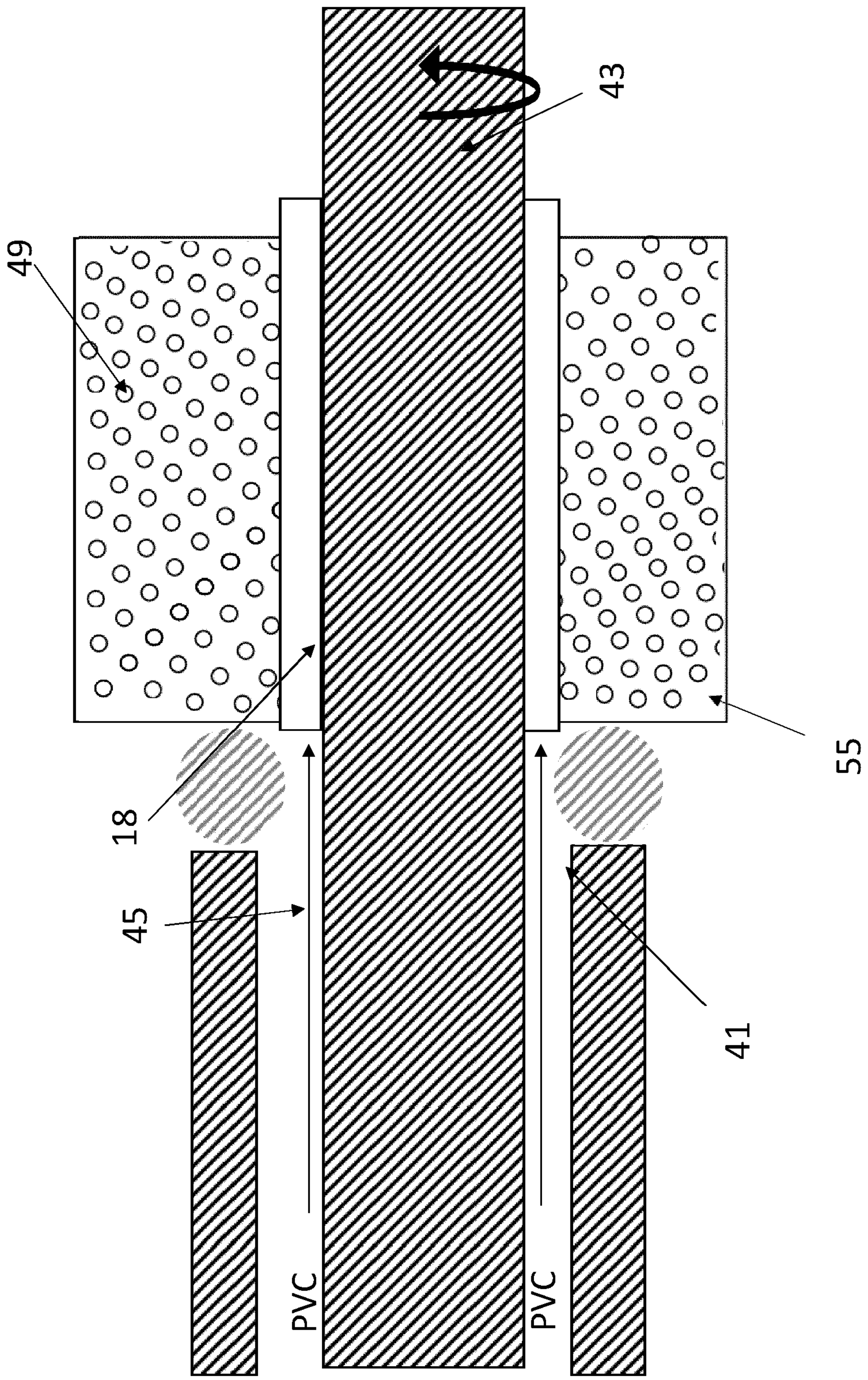


Fig. 12

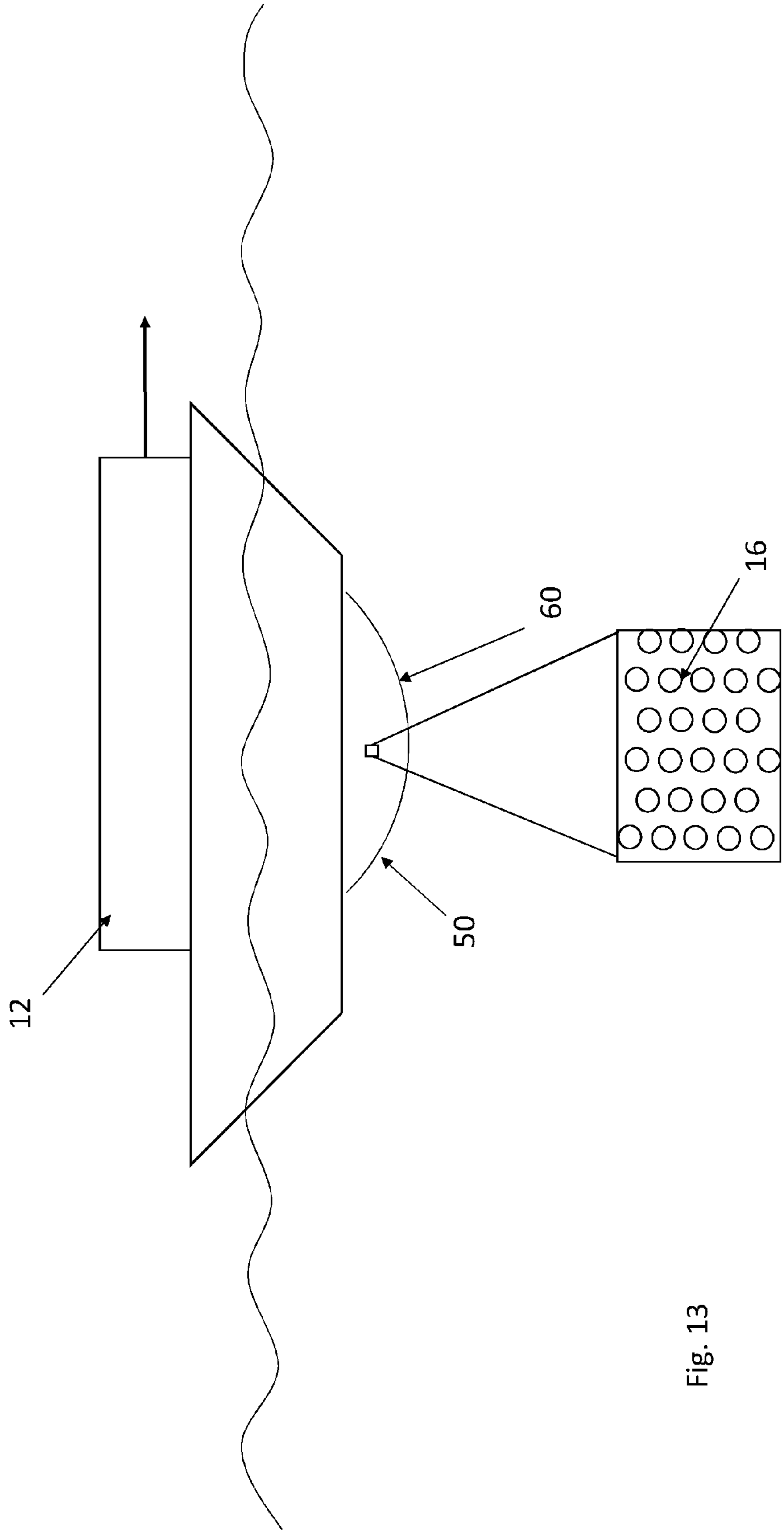


Fig. 13

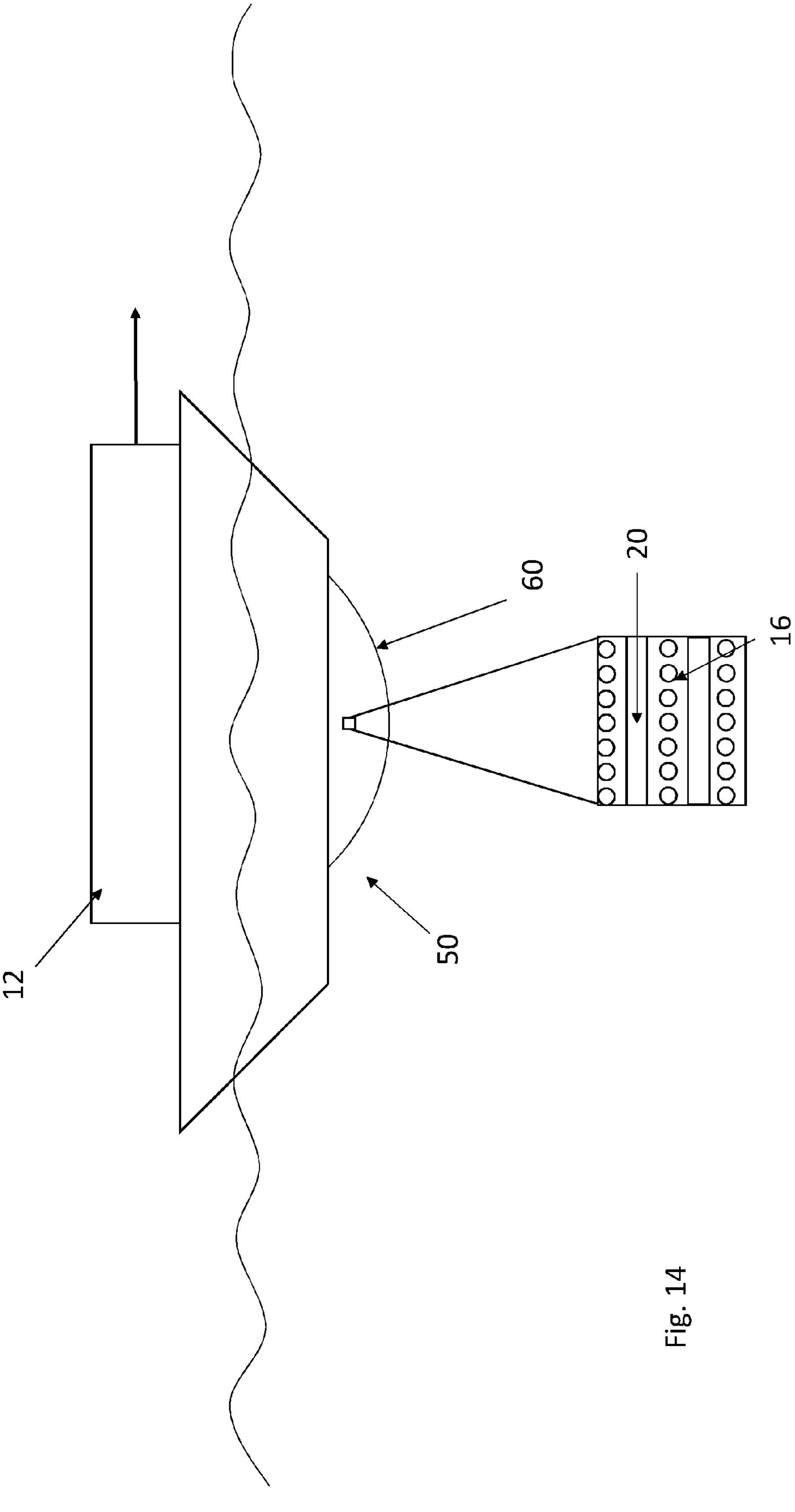


Fig. 14

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 21 21 7136

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 2017/100332 A1 (TONKIN LEAH [US] ET AL) 13 April 2017 (2017-04-13) * paragraphs [0008], [0009], [0122], [0177], [0216], [0217] * * figures 3, 8C * -----	1,2,4-7, 12,13	INV. B63B1/36 B63G8/42 ADD. B63G9/00
X	US 2006/219143 A1 (BRENNAN ANTHONY B [US] ET AL) 5 October 2006 (2006-10-05) * paragraphs [0011], [0027] * * figures 1, 3 * -----	1,2,4-7, 9,12,13	
X	DE 10 2018 003141 A1 (BADEN WURTTEMBERG FOUND) 17 October 2019 (2019-10-17) * paragraphs [0010], [0023], [0040] * -----	1,2,5-7	
X	US 2014/362660 A1 (PEARCE RICHARD E [US]) 11 December 2014 (2014-12-11) * paragraphs [0020], [0035], [0036], [0052], [0082], [0168], [0179], [0231] * * claims 1, 2, 9, 12 * -----	1-3,7-13	
			TECHNICAL FIELDS SEARCHED (IPC)
X	WO 2016/150816 A1 (RHEINISCHE FRIEDRICH-WILHELMS UNIVERSITÄT BONN [DE]) 29 September 2016 (2016-09-29) * page 18, paragraph 2 - page 19, paragraph 3 * * page 23, paragraph 3 * * page 25, paragraph 4 * * figure 10 * -----	1-8, 10-13	B63B B63J B63G G01S
X	US 2005/039661 A1 (KORNBLIT AVINOAM [US] ET AL) 24 February 2005 (2005-02-24) * paragraphs [0005], [0035] * * figure 6 * ----- -/--	1,2,4-7, 12	

1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	21 January 2022	Allen, Katie

CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number
EP 21 21 7136

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	WO 98/08677 A1 (MINNESOTA MINING & MFG [US]) 5 March 1998 (1998-03-05) * page 2, paragraph 1 * * page 9, paragraph 2 * * page 12, paragraph 1 * * figure 4 * -----	1,2,5,7,9,12	
X	DE 10 2011 121796 A1 (UNIV BONN [DE]) 16 August 2012 (2012-08-16) * paragraph [0036] * * figure 1 * -----	1,2,5,6	
X	CN 109 625 154 A (UNIV WUHAN) 16 April 2019 (2019-04-16) * figures 1, 2 * -----	1,2,4,5,7,12,14,15	
X	WO 2012/015700 A2 (UNIV CALIFORNIA [US]; KIM CHANG-JIN [US]; LEE CHOONGYEOP [US]) 2 February 2012 (2012-02-02) * paragraph [0033] * * figure 6A * -----	1,6,12	TECHNICAL FIELDS SEARCHED (IPC)
A	EP 3 088 290 A1 (BOEING CO [US]) 2 November 2016 (2016-11-02) * paragraphs [0008], [0017] * -----	1,14,15	
A	WO 2019/077370 A1 (BALMORAL COMTEC LTD [GB]) 25 April 2019 (2019-04-25) * pages 1, 29 * * figure 11A * -----	1-15	
A	US 2020/216424 A1 (SCHIMMEL THOMAS [DE]) 9 July 2020 (2020-07-09) * paragraph [0205] * * figure 16c * -----	1,7	

1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	21 January 2022	Allen, Katie

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 21 21 7136

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21-01-2022

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2017100332 A1	13-04-2017	US 2017100332 A1	13-04-2017
		WO 2017066265 A1	20-04-2017
US 2006219143 A1	05-10-2006	NONE	
DE 102018003141 A1	17-10-2019	BR 112020021199 A2	19-01-2021
		CA 3097076 A1	24-10-2019
		CN 111989498 A	24-11-2020
		DE 102018003141 A1	17-10-2019
		EP 3781820 A1	24-02-2021
		JP 2021521390 A	26-08-2021
		KR 20210002491 A	08-01-2021
		US 2021033119 A1	04-02-2021
		WO 2019201744 A1	24-10-2019
US 2014362660 A1	11-12-2014	US 2012160030 A1	28-06-2012
		US 2012161580 A1	28-06-2012
		US 2012163119 A1	28-06-2012
		US 2014362660 A1	11-12-2014
		US 2016154126 A1	02-06-2016
		US 2019154854 A1	23-05-2019
		WO 2012092368 A1	05-07-2012
WO 2016150816 A1	29-09-2016	DE 102015104257 A1	22-09-2016
		WO 2016150816 A1	29-09-2016
US 2005039661 A1	24-02-2005	NONE	
WO 9808677 A1	05-03-1998	AU 1824097 A	19-03-1998
		DE 69728404 T2	24-03-2005
		EP 0920378 A1	09-06-1999
		JP 2000517258 A	26-12-2000
		US 5848769 A	15-12-1998
		WO 9808677 A1	05-03-1998
DE 102011121796 A1	16-08-2012	NONE	
CN 109625154 A	16-04-2019	NONE	
WO 2012015700 A2	02-02-2012	CN 103153841 A	12-06-2013
		EP 2598433 A2	05-06-2013
		JP 6320754 B2	09-05-2018
		JP 2013536093 A	19-09-2013
		KR 20140023245 A	26-02-2014
		US 2013122195 A1	16-05-2013
		US 2016208110 A1	21-07-2016

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 21 21 7136

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

21-01-2022

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		WO 2012015700 A2	02-02-2012
EP 3088290 A1	02-11-2016	EP 3088290 A1	02-11-2016
		US 9482096 B1	01-11-2016
WO 2019077370 A1	25-04-2019	AU 2018351898 A1	05-03-2020
		BR 112020007661 A2	06-10-2020
		CA 3073482 A1	25-04-2019
		CN 111433429 A	17-07-2020
		EP 3698006 A1	26-08-2020
		GB 2569434 A	19-06-2019
		GB 2577658 A	01-04-2020
		JP 2021500495 A	07-01-2021
		KR 20200062245 A	03-06-2020
		SG 10202010381X A	27-11-2020
		SG 11202001522Q A	28-05-2020
		US 2020248731 A1	06-08-2020
		WO 2019077370 A1	25-04-2019
US 2020216424 A1	09-07-2020	BR 112014021810 B1	15-12-2020
		CA 2866082 A1	12-09-2013
		CA 3114548 A1	12-09-2013
		CN 104271259 A	07-01-2015
		CN 106984510 A	28-07-2017
		DE 112013001273 A5	11-12-2014
		DK 2822704 T3	21-12-2020
		EP 2822704 A2	14-01-2015
		EP 3791968 A1	17-03-2021
		ES 2842502 T3	14-07-2021
		JP 6270745 B2	31-01-2018
		JP 6715821 B2	01-07-2020
		JP 2015516310 A	11-06-2015
		JP 2018094925 A	21-06-2018
		KR 20150008048 A	21-01-2015
		KR 20190116531 A	14-10-2019
		KR 20210013328 A	03-02-2021
		PT 2822704 T	07-01-2021
		US 2015273791 A1	01-10-2015
		US 2017203822 A1	20-07-2017
		US 2020216424 A1	09-07-2020
		WO 2013131618 A2	12-09-2013

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