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(54) A NOZZLE FOR A SNOWMAKING APPARATUS, A SNOW LANCE HEAD AND A METHOD FOR PRODUCING A SLITTED HOLLOW CONE SPRAY

(57) A nozzle (1) for a snowmaking apparatus for producing a slitted hollow cone spray (2) wherein the slitted hollow cone spray (2) is formed by a spray curtain (4) of water droplets (6), said spray curtain (4) having the shape of a hollow cone with a slit (8) that forms a lateral air path (10) into a hollow cone interior (14); the nozzle (1) comprises a water swirler (30) configured to receive and to guide a flow of water (80) such that a flow of swirling water (82) with a rotational motion is produced, a spray outlet (42) configured to receive the flow of swirling water (82) from the water swirler (30) and to eject it through an orifice (40), wherein the orifice (40) is shaped so as to define a flow diverter (44) configured to locally disturb the rotational motion as the water is being ejected, whereby the spray outlet (42) is configured to eject a spray curtain (4) of water droplets (6) in the shape of a conical surface with a lateral slit (8) formed by the flow diverter (44).

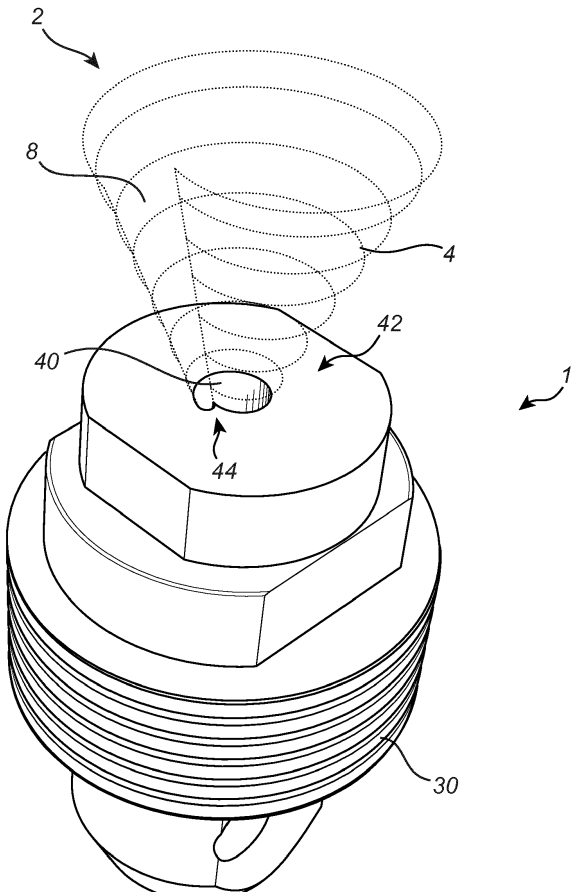

Fig. 2

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Description

TECHNICAL FIELD

[0001] The present invention relates, in general, to nozzles and methods for producing snow.

BACKGROUND

[0002] Snowmaking apparatuses are used for producing artificial snow, for example for winter sports such as e.g. downhill skiing and cross-country skiing. One such snowmaking apparatus is a snow lance. A snow lance generally comprises a relatively long vertical or somewhat inclined tube which delivers water to a snow lance head, which is arranged at the upper end of the tube and may be situated several meters above the ground. The snow lance head comprises at least one snow lance nozzle which receives water and ejects it in a spray curtain of water droplets into the freezing atmosphere. The water droplets subsequently freeze to form snow flakes which fall to the ground. The process is frequently aided by injecting ice nuclei into the spray curtain of water droplets, such that the ice nuclei may act as seeds for the crystallization of the water droplets which may facilitate the snow formation. The ice nuclei may be produced by at least one ice nucleator nozzle which mixes water with compressed air and forcibly expels the mixture. The compressed air may then expand and cool, thereby creating an ice nuclei jet. The at least one ice nucleator nozzle is frequently placed at the snow lance head in the vicinity of the snow lance nozzle and arranged to direct the ice nuclei jet such that it overlaps with the spray curtain of water droplets.

[0003] The snow lance nozzle is generally configured to produce a spray curtain of water droplets in the form of a flat fan or a hollow cone. A flat fan spray may be produced by expelling the water from a narrow slit. A hollow cone spray may be produced by swirling a flow of water and then ejecting it through a round orifice. The flow of water may be injected tangentially along the inner surface of a cylindrical cavity at the bottom portion of the cylindrical cavity. The flow of water may then move along a swirling path towards the orifice at the top of the cylindrical cavity where it is expelled. Subsequently, the centrifugal force from the swirling motion of the water may cause the expelled water to take the shape of a hollow cone spray.

[0004] Although these snow lance nozzles are fully functional, their performance may be improved.

SUMMARY

[0005] It is an object of the invention to provide a nozzle for a snowmaking apparatus which facilitates a more cost effective production of artificial snow. It is a particular object of the invention to provide a nozzle that enables a long range of a spray from the nozzle.

[0006] These and other objects of the invention are at least partly met by the invention as defined in the independent claims. Preferred embodiments are set out in the dependent claims.

[0007] The nozzle for a snowmaking apparatus described herein may be particularly useful for snow lances. For that reason, the nozzle may be referred to as a snow lance nozzle in the text. It should be understood that the terms nozzle for a snowmaking apparatus and snow lance nozzle may be used interchangeably in the text. However, it should also be understood that the nozzle may be used for other snowmaking apparatuses, such as e.g. fan guns.

[0008] According to a first aspect of the invention, there is provided a nozzle for a snowmaking apparatus for producing a slitted hollow cone spray wherein the slitted hollow cone spray is formed by a spray curtain of water droplets, said spray curtain having the shape of a hollow cone with a slit, said slit forming a lateral air path into a hollow cone interior; the snow lance nozzle comprising:

a water swirler configured to receive and to guide a flow of water such that the water flows along a main direction while simultaneously having a rotational motion which spirals around the main direction, thereby producing a flow of swirling water;

a spray outlet configured to receive the flow of swirling water from the water swirler and to eject the flow of swirling water through an orifice,

wherein the orifice is shaped so as to define a flow diverter configured to locally disturb the rotational motion of the flow of swirling water as the water is being ejected;

whereby the spray outlet is configured to eject a spray curtain of water droplets, the spray curtain having the shape of a conical surface with a lateral slit formed by the flow diverter.

[0009] The inventors have realized that artificial snow may be produced in a more cost effective manner if snow lances can be made to produce more snow far away from the snow lance, so that the range of the snow lance increases. This may e.g. result in fewer snow lances being needed to cover the same ground area of a piste in a ski slope, thus saving installation costs. Alternatively, or additionally, snow lances can be made to produce less snow close to the snow lance. This may reduce close vicinity losses in terms of snow ending up outside the piste or at the edges of the piste.

[0010] Such long range and/or low close vicinity loss snow lances may also improve the experience for the visitors at a winter sport venue. The pistes can be made wider if the snow lances reach further. Snow lances placed in the middle of the piste may not be needed which gives more room for skiing and reduces the risk of accidents. The snow cover may become less patchy when long range snow lances are arranged to form highly overlapping deposition areas. If the snow lances are placed at the sides of the piste (as they normally are), more snow can be placed at the center of the piste (where most of the skiing take place) when less snow is produced at the edges of the piste.

[0011] A snow lance producing a hollow cone spray may at least in some respects perform better than a snow lance producing a flat fan spray. The hollow cone spray has a larger surface area which improves the heat transfer. A higher flowrate is therefore possible, which may result in more snow per time unit. The snow lance nozzle according to a first aspect of the invention may be used to increase the range of a hollow cone spray and to reduce close vicinity losses. Experiments have shown that the range may increase by a factor 2 to 3 with a snow lance nozzle producing a slitted hollow cone spray as compared to a snow lance nozzle producing a non-slitted hollow cone spray, while reducing the snow production in close proximity to the snow lance.

[0012] It is a realization of the inventors that a slit in the spray curtain may improve the range. Without a slit the air pressure may drop inside the cone due to a high dynamic pressure from the outflowing spray in accordance with Bernoulli's principle. Bernoulli's principle states that the total pressure is the sum of the static and the dynamic pressure. Thus, if the dynamic pressure increases the static pressure drops. A low pressure in the interior of the cone may suck in water droplets, in particular smaller ones. The change of trajectory may slow the droplets down which may have two effects. Firstly, droplets which deviate from the intended spray pattern and enter into the cone interior may fall out as snow at an early stage, close to the snow lance. Secondly, deviating droplets may interfere with non-deviating droplets, thus slowing these down as well and reducing the range of the spray. Another effect of a low pressure in the hollow cone interior may be that the front of the hollow cone collapses at an early stage. At the front of the hollow cone the droplets of the spray curtain may have slowed down due to air resistance and interference with deviating droplets. A low pressure in the hollow cone interior may fold the sidewalls inwards such that the front collapses, thereby effectively ending the range of the spray.

[0013] According to the first aspect of the invention a lateral slit in the conical surface of the hollow cone may create an air path which may allow pressure equalization between the interior and exterior of the hollow cone. This in turn may improve the performance in accordance with the above realizations. In the context of this application the slit should be construed as a lateral reduction in the denseness of the water droplets, the slit may thus not necessarily be completely free of water droplets as it may be difficult to ensure that no droplet finds its way into the intended slit. Nevertheless, it should be understood that a slit comprising a significant reduction in the denseness of the water droplets also may allow for sufficient pressure equalization.

[0014] In one embodiment the water swirler and the orifice are further configured such that the cross-section of the slitted hollow cone spray has a denseness of water droplets at a central part of the slit which is below 50% of the denseness of water droplets at a central part of the spray curtain.

[0015] Furthermore, in the context of this application the hollow cone should be construed as a cone with a reduction in the denseness of the water droplets at the cone axis. It should be understood that the lateral thickness of the spray curtain as well as the cone apex angel may vary from one embodiment to another and that the denseness of the water droplets may vary radially according to e.g. a normal distribution. Thus the center of the cone may not necessarily be completely free of water droplets. Nevertheless, it should be understood that a cone with a significant reduction in the denseness of the water droplets along the cone axis may also function effectively.

[0016] In one embodiment the water swirler and the orifice are further configured such that the cross-section of the slitted hollow cone spray has a denseness of water droplets at the cone axis which is below 50% of the denseness of water droplets at a central part of the spray curtain.

[0017] In an embodiment the water swirler and the orifice are configured such that the slitted hollow cone spray has a cone apex angle of 15° to 90°. This may result in a reasonable compromise between range and lateral coverage of the snow deposition. A larger cone apex angle may result in a shorter range and wider lateral coverage of the snow deposition.

[0018] In an embodiment the water swirler and the orifice are configured such that the air pressure in the hollow cone interior is the same as the air pressure at the hollow cone exterior. However, it should be understood that an air pressure in the hollow cone interior which is lower than the air pressure at the hollow cone exterior may still be acceptable. Any reduction of the pressure drop in the hollow cone when a slit is used compared to when a slit is not used may result in a valuable improvement of the performance of the snow lance.

[0019] As used herein, the term "orifice" should be construed as an opening at an end of the spray outlet. The orifice may form a shape of an end surface for the spray outlet. However, the orifice may also form part of a shape extending a distance into the spray outlet and/or form a shape partly extending out from a planar end surface of the spray outlet.

[0020] According to an embodiment, the water swirler and the orifice are further configured such that a cross-section of the slitted hollow cone spray, the cross-section being perpendicular to a cone axis, forms an open curve spanning an angle of 270° to 450°. It should be understood that spanning an angle herein refers to the angle around the cone axis spanned when tracing the open curve from one endpoint to another. Furthermore, it should be understood that if the cross-section has a circular shape the cross-section may not form an open curve unless the open curve spans an angle below 360°.

A cross-section forming an open curve spanning an angle above 360° may be implemented e.g. by forming the cross-section into the form of a spiral curve segment, i.e. that one endpoint of the open curve has a first radius relative to the cone axis and that the radius increases along the open curve to reach a second radius at the other endpoint of the open curve. The radius may increase continuously from one endpoint to another. Alternatively, one part of the open curve, e.g. comprising a first endpoint, may have a constant radius while the other part, e.g. comprising a second endpoint, may have a continuously increasing radius. In this manner the open curve may span an angle above 360°, as the second endpoint has a larger radius and therefore may overlap the rest of the curve without forming a closed curve. It should be understood that other open curves, not necessarily comprising circle segments and spiral curve segments, may also be used. A snow lance nozzle according to the embodiment may provide a reasonable trade-off between generating a slitted hollow cone spray with as large surface area as possible while still achieving an efficient air path into the hollow cone interior.

[0021] In an embodiment the water swirler and the orifice are further configured such that a cross-section of the slitted hollow cone spray, the cross-section being perpendicular to a cone axis, forms an open curve spanning an angle of 330° to 390°. This may allow the hollow cone spray to be output in a large angular range while allowing air to efficiently equalize pressure between the interior and the exterior of the hollow cone.

[0022] According to an embodiment, the open curve comprises a spiral curve segment. Creating a slitted hollow cone spray wherein the cross-section forms an open curve wherein at least part of the open curve is shaped like a spiral curve segment may be easier to practically achieve, from a fluid dynamics point of view, than cross-sections shaped elsewise.

[0023] According to an embodiment, the flow diverter comprises an orifice perimeter step,

said orifice perimeter step being a kink in a curve, wherein the curve defines a perimeter of a cross-section of the orifice, the cross-section being taken perpendicular to the main direction of the flow of swirling water,

wherein the orifice perimeter step is configured to divert the flow of swirling water in a direction away from the cone axis such that the flow of swirling water rotationally passing over the orifice perimeter step is centrifugally spun outwards, thereby locally disturbing the rotational motion of the flow of swirling water to produce a slitted hollow cone spray.

[0024] A possible explanation for creation of the hollow cone is that the rotational motion of the swirling water as it is ejected through the orifice that creates the hollow cone shape through the centrifugal force. The centrifugal force being an inertial force in a direction away from the cone axis. When the swirling water passes over an orifice perimeter step, the orifice perimeter step being an outwards step in the rotational direction, the centrifugal force may allow the water to suddenly change direction out of the rotational frame of reference such that the spray curtain becomes discontinuous and a slit opens up. In this context the orifice perimeter step is a kink in a curve, wherein the curve defines a perimeter of a cross-section of the orifice, and a kink may be seen as any sharp turn in the curve which is sharp enough to create a sudden change of direction out of the rotational frame of reference for the swirling water.

[0025] An advantage of this embodiment may be that the manufacturing process can be very simple. An orifice may be milled such that an orifice perimeter step is formed. Alternatively, an existing round orifice may be modified by e.g. milling. Furthermore, as snow lance nozzles often use an exchangeable insert comprising the orifice, new inserts comprising an orifice perimeter step may be sold separately. This means that an existing snow lance nozzle producing a hollow cone spray may easily be modified into a snow lance nozzle producing a slitted hollow cone spray. The modification may then be done in the time that it takes to unscrew the old insert and screw in the new, resulting in virtually no down time for the snow lance.

[0026] According to an embodiment, the orifice perimeter step is configured such that the flow of swirling water loses contact with a surface of the orifice as the flow of swirling water rotationally passes over the orifice perimeter step. It may be advantageous to allow the water to be freely spun outwards without being in contact with the surface of the orifice. When there is no surface counteracting the centrifugal force this force may be optimally utilized for opening up the slit. Such an embodiment may also mean that the last contact between the water and the orifice as the water is being ejected from the orifice, forms an open curve. Thus a cross-section of the slitted hollow cone spray may also form an open curve. Additionally or alternatively, when the flow of swirling water loses contact with the surface of the orifice a low pressure region may be created on the outside of the water flowing over the orifice perimeter step in accordance with Bernoulli's principle. The low pressure region may help to locally disturb the rotational motion such that the slit is opened up.

[0027] According to an embodiment, the perimeter of the cross-section of the orifice comprises a curve in the form of a spiral segment. This form may be advantageous from a fluid dynamics point of view as a gradual change in the rotational radius of the water may reduce e.g. turbulence and energy losses. Furthermore, the spiral segment may represent a smooth change in radius without kinks and it may thereby prevent slits being opened up at other places than at the intended orifice perimeter step.

[0028] According to an embodiment, the ratio between a maximum radius of the spiral segment and a minimum radius of the spiral segment is at least 5/3. The inventors have found that this radius ratio may be particularly advantageous in generating a slit in the hollow cone spray to generate a long range of the snow lance nozzle.

[0029] According to an embodiment, the orifice perimeter step comprises a corner in a path along the perimeter of the cross-section of the orifice, wherein the path approaches the corner in the same direction as the flow of swirling water and wherein the corner comprises an at least 90° turn in the path in a direction away from the cone axis. Such an orifice perimeter step can e.g. be advantageous as it may allow the flow of swirling water to effectively lose contact with the surface of the orifice. At one moment the water may be flowing tangentially to the surface of the orifice and at the next moment, as the water passes over the orifice perimeter step, the water may be spun along a trajectory at an angle of at least 90° to the surface of the orifice. However, it should be understood that in some embodiments an angle below 90° may also be used, e.g. an angle of at least 45°. The rotational speed of the flow of swirling water may still allow the water to lose contact with the orifice surface.

[0030] According to an embodiment, the orifice perimeter step comprises a circular curve segment, wherein the circular curve segment connects two endpoints of the spiral segment. It may be fluid dynamically advantageous to have a rounded indentation of the orifice surface on the outside of the water flowing over the orifice perimeter step, as formed by the circular curve segment. Experiments and simulations have shown that this may give a desired slitted hollow cone spray, possibly with a cross-section forming an open curve spanning an angle above 360°. It is possible that a low pressure region formed in the rounded indentation sucks water into the indentation, the water following the rounded surface smoothly such that in the rounded indentation the water may have a velocity vector component in the reverse direction to the rotational motion of the rest of the swirling water. This may result in a cross-section of the slitted hollow cone spray having the shape of a spiral curve segment spanning an angle above 360°. Furthermore, an orifice perimeter step comprising a circular curve segment may be easy to manufacture as it may be created by milling.

[0031] According to an embodiment, the cross-section of the orifice that forms the orifice perimeter step extends an orifice depth in the main direction of the flow of swirling water, wherein the orifice depth is up to four times as long as the minimum radius of the orifice. It has been found that in such an embodiment, the water may interact sufficiently with the orifice perimeter step to create an effective disturbance of the rotational motion. At the same time such an interaction length is not too long so that unnecessary turbulence and energy losses may thereby be avoided.

[0032] According to an embodiment, the flow diverter comprises an orifice flange,
said orifice flange being formed by an orifice rim which is not confined to a single plane, wherein a protuberance out of a main orifice rim plane is configured such that a curve, defining the last contact between the water and the orifice rim as the water is being ejected from the orifice, does not form a closed curve.

[0033] It should be understood that the flange may be formed in many different shapes. The orifice rim may be shaped e.g. like a fin, a wedge or the bow of a ship. Water which flows on one side of the orifice flange may not be in contact with the water flowing on the other side of the orifice flange as it leaves the orifice rim. If a line is drawn along the last contact point between the water and the orifice rim and the line forms an open curve rather than a closed curve, then the water which is centrifugally spun outwards from that last contact point may be likely to retain a cross-section which also forms an open curve. Thus the cross-section of the slitted hollow cone spray, the cross-section being perpendicular to a cone axis, may form an open curve.

[0034] According to a second aspect of the present inventive concept there is provided a snow lance head for producing artificial snow, the snow lance head comprising:

a first water supply, said water supply being configured to supply a first flow of water;
a nozzle according to any one of the preceding claims, acting as a snow lance nozzle, wherein the water swirler of the snow lance nozzle is configured to receive and to guide the first flow of water;
a second water supply, said water supply being configured to supply a second flow of water;
a compressed air supply;
an ice nucleator nozzle, said ice nucleator nozzle being configured to receive the second flow of water from the second water supply, mix the second flow of water with compressed air from the compressed air supply and forcibly expel the mixture to form an ice nuclei jet, wherein the ice nuclei jet is directed into the slitted hollow cone spray such that artificial snow is formed.

[0035] Effects and features of the second aspect are largely analogous to those described in connection with the first aspect. Embodiments mentioned in relation to the first aspect are largely compatible with the second aspect.

[0036] A snow lance head according to the second aspect may have a long range and/or low close vicinity losses, i.e. it may deposit a large amount of snow far away from the snow lance head and a small amount of snow close to the snow lance head. Furthermore, the snow lance head may provide an efficient use of the ice nuclei jet. When water droplets are sucked into a low pressure region in the interior of a hollow cone spray they may slow down. By interacting with the ice nuclei jet these slow moving droplets may drain the ice nuclei jet from ice nuclei which would be of better use interacting with fast moving droplets which could fall out as snow further away. Therefore, a snow lance head comprising a snow lance nozzle for producing a slitted hollow cone spray may not need an ice nuclei jet which is as intense as if the snow lance nozzle produced a hollow cone spray without a slit. Thus the compressed air consumption and power consumption may be reduced.

[0037] According to a third aspect of the present inventive concept there is provided a method for producing a slitted hollow cone spray wherein the slitted hollow cone spray is formed by a spray curtain of water droplets, said spray curtain having the shape of a hollow cone with a slit, said slit forming a lateral air path into a hollow cone interior; the method comprising:

receiving a flow of water;
guiding the flow of water such that the water flows along a main direction while simultaneously acquiring a rotational motion which spirals around the main direction, thereby producing a flow of swirling water;
passing the flow of swirling water to a spray outlet;
ejecting the flow of swirling water through an orifice of the spray outlet while simultaneously disturbing the rotational motion of the flow of swirling water as the water is being ejected;
wherein ejecting the flow of swirling water and disturbing the rotational motion of the flow of swirling water forms a spray curtain of water droplets, the spray curtain having the shape of a conical surface with a lateral slit formed by disturbing the rotational motion of the flow of swirling water.

[0038] Effects and features of the third aspect are largely analogous to those described in connection with the first and second aspects. Embodiments mentioned in relation to the first and second aspects are largely compatible with the third aspect.

[0039] According to an embodiment of the third aspect, ejecting the flow of swirling water and simultaneously disturbing the rotational motion of the flow of swirling water comprises:
forming a cross-section of the slitted hollow cone spray, the cross-section being perpendicular to a cone axis, into an open curve spanning an angle of 330° to 390°.

BRIEF DESCRIPTION OF THE DRAWINGS

[0040] The above, as well as additional objects, features and advantages of the present inventive concept, will be better understood through the following illustrative and non-limiting detailed description, with reference to the appended drawings. In the drawings like reference numerals will be used for like elements unless stated otherwise.

Fig. 1a is a perspective view of a snow lance nozzle in operation.
Fig. 1b is an open curve.
Fig. 1c is an open curve.
Fig. 2 is a perspective view of a snow lance nozzle in operation.
Fig. 3 is a partial cross-sectional perspective view of a water swirler.
Fig. 4 is a partial cross-sectional perspective view of a water swirler.
Fig. 5 is a cross-sectional view of a spray outlet.
Fig. 6 is a perspective view of a spray outlet.
Fig. 7a is a top view of a spray outlet.
Fig. 7b is a curve.
Fig. 8a is a bottom view of a spray outlet.
Fig. 8b is a top view of a spray outlet.
Fig. 9 is a simulation of water velocity vectors.
Fig. 10 is a simulation of water velocity vectors.
Fig. 11 is a top view of a spray outlet.
Fig. 12a is a top view of a spray outlet.
Fig. 12b is a top view of a spray outlet.
Fig. 13a is a top view of a spray outlet.
Fig. 13b is a top view of a spray outlet.
Fig. 14 is a perspective view of a spray outlet in operation.
Fig. 15a-d schematically illustrates different shapes of a slitted hollow cone spray
Fig. 16 is a perspective view of a snow lance head.
Fig. 17 is a cross-sectional view of a snow lance head.
Fig. 18 is a cross-sectional view of a snow lance head in operation.
Fig. 19 is a flow chart of a method according to an embodiment.

DETAILED DESCRIPTION

[0041] In cooperation with attached drawings, the technical contents and detailed description of the present invention are described hereinafter according to preferable embodiments, being not used to limit the claimed scope. This invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided for thoroughness and completeness, and fully convey the scope of the invention to the skilled person.

[0042] Fig. 1a shows a snow lance nozzle 1, producing a slitted hollow cone spray 2. The slitted hollow cone spray 2 is formed by a spray curtain 4 of water droplets 6, wherein the spray curtain 4 has the shape of a hollow cone with a slit 8. The slit 8 forms a lateral air path 10 from the hollow cone exterior 12 into the hollow cone interior 14. The apex 16 of the slitted hollow cone spray 2 is situated at the orifice 40 of the snow lance nozzle 1 from which the water droplets 6 are ejected. Thus the slitted hollow cone spray 2 may be centered around a cone axis 18 which runs through the apex 16 and through the orifice 40 and the water droplets 6 travel such that most of the water may diverge from the cone axis 18.

[0043] A cross-section of the slitted hollow cone spray 2 perpendicular to a cone axis 18 may form an open curve 20, i.e. a curve with end points 26, 28 wherein the end points 26, 28 are not joined. Fig. 1b shows an open curve 20 formed by a cross-section of the slitted hollow cone spray 2, the cross section being taken relatively far from the snow lance nozzle. Fig. 1c shows an open curve 20 formed by a cross-section of the slitted hollow cone spray 2, the cross section being taken relatively close to the snow lance nozzle. It should be understood that the open curves 20 relatively far and relatively close to the snow lance nozzle may have the same shape and only differ by a scale factor or they may have different shapes. It should also be understood that gravity may affect the slitted hollow cone spray 2 such that the water droplets 6 travel along a trajectory which to some extent may deform the slitted hollow cone spray 2. This does not affect the scope of the inventive concept. Thus this text should be read with disregard to gravitational effects.

[0044] Fig. 2 shows a close-up view of a snow lance nozzle 1, producing a slitted hollow cone spray 2. The snow lance nozzle 1 comprises a water swirler 30 and a spray outlet 42, wherein the spray outlet 42 ejects the water from an orifice 40 as a spray curtain 4. The orifice 40 is shaped so as to define a flow diverter 44 which creates the slit 8, thus forming the spray curtain 4 into a slitted hollow cone spray 2.

[0045] The snow lance nozzle 1 may preferably be made of material which can withstand freezing temperatures and does not corrode when in contact with water, such as e.g. stainless steel or aluminum. The snow lance nozzle 1 may be produced as a single part or as several parts which may be connected by e.g. screw threads. In a preferred embodiment the snow lance nozzle is constructed as a separate water swirler 30 part and a spray outlet 42 part.

[0046] The snow lance nozzle 1 or the separate parts of the snow lance nozzle 1 may e.g. be manufactured from a solid block of e.g. metal, e.g. a metal cylinder, which may be shaped by means of drilling, milling,or the like, or combinations thereof. The snow lance nozzle 1 or the separate parts of the snow lance nozzle 1 may also be produced by other methods such as e.g. casting or 3D printing.

[0047] Fig. 3 and Fig. 4 show partial cross-sectional perspective views of a water swirler 30. The water swirler is configured to receive and to guide a flow of water 80 such that the water flows along a main direction 90 while simultaneously having a rotational motion which spirals around the main direction 90, thereby producing a flow of swirling water 82.

[0048] In a preferred embodiment the water swirler 30 is configured as a hollow cylinder, the hollow cylinder being symmetrical around a water swirler axis 34 wherein the water swirler axis 34 may define the main direction. Furthermore, the water swirler may have at least one tangential inlet 32 at a side wall.

[0049] The tangential inlet 32 may be configured such that the flow of water 80 enters the hollow cylinder essentially along a tangent to the side wall at a bottom portion of the hollow cylinder and then follows an essentially helical path along the inner surfaces of the hollow cylinder. Thus the flow of water may form a flow of swirling water 82 which moves as a film of water which covers the inner side walls of the hollow cylinder and moves with a rotational motion which spirals around the main direction 90. The at least one tangential inlet 32 may be orthogonal to the main direction 90 or have some vector component along the main direction 90.

[0050] The inner diameter of the hollow cylinder may be configured such that the film of water does not extend all the way in to the water swirler axis 34, this may affect the radial distribution of water in the slitted hollow cone spray 2. Furthermore, the cylinder diameter may affect the rotational speed of the flow of swirling water 82, thus affecting the apex angle of the slitted hollow cone spray 2. Additionally, the area of the at least one tangential inlet 32 may affect the apex angle of the slitted hollow cone spray 2, wherein a small tangential inlet 32 may lead to a large apex angle and a large tangential inlet 32 may lead to a small apex angle.

[0051] In a preferred embodiment the water swirler 30 comprises a connecting means, e.g. a screw thread 36, such that it may be connected to a spray outlet 42. The water swirler 30 may also comprise a connecting means, e.g. a screw thread 38, which allows the tangential inlet 32 to be connected to e.g. a snow lance head.

[0052] It should be understood that the water swirler 30 may not necessarily have the shape of a hollow cylinder, it may alternatively have the shape of another hollow body, preferably with a rounded internal shape e.g. conical. The at least one tangential inlet 32 may be round or rectangular or of another shape and it may extend over a small portion of the side wall or the entire side wall up to the point where the spray outlet 42 is connected.

[0053] Fig. 5 shows a cross-sectional view of a spray outlet 42 while Fig. 6 shows a perspective view of a spray outlet 42. The spray outlet 42 comprises an orifice 40 with a flow diverter 44. In Fig. 5 and Fig. 6 a preferred embodiment is illustrated wherein the spray outlet 42 is configured as an exchangeable insert comprising the orifice 40, such that the size of the orifice 40 and configuration of the flow diverter 44 may be easily modified. The spray outlet 42 may in a preferred embodiment comprise a connecting means such that it may be connected to the water swirler 30. The connecting means may be a screw thread 36 which corresponds to a screw thread 36 of the water swirler 30. However, it should be understood that the water swirler 30 and the spray outlet 42 may also be configured as one piece.

[0054] The spray outlet 42 may further comprise a funnel inlet 46 which receives the flow of swirling water 82 from the water swirler 30 and funnels it towards the orifice 40, wherein the water may retain its rotational motion while the rotational diameter is compressed. The funnel inlet 46 may be a cone shaped structure which may be symmetrical around an orifice axis 48 going essentially through the center of the orifice. It should however be understood that other suitable funnel shapes may be used, e.g. a half-spherical shape or the like. It should also be understood that if the diameter of the flow of swirling water 82 does not need to be compressed to pass through the orifice 40 in a suitable manner then the inlet may not need to be funnel shaped at all, it may e.g. be cylindrical. Furthermore, the spray outlet 42 may be configured such that the main direction 90 of the flow of swirling water 82 points through the orifice 40 along a normal to a main orifice rim plane. In a preferred embodiment wherein the water swirler 30 and the spray outlet 42 are separate parts this may be achieved by arranging the connecting means such that the water swirler axis 34 and the orifice axis 48 are the same.

[0055] Additionally, the flow diverter 44 may extend a certain distance along the main direction 90 of the flow of swirling water 82, that distance being the orifice depth 63 which in an embodiment is up to four times as long as the minimum radius of the orifice 40.

[0056] Fig. 7a shows a top view of a spray outlet 42 as seen from the water ejecting side. The spray outlet 42, having an orifice axis 48 going out of the plane of the figure, may be configured to receive a flow of swirling water 82 with a main direction 90 along the orifice axis 48 and a rotational direction 92. The rotational direction may be defined by the at least one tangential inlet 32 of the water swirler 30.

[0057] Fig. 7b illustrates a curve defining the perimeter 50 of the cross-section of the orifice 40 in Fig. 7a, wherein the cross-section is taken perpendicular to the main direction of the flow of swirling water 82. In a preferred embodiment the orifice 40 is shaped such that the perimeter 50 of the cross-section of the orifice 40 comprises a curve in the form of a spiral segment 52 with two endpoints 54, wherein the two endpoints are connected by a circular curve segment 56 and the ratio between the maximum 58 and the minimum 60 radius of the spiral segment is at least 5/3. However, it should be understood that other embodiments also are possible.

[0058] It should be understood that whether a snow lance nozzle 1 functions satisfactory depends on many different parameters, e.g. the dimensions and orientation of the tangential inlets 32, the inner diameter of the water swirler 30, the shape and dimensions of the orifice 40, and the volumetric flow rate of the water passing through the snow lance nozzle 1. The relationship between these parameters is complex and many different parameter settings may give an equally satisfactory performance of the snow lance nozzle 1. It should be understood that a specific snow lance nozzle which works well at one volumetric flow rate may not work as well at another volumetric flow rate. Nevertheless, a snow lance nozzle 1 may work well over a range of volumetric flow rates.

[0059] An example of an embodiment of the snow lance nozzle 1 which works well at a volumetric flow rate of 25 l/min (of water passing through the snow lance nozzle) may be given. In this embodiment the snow lance nozzle 1 has two tangential inlets 32 orthogonal to the main direction 90, wherein the diameter of the tangential inlets 32 is 4.5 mm. Furthermore, the inner diameter of the water swirler 30 is 10 mm. The spray outlet 42 has an orifice 40 shaped such that the perimeter 50 of the cross-section of the orifice 40 comprises a curve in the form of a spiral segment 52, wherein the maximum radius 58 of the spiral segment is 5.4 mm and the minimum radius 60 of the spiral segment is 3.2 mm.

[0060] Another example of an embodiment of the snow lance nozzle 1 which works well at a volumetric flow rate of 50 l/min (of water passing through the snow lance nozzle) may be given. In this embodiment the snow lance nozzle 1 has two tangential inlets 32 orthogonal to the main direction 90, wherein the diameter of the tangential inlets 32 is 6 mm. Furthermore, the inner diameter of the water swirler 30 is 10 mm. The spray outlet 42 has an orifice 40 shaped such that the perimeter 50 of the cross-section of the orifice 40 comprises a curve in the form of a spiral segment 52, wherein the maximum radius 58 of the spiral segment is 6.4 mm and the minimum radius 60 of the spiral segment is 3.8 mm.

[0061] It should however be understood that these embodiments also may work satisfactory in a volumetric flow rate range around the given values of the volumetric flow rate. It should also be understood that other variations of the dimensions given may also work well at the volumetric flow rate and within the volumetric flow rate range. It should also be understood that the snow lance nozzle may alternatively be designed to work satisfactory within a different volumetric flow rate range.

[0062] In a preferred embodiment the flow of swirling water 82 may be ejected as a slitted hollow cone spray 2 where the cone axis 18 may be essentially the same as the orifice axis 48. It may herein be the centrifugal force during the ejection of the water that causes the spray curtain 4 to diverge from the cone axis 18 as the water droplets 6 move away from the orifice 40. The shape of the orifice 40 may form an orifice perimeter step 62 which may act as a flow diverter 44. As the flow of swirling water 82 rotationally passes over the orifice perimeter step 62 the water may be centrifugally spun outwards which may be what causes the slit 8 to form in the slitted hollow cone spray 2.

[0063] Fig 8a and 8b schematically illustrates a path 64 of a water molecule as it approaches and pass over the orifice perimeter step 62. Fig. 8a is a bottom view of a spray outlet 42, seen from the water swirler 30 side, and Fig. 8b is a top view of a spray outlet 42, seen from the water ejecting side. Fig. 8a and 8b illustrates one way the water may be diverted as it passes over the orifice perimeter step 62. In this example the water also loses contact with the surface of the orifice 40 as the flow of swirling water 82 rotationally passes over the orifice perimeter step 62. However, a redirection of the flow without the water losing contact may also suffice.

[0064] It should be understood that different water molecules may have slightly different paths 64 such that the water may form a film completely covering the inner walls of the water swirler 30 and the funnel inlet 46 as the water approaches the orifice 40. It should also be understood that not all water molecules necessarily pass over the orifice perimeter step 62. Some may miss the orifice perimeter step 62 altogether. Some may pass over the orifice perimeter step 62 and lose contact with the surface of the orifice 40 after which they again hit an orifice 40 surface and leave the orifice rim at another point, away from the orifice perimeter step 62. Some may also pass over the over the orifice perimeter step 62 and continue in free flight without reconnecting with the orifice 40.

[0065] One factor that may affect the creation of the slit 8 may be that the last contact between the water and the orifice 40 as the water is being ejected from the orifice 40, forms an open curve. The opening in the curve may e.g. correspond to a segment of the perimeter 50 of the cross-section of the orifice 40 which is missed by water which loses contact with the orifice 40 surface as it rotationally passes over an orifice perimeter step 62, e.g. part of the circular curve segment 56 in Fig. 7b. Thus a cross-section of the slitted hollow cone spray 2 may also form an open curve. Another factor may be that the last contact between the water and the orifice 40 as the water is being ejected from the orifice 40, forms a closed curve but where less water passes over a particular segment of the curve than over the other segments of the curve. Another factor may be that water leaving the orifice 40 by passing over the orifice perimeter step 62 at some distance into the orifice 40, the step herein forming an edge parallel to the main direction 90, may have a slightly different angle towards the cone axis 18 than water leaving the orifice 40 by passing over an edge along the orifice rim where the edge is perpendicular to the main direction 90. Another factor may be that when the flow of swirling water 82 loses contact with the surface of the orifice 40 a low pressure region may be created on the outside of the water flowing over the orifice perimeter step 62, in Fig. 7a close to the circular curve segment 56, in accordance with Bernoulli's principle. The low pressure region may help to locally disturb the rotational motion such that the slit is opened up.

[0066] Support for the latter theory may be found in computational fluid dynamics simulations. Fig. 9 and Fig. 10 show such simulations of water velocity vectors 66 at a cross-section of the orifice rim as seen from the water ejecting side. The simulations indicate that a low pressure may be formed in a region below an orifice perimeter step 62, in this case at a circular curve segment 56, wherein water may be sucked into this low pressure region such that the low pressure helps to divert the water. In Fig. 9 and 10 it seems like water may follow the orifice rim smoothly such that it receives a velocity vector component in the reverse direction to the rotational motion of the rest of the swirling water while still leaving a region just below the orifice perimeter step 62 where less water leaves the orifice rim. Such a region where less water leaves the orifice rim may give rise to a slit 8 opening up to form a slitted hollow cone spray 2. Furthermore, a velocity vector component in the reverse direction to the rotational motion of the rest of the swirling water may give rise to the slitted hollow cone spray 2 having the shape of a spiral curve segment spanning an angle above 360°.

[0067] It should be understood that the preferred embodiment wherein the cross-section of the orifice comprises a curve in the form of a spiral segment and wherein a circular curve segment 56 connects the two endpoints 54 of the spiral segment 52 may be implemented in different ways. For example, the spiral segment may have a fixed center point wherein part of the spiral segment may have a radius, measured from the fixed center point, which continuously increases as the spiral segment curve is followed in a direction opposite to the rotational direction 92 of the flow of swirling water 82. It should herein be understood that whether the spiral segment 52 winds clockwise or counter-clockwise is dependent on whether the flow of swirling water 82 has a rotational direction 92 clockwise or counter-clockwise, as apparent when Fig. 11 is compared to Fig. 8b, the two embodiments being arranged for different rotational directions 92.

[0068] The continuous increase in radius may be described in a two dimensional polar coordinate system as where the radius (r) is a monotonic continuous function of an angle (θ). Examples of spirals may be:

Archimedean spiral: $r=a+b^*\theta$, wherein a and b are constants
Fermat's spiral: $r=\theta^{1/2}$

[0069] The logarithmic spiral: $r= a^*e^{b^*\theta}$, wherein a and b are constants, e is Euler's number.

[0070] It should also be understood that the spiral segment may be a segment represented by one of the spirals above or any other spiral wherein θ spans a specific range, e.g. $180° < \theta < 360°$, or $0° < \theta < 360°$, or $180° < \theta < 370°$.

[0071] Another part of the spiral segment may have a constant radius, measured from the fixed center point. For example,
$r=c$, wherein c is a constant
in a specific range, e.g. $0° < \theta < 180°$.

[0072] A circular curve segment 56 may connect the two endpoints of the spiral segment. It should be understood that if the spiral segment spans $0° < \theta < 360°$ then the circular curve segment 56 may be a half circle with a diameter that equals the difference between the maximum 58 and the minimum 60 radius of the spiral segment. However, other circular curve segments 56 may also be possible with other diameters and other arc lengths, e.g. a quarter circle or 5/8 of a circle.

[0073] It should also be understood that embodiments without the circular curve segment 56 may be possible. For example, non-circular rounded curve may connect the two endpoints 54 of the spiral segment 52. Furthermore, although a rounded curve may be preferred from a fluid dynamics point of view a straight line connecting the two endpoints 54 of the spiral segment 52 may also suffice. For example, in Fig. 12a a straight line forming a 90° corner to the spiral segment 52 endpoint 54 with the smallest radius may create an orifice perimeter step

62 such that a path approaching the orifice perimeter step 62 along the spiral segment 52 in the same direction as the flow of swirling water forms a 90° turn in the path in a direction away from the cone axis. In another example, in Fig. 12b a straight line forming a more than 90° corner to the spiral segment 52 endpoint 54 with the smallest radius may create an orifice perimeter step 62 such that a path approaching the orifice perimeter step 62 along the spiral segment 52 in the same direction as the flow of swirling water forms more than 90° turn in the path in a direction away from the cone axis.

[0074] It should also be understood that the orifice perimeter step 62 may be constructed in alternative ways. Such as e.g. simply drilling a flow diverting hole 68 joined with a round orifice 40 hole as illustrated in Fig. 13a. Another way may be to mount a blade 70 or hydrofoil in a round orifice 40 hole as illustrated in Fig. 13b.

[0075] Fig. 14 illustrates one embodiment wherein the flow diverter 44 comprises an orifice flange 72. The snow lance nozzle 1 may herein define a nozzle, wherein the last contact between the water and the orifice rim may define a main orifice rim plane 74, with the addition of an orifice flange 72. The orifice flange 72 may then be a protuberance out of the main orifice rim plane 74 such that part of the water being ejected flows along the surface of the orifice flange 72 instead of going into free flight at the main orifice rim plane. The orifice flange 72 may be shaped such that when the water flows over the surface of the orifice flange 72 it is slightly redirected from the trajectory it would have, had the orifice flange 72 not been there. Thus the orifice flange 72 may open up a slit 8 in the hollow cone spray, thereby producing a slitted hollow cone spray 2. The orifice flange 72 may be shaped like a wedge, a fin, a blade or the bow of a ship which cuts the slit 8 into the hollow cone spray. The orifice flange 72 may be configured such that a curve 76, defining the last contact between the water and the orifice rim as the water is being ejected from the orifice 40, does not form a closed curve, i.e. that it has end points which are not connected to each other. It should be understood that even if the curve 76 touches itself at a point some distance from the end points a slitted hollow cone spray 2 may still be formed. In Fig. 14 a cross-section of the slitted hollow cone spray 2 is illustrated using dotted lines while the curve 76, defining the last contact between the water and the orifice rim as the water is being ejected from the orifice 40, is illustrated using a dashed line. Furthermore, it should be understood that when an orifice flange 72 is used a cross-section of the orifice 40 below the main orifice rim plane 74 may have either a circular shape or a shape comprising a spiral segment or another shape.

[0076] Fig. 15a-d show slitted hollow cone sprays 2 of different shapes, all of which being within the inventive concept. It should be understood that the snow lance nozzle 1 may be configured to produce a slitted hollow cone spray 2 wherein a cross-section of the slitted hollow cone spray 2, the cross-section being perpendicular to the cone axis 18, forms an open curve 20 spanning an angle 22. The angle 22 may be defined by the angle spanned when moving from one end point of the open curve 20 to the other end point, around the centroid of the open curve 20. The snow lance nozzle 1 may be configured to produce a slitted hollow cone spray 2 wherein the angle 22 is greater than 360°, as in Fig. 15a, or smaller than 360°, as in Fig. 15c, or exactly 360°. In a preferred embodiment the open curve 20 spans an angle 22 of 270° to 450°. In a further preferred embodiment the open curve 20 spans an angle 22 of 330° to 390°. It should be understood that the open curve 20 may be of different forms. For example, the open curve 20 may be a spiral curve segment, e.g. as in Fig. 15b, it may also be a segment of a circle, e.g. as in Fig 15c, it may also be a combination of a circle segment and a spiral curve segment, or it may have any other shape. The shape of the open curve 20 formed by the cross-section of the slitted hollow cone spray 2 may to some extent reflect the shape of part of the perimeter 50 of a cross-section of the orifice 40. A spiral shaped orifice 40 cross-section may give rise to a spiral shaped slitted hollow cone spray 2 cross-section. However, it should be understood that there may be differences which may originate from fluid dynamic effects such as e.g. pressure differences along the orifice rim. Furthermore, it should be understood that the use of an orifice with several flow diverters 44 to produce several slits 8, as illustrated in Fig. 15d, is within the inventive concept.

[0077] The angle 22 spanned by the open curve 20 may e.g. be affected by the ratio between the maximum 58 and minimum 60 radius (see e.g. Fig. 7b) of the spiral segment 52 of the perimeter 50 of the cross-section of the orifice 40. It should be understood that said ratio may affect the shape of the cross-section of the slitted hollow cone spray 2 and thus the width of the slit 8 which may be roughly equal to the difference between the maximum and minimum radius of the spiral curve segment of the open curve 20 formed by the cross-section of the slitted hollow cone spray 2. Said ratio may also affect the angle 22. Both the width of the slit 8 and the angle 22 may affect the airflow into the slitted hollow cone spray 2. The reason why the ratio between the maximum 58 and minimum 60 radius may affect the angle 22 may be that it affects where the water reconnects with the surface of the orifice 40 when the flow of swirling water 82 rotationally passes over the orifice perimeter step, i.e. how big the overshoot is. A large overshoot may give rise to an angle 22 smaller than 360°. It should also be understood that the overshoot may also depend on other factors of the snow lance nozzle 1, such as the configuration of the water swirler 30. The water swirler 30 may affect the rotational speed of the flow of swirling water 82 and thus affect the overshoot. For example, the angle between a water injection direction of a tangential inlet 32 and the water swirler axis 34 may affect the rotational speed of the flow of swirling water 82 as it may define how much of the water speed is transferred into a rotational motion and how much is transferred into a forward motion along the main direction

90. Additionally, the areal size of the at least one tangential inlet 32 may affect the water pressure and thus the rotational speed. Furthermore, fluid dynamic effects such as a low pressure region created on the outside of the water flowing over the orifice perimeter step 62 may suck the water passing over the orifice perimeter step 62 backwards relative to the rotational direction 92. This may give rise to an angle 22 greater than 360°.

[0078] The snow lance nozzle 1 may in a preferred embodiment be configured to produce a slitted hollow cone spray 2 with a cone apex angle 24 within a range of 15° to 90°. The cone apex angle 24 may be affected by e.g. the areal size of the at least one tangential inlet 32 of the water swirler 30.

[0079] It should be understood that the shape of the cross-section of the slitted-hollow cone spray 2, the angle 22 spanned and the cone apex angle 24 may be linked to many different parameters of the snow lance nozzle 1 such that a particular slitted hollow cone spray 2 may be achieved in several different ways.

[0080] The inventive concept includes a snow lance head 100 for producing artificial snow, wherein the snow lance head 100 comprises any of the embodiments of the snow lance nozzle 1 described above or derived therefrom. Fig. 16 and 17 show an embodiment of a snow lance head 100. Fig. 16 is a side view of the snow lance head 100 and Fig. 17 is cross-sectional view of the snow lance head 100. The snow lance head 100 may comprise at least one snow lance nozzle 1 and at least one ice nucleator nozzle 102. The at least one ice nucleator nozzle 102 may be configured so that it may inject ice nuclei in the slitted hollow cone spray 2 of at least one of the at least one snow lance nozzles 1. However, it should be understood that one ice nucleator nozzle 102 may serve several snow lance nozzles 1. In Fig. 16 and 17 the nozzles are arranged in groups such that each of the two ice nucleator nozzle 102 serves two snow lance nozzles 1, wherein the one ice nucleator nozzle 102 and two snow lance nozzles 1 within each group are pointed in roughly the same direction. Furthermore, it should be understood that snow lance nozzles 1 producing slitted hollow cone sprays 2 may be combined with snow lance nozzles producing non-slitted hollow cone sprays.

[0081] The snow lance nozzle 1 may further comprise a body 104 having at least one first water supply 106, at least one second water supply 108 and at least one compressed air supply 110. The at least one first water supply 106 may be an internal channel within the body 104 which may be connected to a water source, e.g. a water pump, at one end and may be connected to the at least one tangential inlet 32 of the water swirler 30 of the at least one snow lance nozzle 1. Analogously, the at least one second water supply 108 may be an internal channel within the body 104 which connects the at least one ice nucleator nozzle 102 to a water source. The at least one compressed air supply 110 may be an internal channel which may be connected to a source of compressed air, e.g. an air compressor, at one end and may be connected to the at least one ice nucleator nozzle 102 at the other end. It should be understood that each of the internal channels may be configured to serve one single or several nozzles. In Fig. 17 each snow lance nozzle 1 has its own first water supply 106. This may be advantageous as individual nozzles or individual groups of nozzles may be turned on or off separately, depending on e.g. how large total flow of water the ambient freezing temperature may sustain. However, different nozzles may also share a water supply so that e.g. two snow lance nozzles 1 share one single first water supply 106. The snow lance head 100 may be configured so that the second water supply 108 is separate from the first water supply 106, as shown in Fig. 17, as the snow lance nozzle 1 and the ice nucleator nozzle 102 often operate at different water pressures.

[0082] The snow lance head 100 may preferably be made of material which can withstand freezing temperatures and does not corrode when in contact with water, such as e.g. stainless steel or aluminum. The snow lance head 100 may be produced as a single part or as several parts which may be connected by e.g. screw threads. In a preferred embodiment the at least one snow lance nozzle 1, the at least one ice nucleator nozzle 102 and the body are all separate parts which may be screwed together. Each part may then comprise further parts. The body may be configured to have threaded seats 116, into which the at least one snow lance nozzle 1 and the at least one ice nucleator nozzle 102 may be screwed. The snow lance head 100 or the separate parts of the snow lance head 100 may e.g. be manufactured from a solid block of e.g. metal, e.g. a metal cylinder, which may be shaped by means of drilling, milling, or the like, or combinations thereof. The snow lance head 100 or the separate parts of the snow lance head 100 may also be produced by other methods such as e.g. casting or 3D printing.

[0083] Fig. 18 shows a cross-sectional view of a snow lance head 100 in use, wherein a cross-section of a slitted hollow cone spray 2 and an ice nuclei jet 112 can be seen. In Fig. 18 the first water supply 106 for the snow lance nozzle 1 furthest away from the ice nucleator nozzle 102 is turned off. This snow lance nozzle 1 is therefore not in operation. The snow lance nozzle 1 closest to the ice nucleator nozzle 102 receives a flow of water 80 from its first water supply 106. The flow of water 80 flows into the snow lance nozzle 1 via tangential inlets 32, wherein a flow of swirling water 82 is produced. As the flow of swirling water 82 is ejected through the orifice 40, the orifice 40 having a flow diverter 44 (the flow diverter 44 is not visible in this figure), a spray curtain 4 of water droplets 6 in the shape of a slitted hollow cone spray 2 is produced. The ice nucleator nozzle 102 receives a second flow of water 114 from the second water supply 108 and mixes it with compressed air from the compressed air supply 110. The mixture is subsequently expelled through an orifice. The compressed air may then expand and cool, thereby creating the ice nuclei jet 112 which is directed into the slitted hollow cone spray 2. How to configure such an ice nucleator nozzle 102 is considered to be well within the capability of a person of ordinary skill in the art.

[0084] Fig. 19 shows a flow chart of a method for producing a slitted hollow cone spray 2 wherein the slitted hollow cone spray 2 is formed by a spray curtain 4 of water droplets 6, said spray curtain 4 having the shape of a hollow cone with a slit 8, said slit 8 forming a lateral air path 10 into a hollow cone interior 14. The method comprises:

receiving 120 a flow of water 80;
guiding 130 the flow of water 80 such that the water flows along a main direction 90 while simultaneously acquiring a rotational motion which spirals around the main direction 90, thereby producing a flow of swirling water 82;
passing 140 the flow of swirling water 82 to a spray outlet 42;
ejecting 150 the flow of swirling water 82 through an orifice 40 of the spray outlet 42 while simultaneously disturbing the rotational motion of the flow of swirling water 82 as the water is being ejected;
wherein ejecting the flow of swirling water 82 and disturbing the rotational motion of the flow of swirling water 82 forms a spray curtain 4 of water droplets 6, the spray curtain 4 having the shape of a conical surface with a lateral slit 8 formed by disturbing the rotational motion of the flow of swirling water 82.

[0085] It should be understood that disturbing the rotational motion of the flow of swirling water 82 may be done by locally diverting the water by passing it over e.g. an orifice perimeter step 62, creating a high or low pressure point at at least one point along the orifice rim wherein the pressure is high or low in comparison to the pressure at the rest of the orifice rim, or guiding the water along an orifice flange 72. Furthermore, it should be understood that the method may be implemented with one of the apparatuses described in this text or with another apparatus. The method may preferentially be configured to form a slitted hollow cone spray 2 with a cross-section, the cross-section being perpendicular to the cone axis 18, into an open curve 20 spanning an angle of 330° to 390°.

[0086] In the above the inventive concept has mainly been described with reference to a limited number of examples. However, as is readily appreciated by a person skilled in the art, other examples than the ones disclosed above are equally possible within the scope of the inventive concept, as defined by the appended claims.

Claims

1. A nozzle for a snowmaking apparatus for producing a slitted hollow cone spray wherein the slitted hollow cone spray is formed by a spray curtain of water droplets, said spray curtain having the shape of a hollow cone with a slit, said slit forming a lateral air path into a hollow cone interior; the nozzle comprising:

   a water swirler configured to receive and to guide a flow of water such that the water flows along a main direction while simultaneously having a rotational motion which spirals around the main direction, thereby producing a flow of swirling water;
   a spray outlet configured to receive the flow of swirling water from the water swirler and to eject the flow of swirling water through an orifice,

   wherein the orifice is shaped so as to define a flow diverter configured to locally disturb the rotational motion of the flow of swirling water as the water is being ejected;
   whereby the spray outlet is configured to eject a spray curtain of water droplets, the spray curtain having the shape of a conical surface with a lateral slit formed by the flow diverter.

2. The nozzle of claim 1, wherein the water swirler and the orifice are further configured such that a cross-section of the slitted hollow cone spray, the cross-section being perpendicular to a cone axis, forms an open curve spanning an angle of 270° to 450°.

3. The nozzle of claim 1 or 2, wherein the water swirler and the orifice are further configured such that a cross-section of the slitted hollow cone spray, the cross-section being perpendicular to a cone axis, forms an open curve spanning an angle of 330° to 390°.

4. The nozzle of claim 2 or 3, wherein the open curve comprises a spiral curve segment.

5. The nozzle of any of the preceding claims, wherein the flow diverter comprises an orifice perimeter step, said orifice perimeter step being a kink in a curve, wherein the curve defines a perimeter of a cross-section of the orifice, the cross-section being taken perpendicular to the main direction of the flow of swirling water,
   wherein the orifice perimeter step is configured to divert the flow of swirling water in a direction away from the cone axis such that the flow of swirling water rotationally passing over the orifice perimeter step is centrifugally spun outwards, thereby locally disturbing the rotational motion of the flow of swirling water to produce a slitted hollow cone spray.

6. The nozzle of claim 5, wherein the orifice perimeter step is configured such that the flow of swirling water loses contact with a surface of the orifice as the flow

of swirling water rotationally passes over the orifice perimeter step.

7. The nozzle of claim 5 or 6, wherein the perimeter of the cross-section of the orifice comprises a curve in the form of a spiral segment.

8. The nozzle of claim 7, wherein the ratio between a maximum radius of the spiral segment and a minimum radius of the spiral segment is at least 5/3.

9. The nozzle of claim 7 or 8, wherein the orifice perimeter step comprises a corner in a path along the perimeter of the cross-section of the orifice, wherein the path approaches the corner in the same direction as the flow of swirling water and wherein the corner comprises an at least 90° turn in the path in a direction away from the cone axis.

10. The nozzle of any of claim 7 to 9, wherein the orifice perimeter step comprises a circular curve segment, wherein the circular curve segment connects two endpoints of the spiral segment.

11. The nozzle of any of claim 5 to 10, wherein the cross-section of the orifice that forms the orifice perimeter step extends an orifice depth in the main direction of the flow of swirling water, wherein the orifice depth is up to four times as long as the minimum radius of the orifice.

12. The nozzle of any of claim 1 to 4, wherein the flow diverter comprises an orifice flange,
said orifice flange being formed by an orifice rim which is not confined to a single plane, wherein a protuberance out of a main orifice rim plane is configured such that a curve, defining the last contact between the water and the orifice rim as the water is being ejected from the orifice, does not form a closed curve.

13. A snow lance head for producing artificial snow, the snow lance head comprising:

a first water supply, said water supply being configured to supply a first flow of water;
a nozzle according to any one of the preceding claims, acting as a snow lance nozzle, wherein the water swirler of the snow lance nozzle is configured to receive and to guide the first flow of water;
a second water supply, said water supply being configured to supply a second flow of water;
a compressed air supply;
an ice nucleator nozzle, said ice nucleator nozzle being configured to receive the second flow of water from the second water supply, mix the second flow of water with compressed air from the compressed air supply and forcibly expel the mixture to form an ice nuclei jet, wherein the ice nuclei jet is directed into the slitted hollow cone spray such that artificial snow is formed.

14. A method for producing a slitted hollow cone spray wherein the slitted hollow cone spray is formed by a spray curtain of water droplets, said spray curtain having the shape of a hollow cone with a slit, said slit forming a lateral air path into a hollow cone interior; the method comprising:

receiving a flow of water;
guiding the flow of water such that the water flows along a main direction while simultaneously acquiring a rotational motion which spirals around the main direction, thereby producing a flow of swirling water;
passing the flow of swirling water to a spray outlet;
ejecting the flow of swirling water through an orifice of the spray outlet while simultaneously disturbing the rotational motion of the flow of swirling water as the water is being ejected;
wherein ejecting the flow of swirling water and disturbing the rotational motion of the flow of swirling water forms a spray curtain of water droplets, the spray curtain having the shape of a conical surface with a lateral slit formed by disturbing the rotational motion of the flow of swirling water.

15. The method of claim 14, wherein ejecting the flow of swirling water and simultaneously disturbing the rotational motion of the flow of swirling water comprises:

forming a cross-section of the slitted hollow cone spray, the cross-section being perpendicular to a cone axis, into an open curve spanning an angle of 330° to 390°.

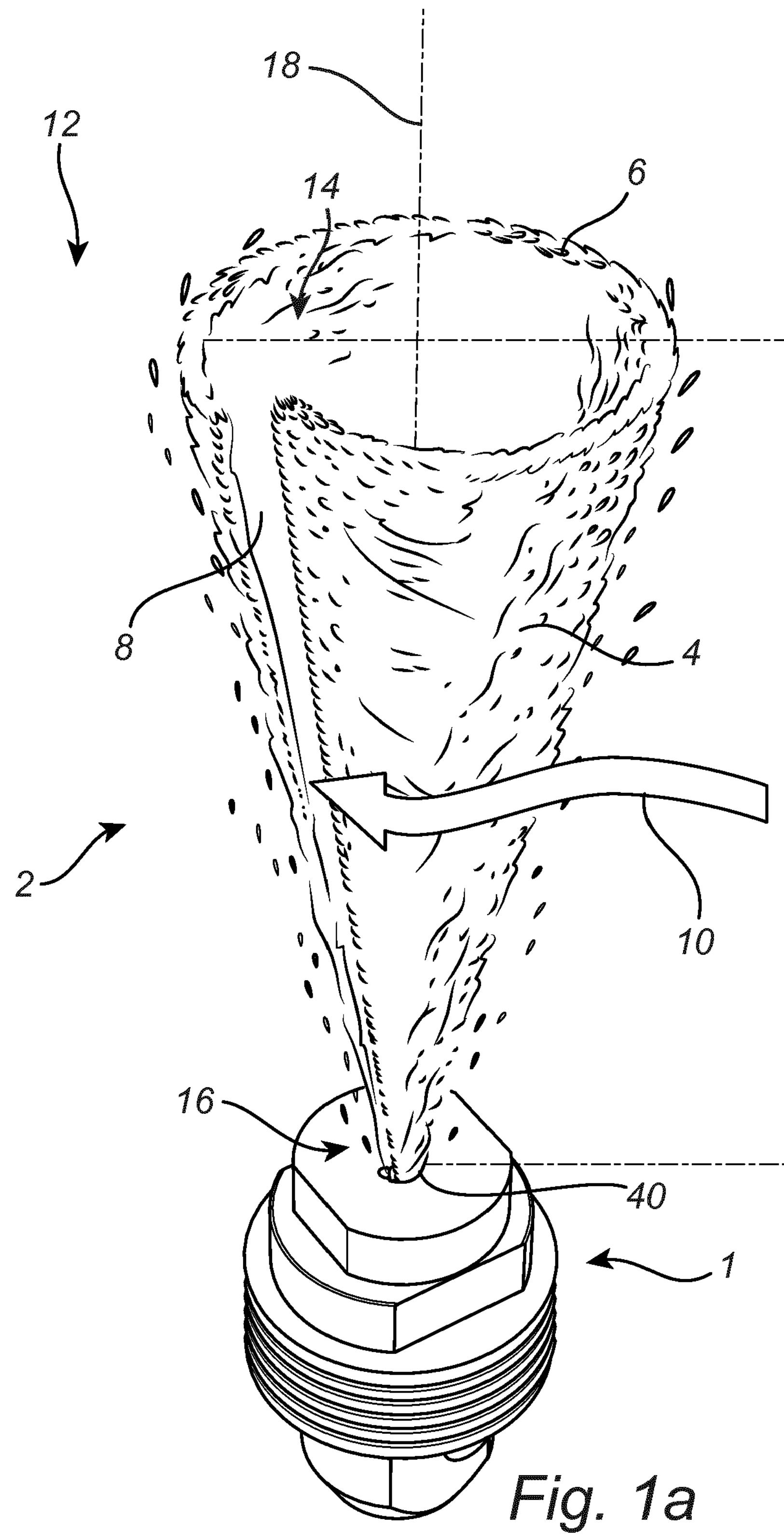

Fig. 1a

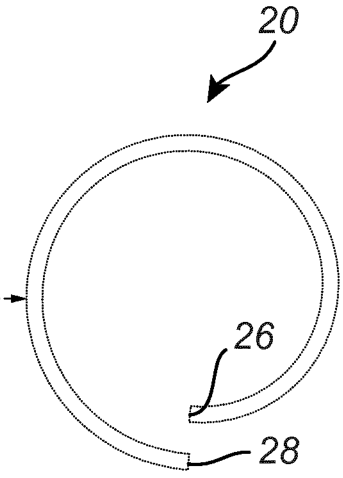

Fig. 1b

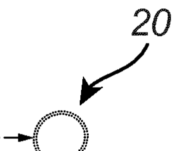

Fig. 1c

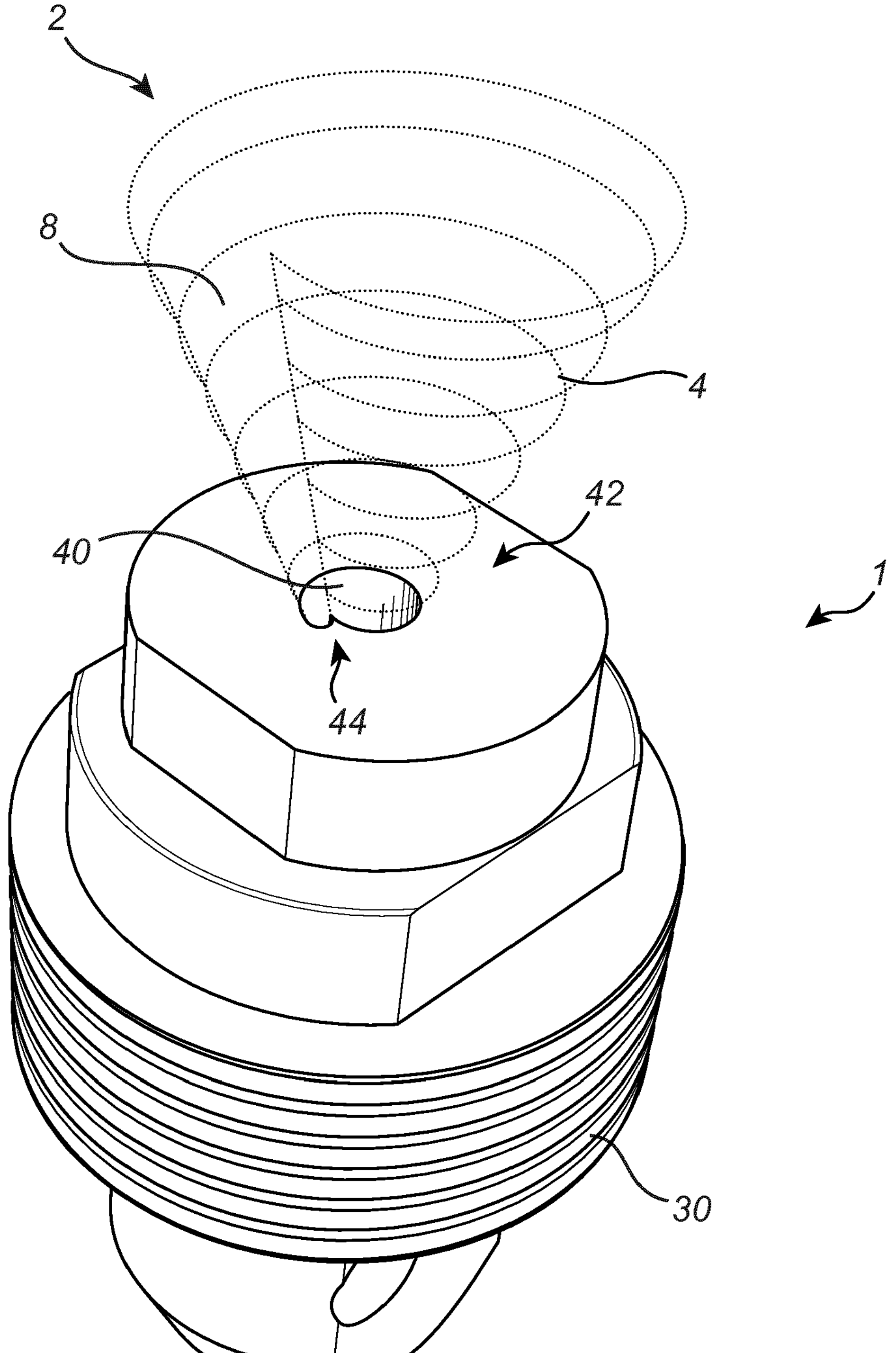

Fig. 2

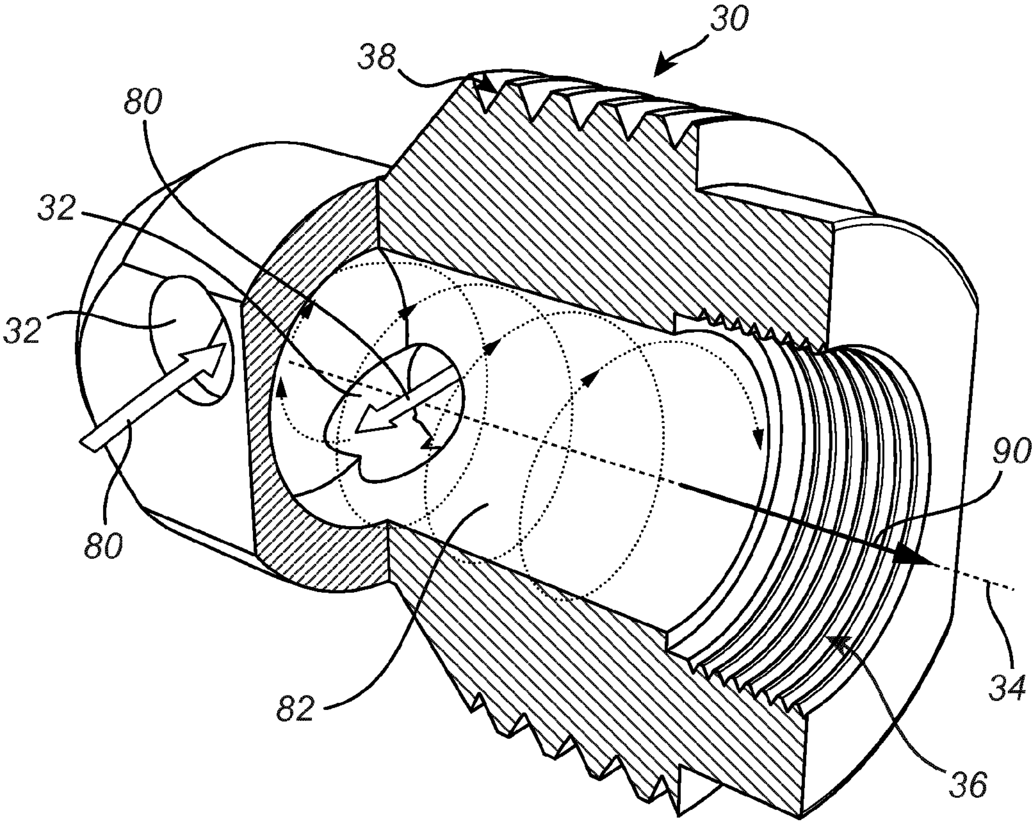

Fig. 3

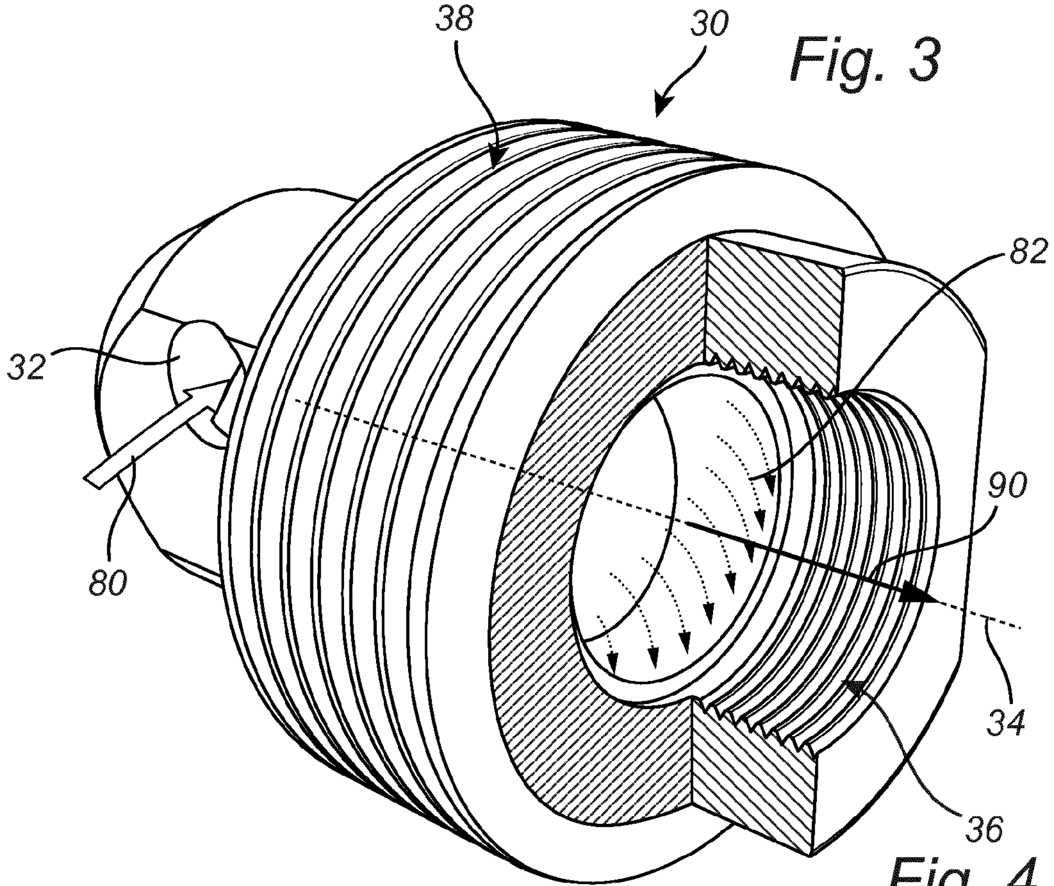

Fig. 4

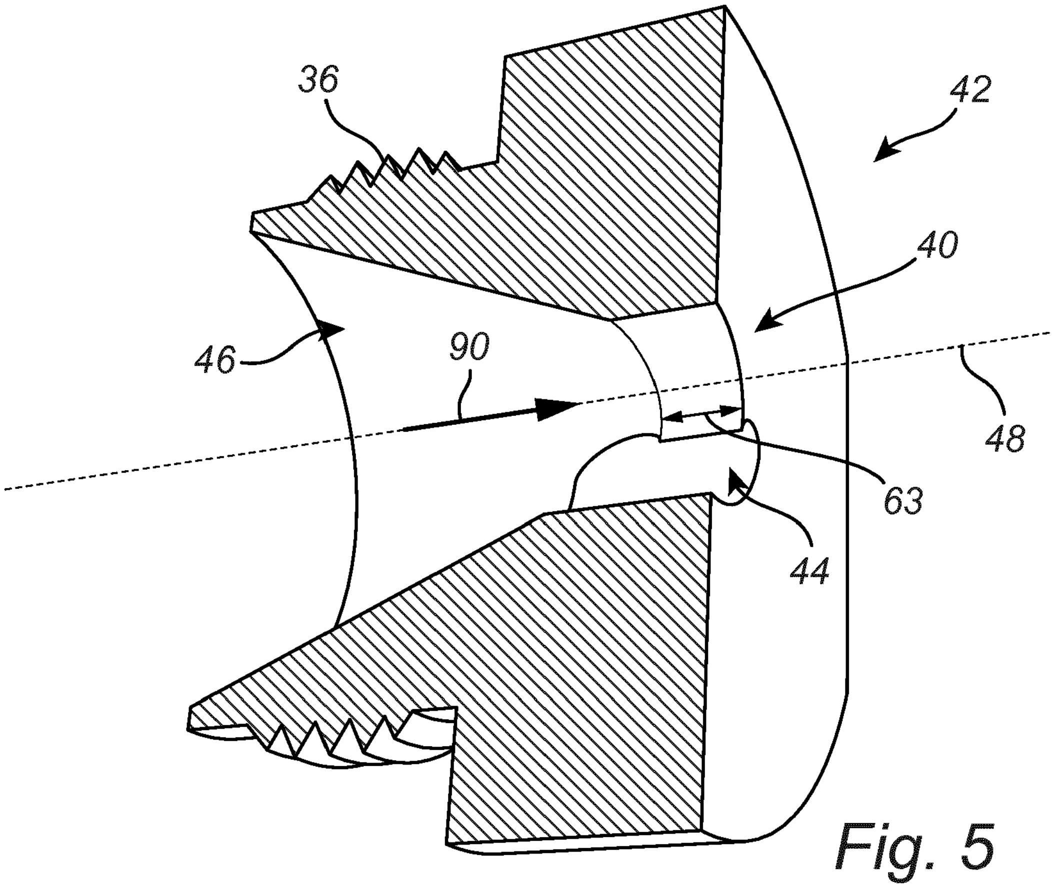

Fig. 5

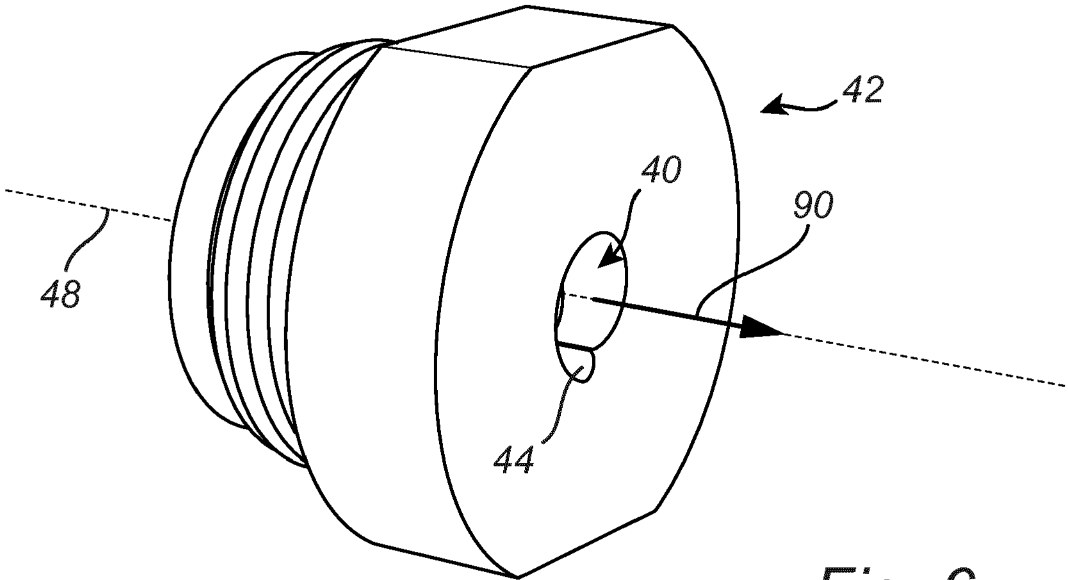

Fig. 6

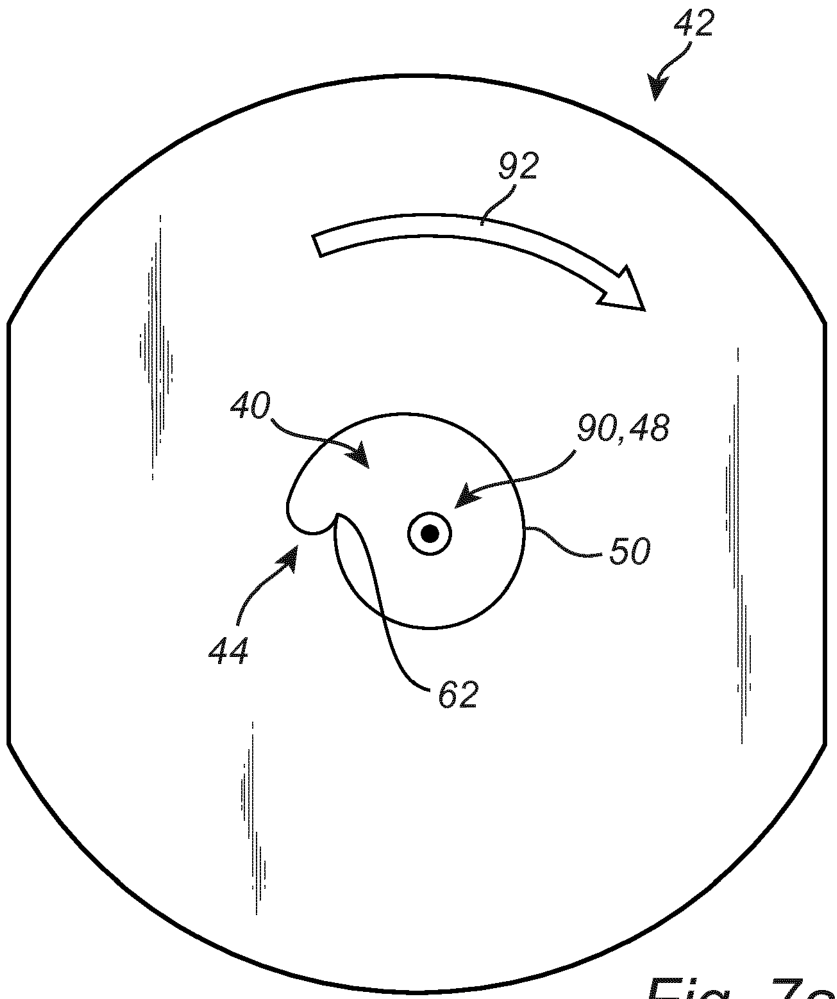

Fig. 7a

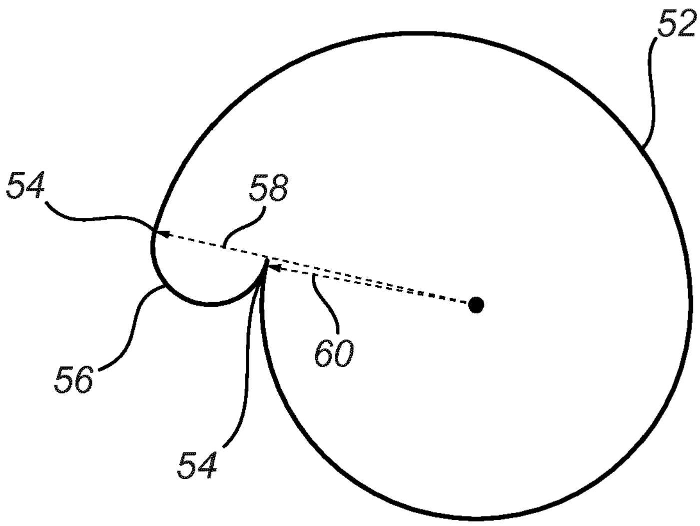

Fig. 7b

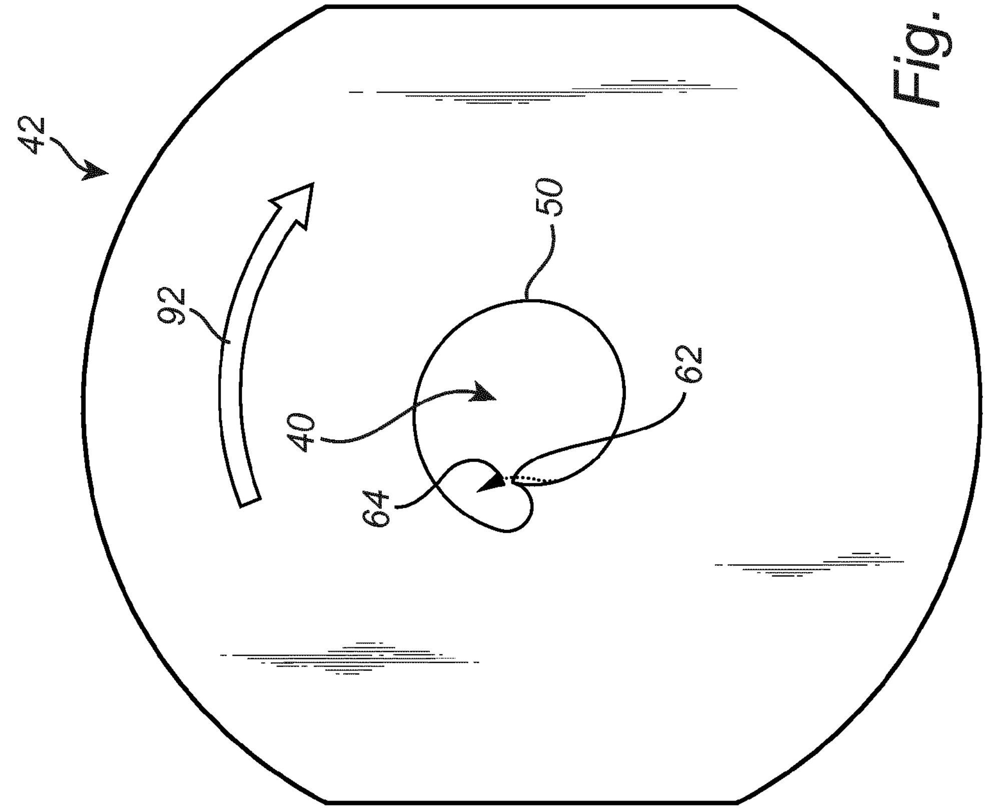

Fig. 8b

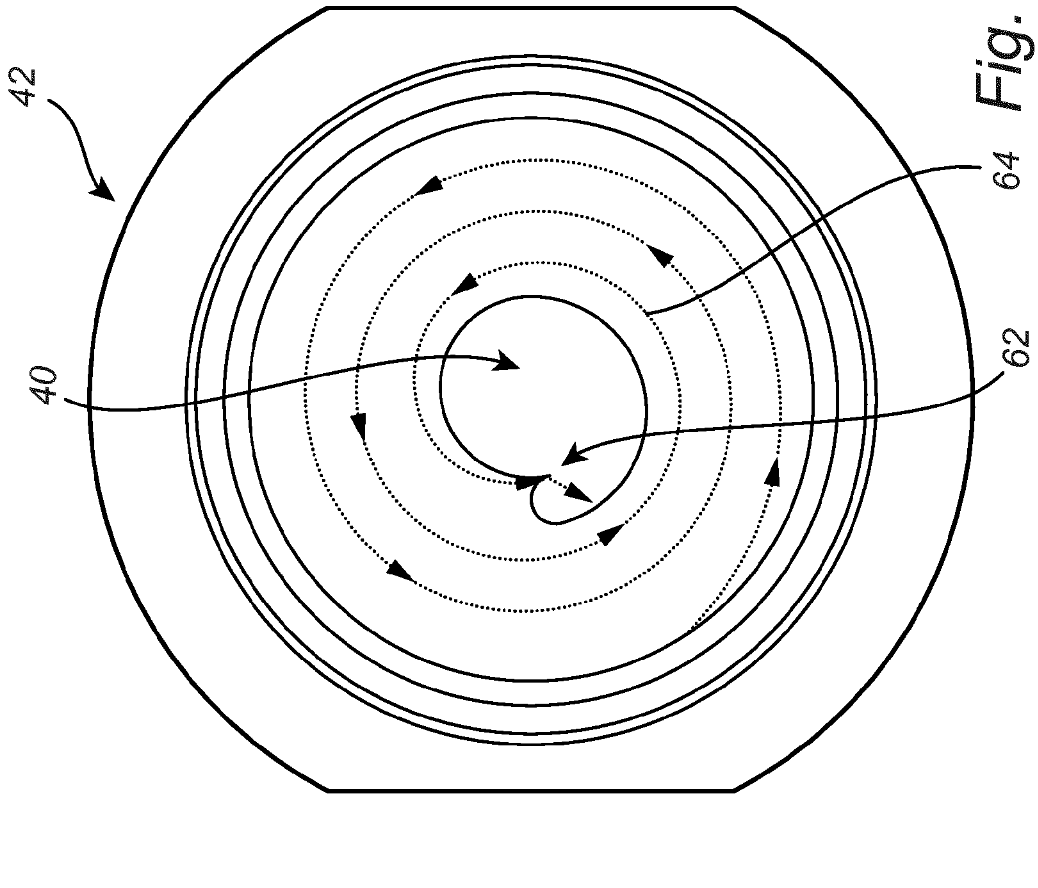

Fig. 8a

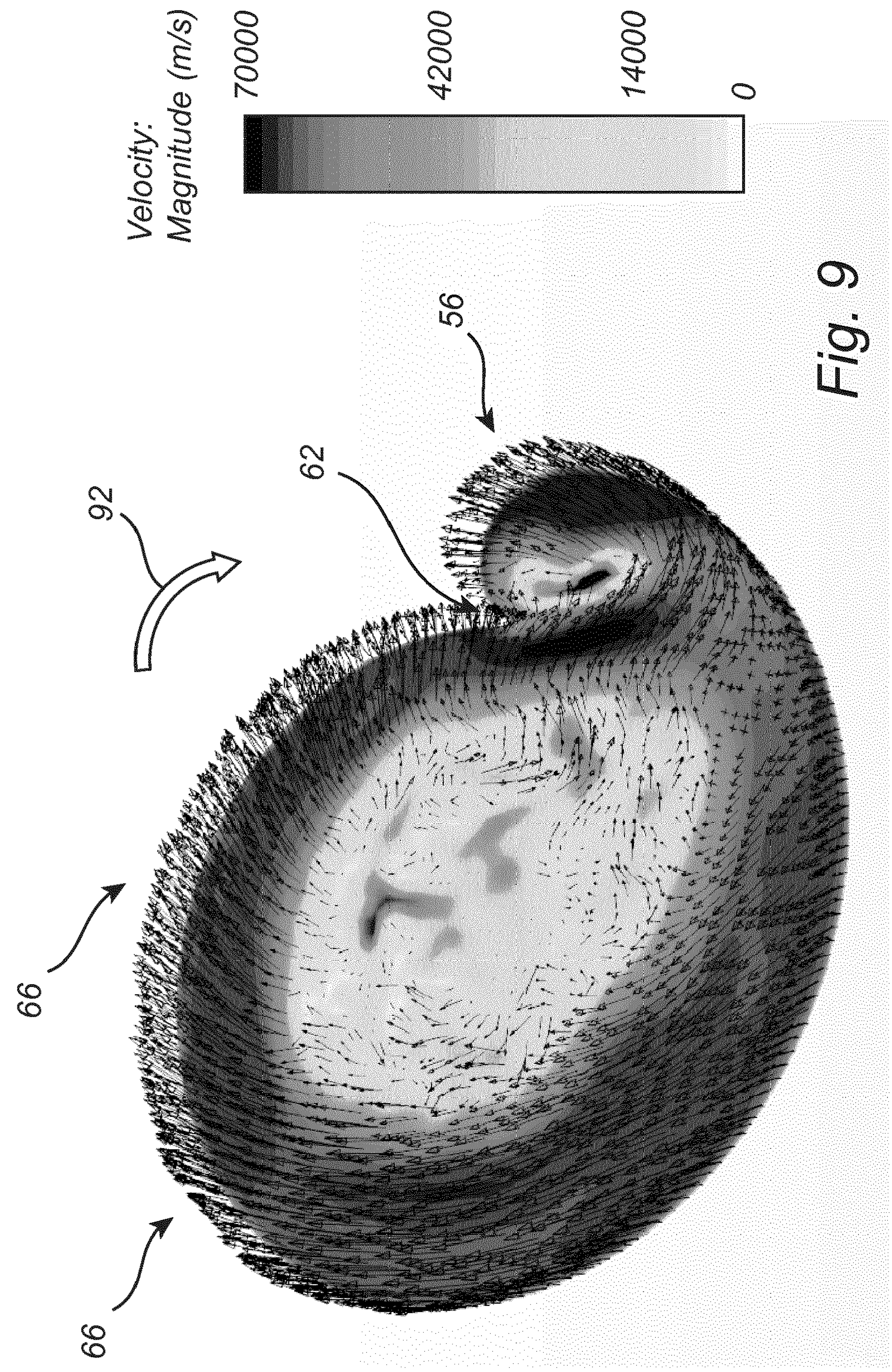

Fig. 9

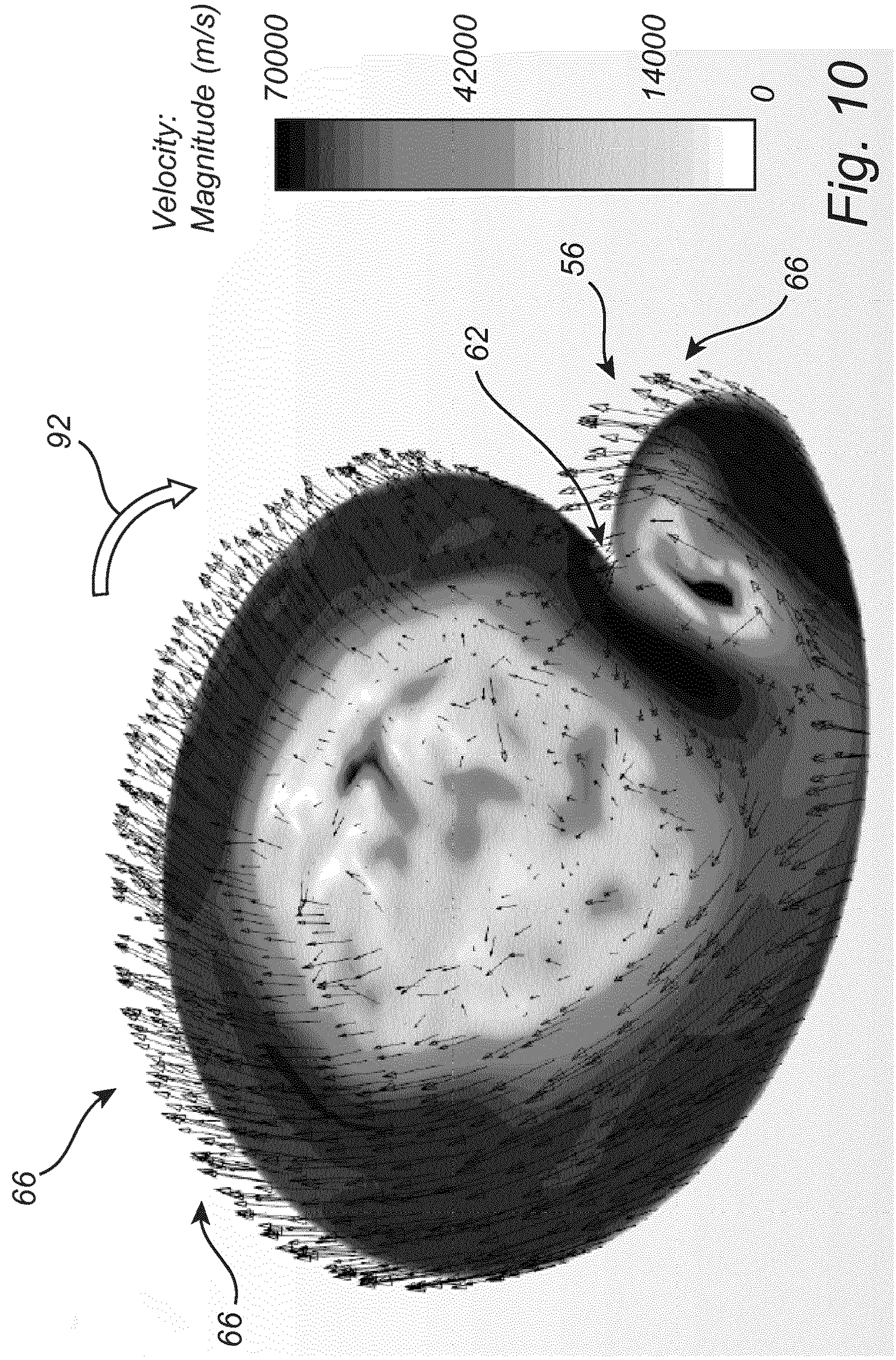

Fig. 10

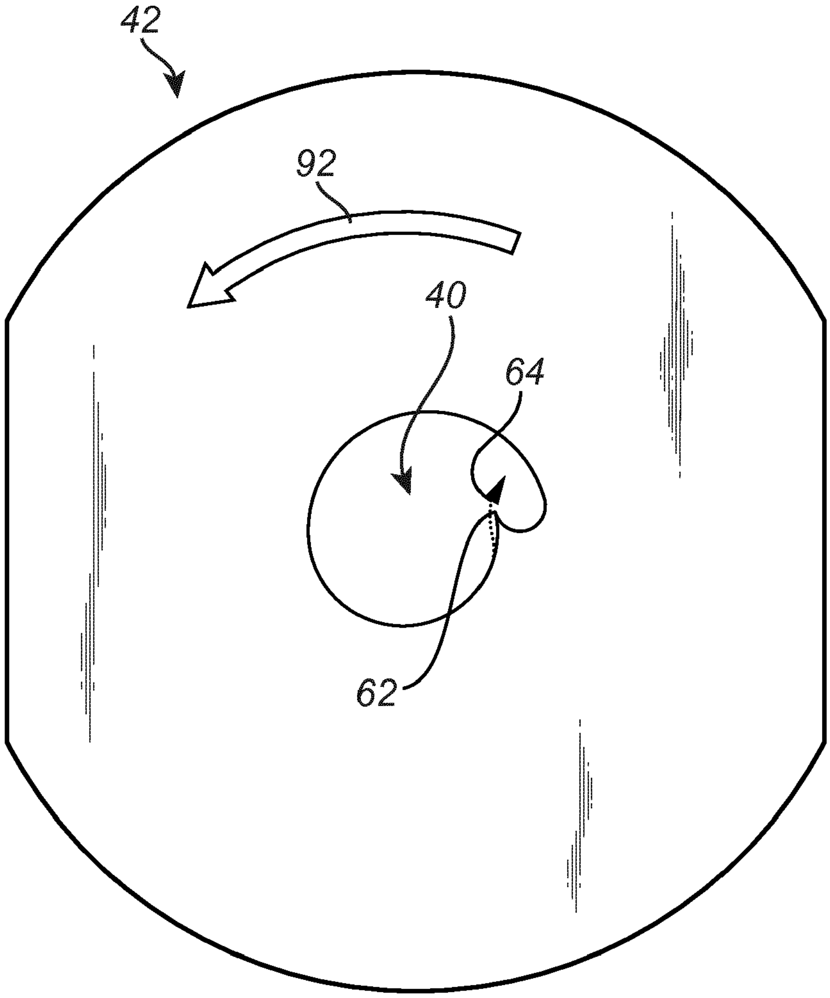

Fig. 11

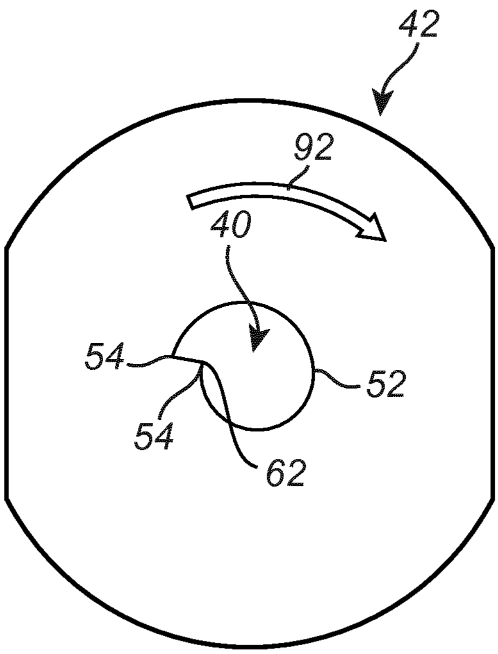

Fig. 12a

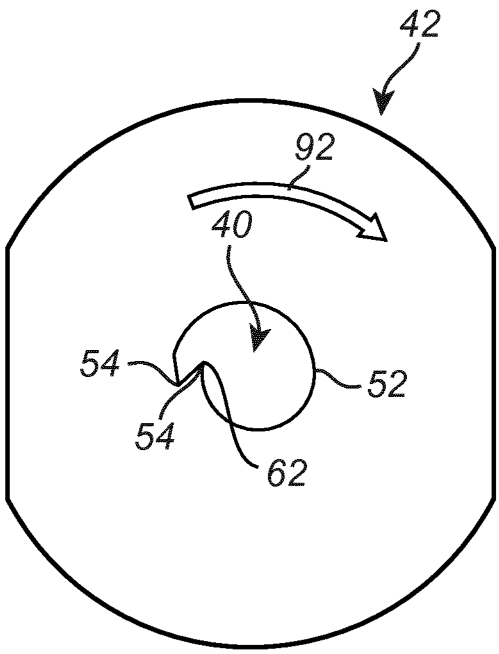

Fig. 12b

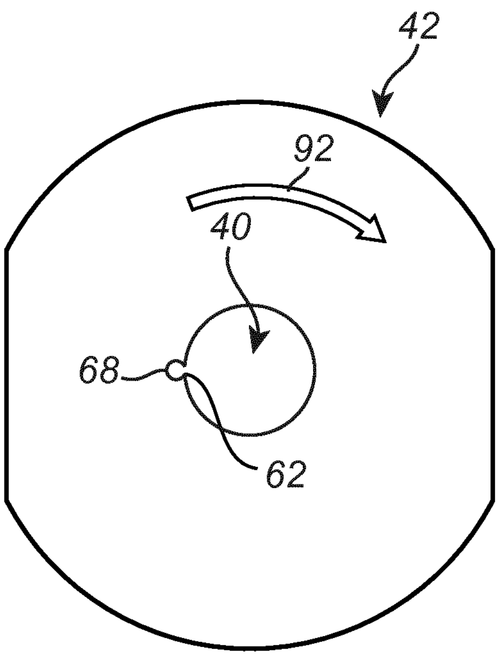

Fig. 13a

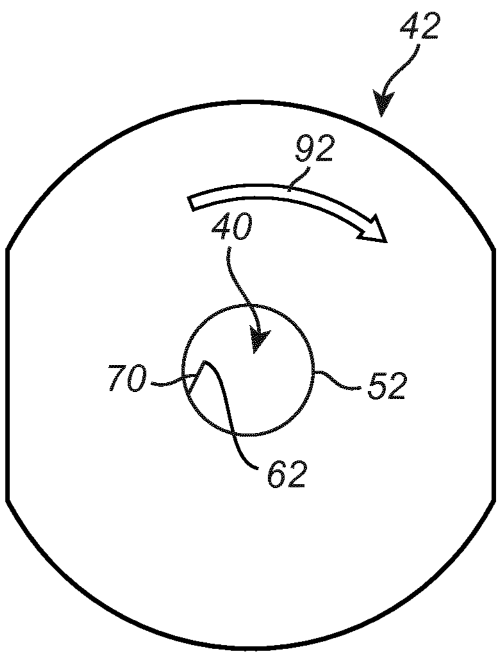

Fig. 13b

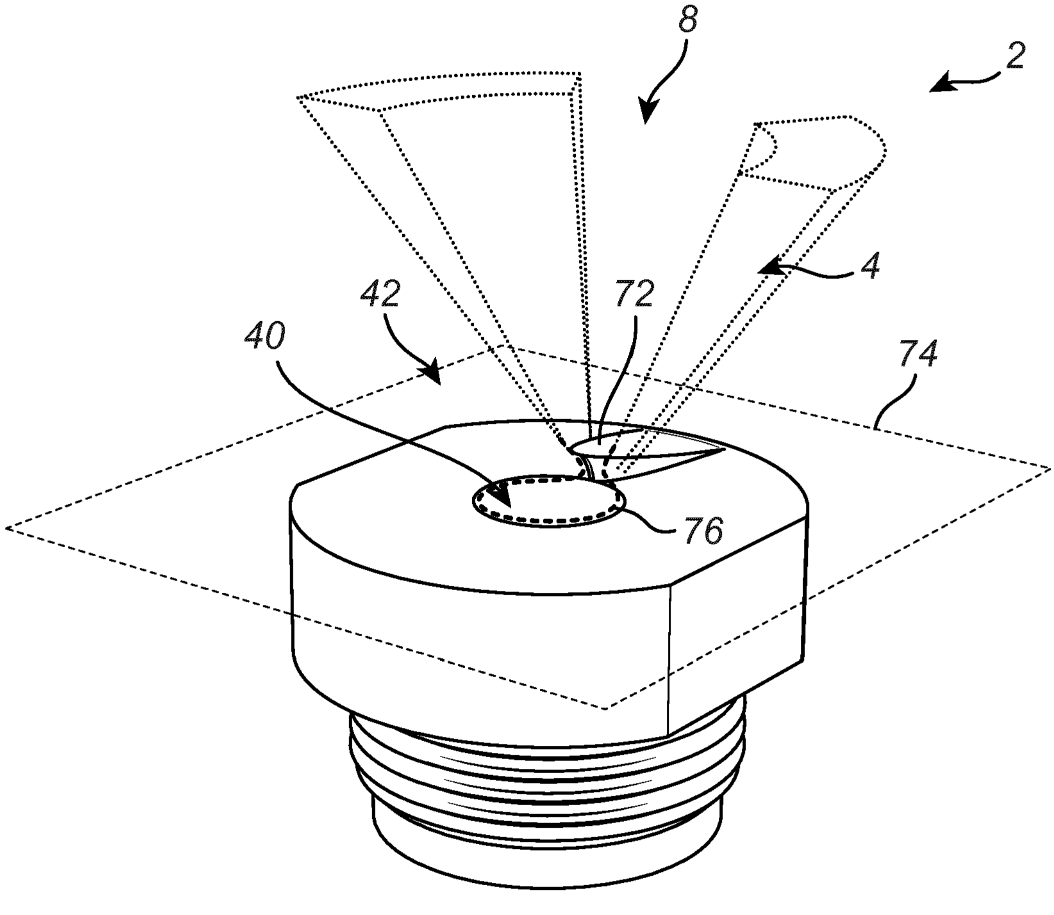

Fig. 14

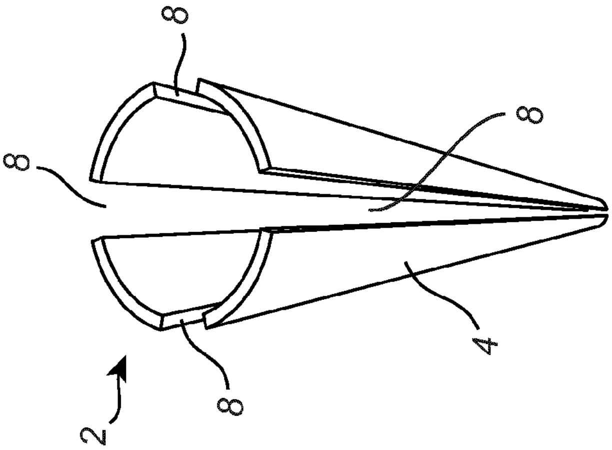

Fig. 15d

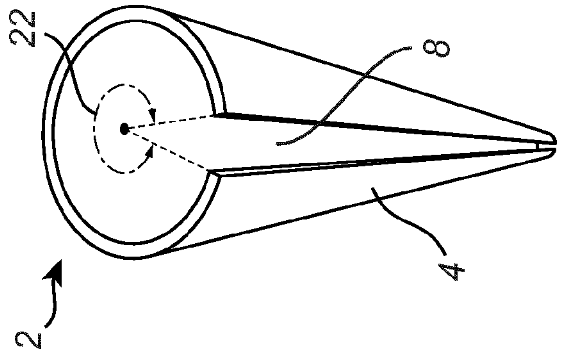

Fig. 15c

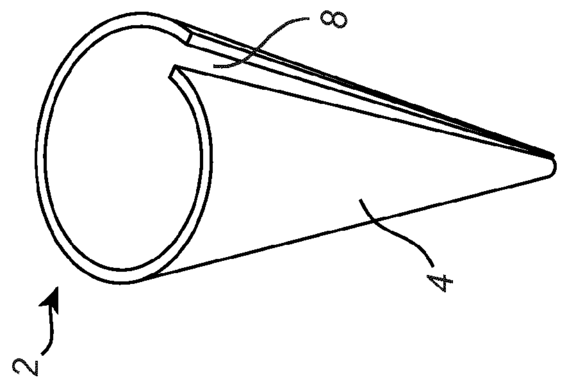

Fig. 15b

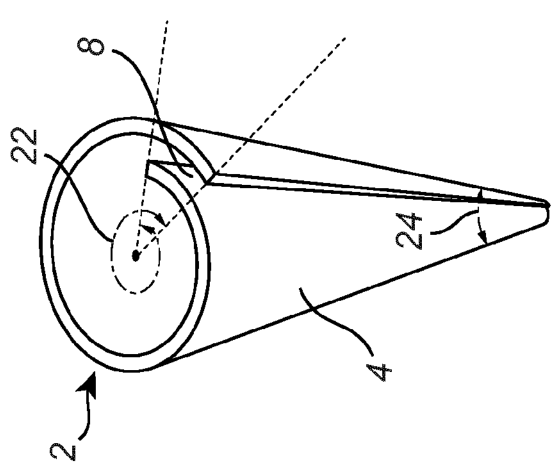

Fig. 15a

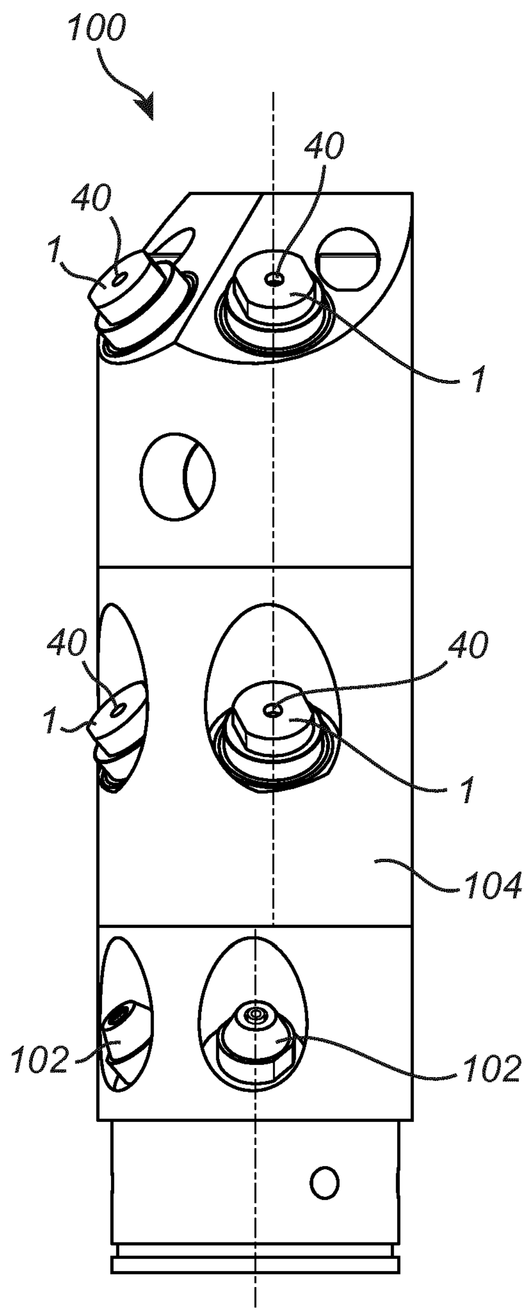

Fig. 16

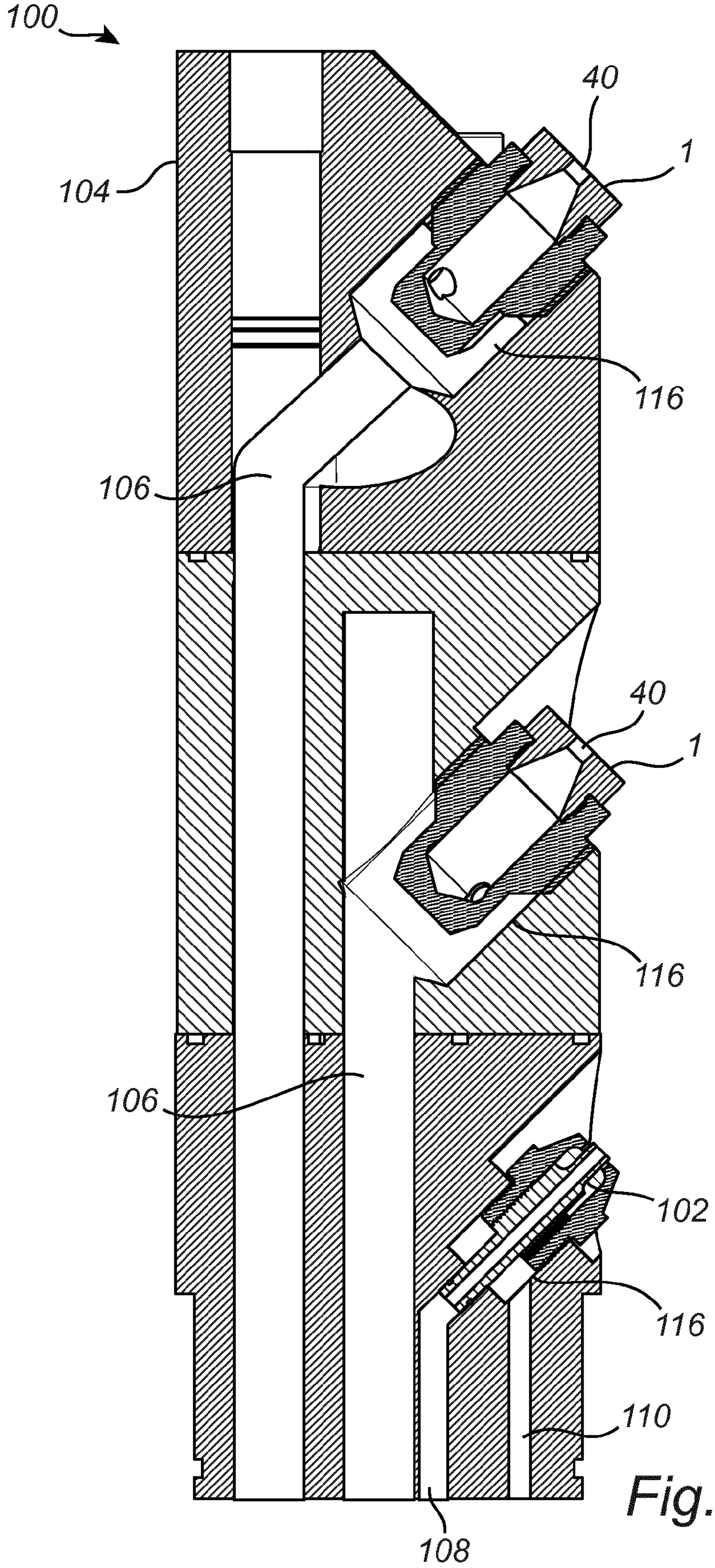

Fig. 17

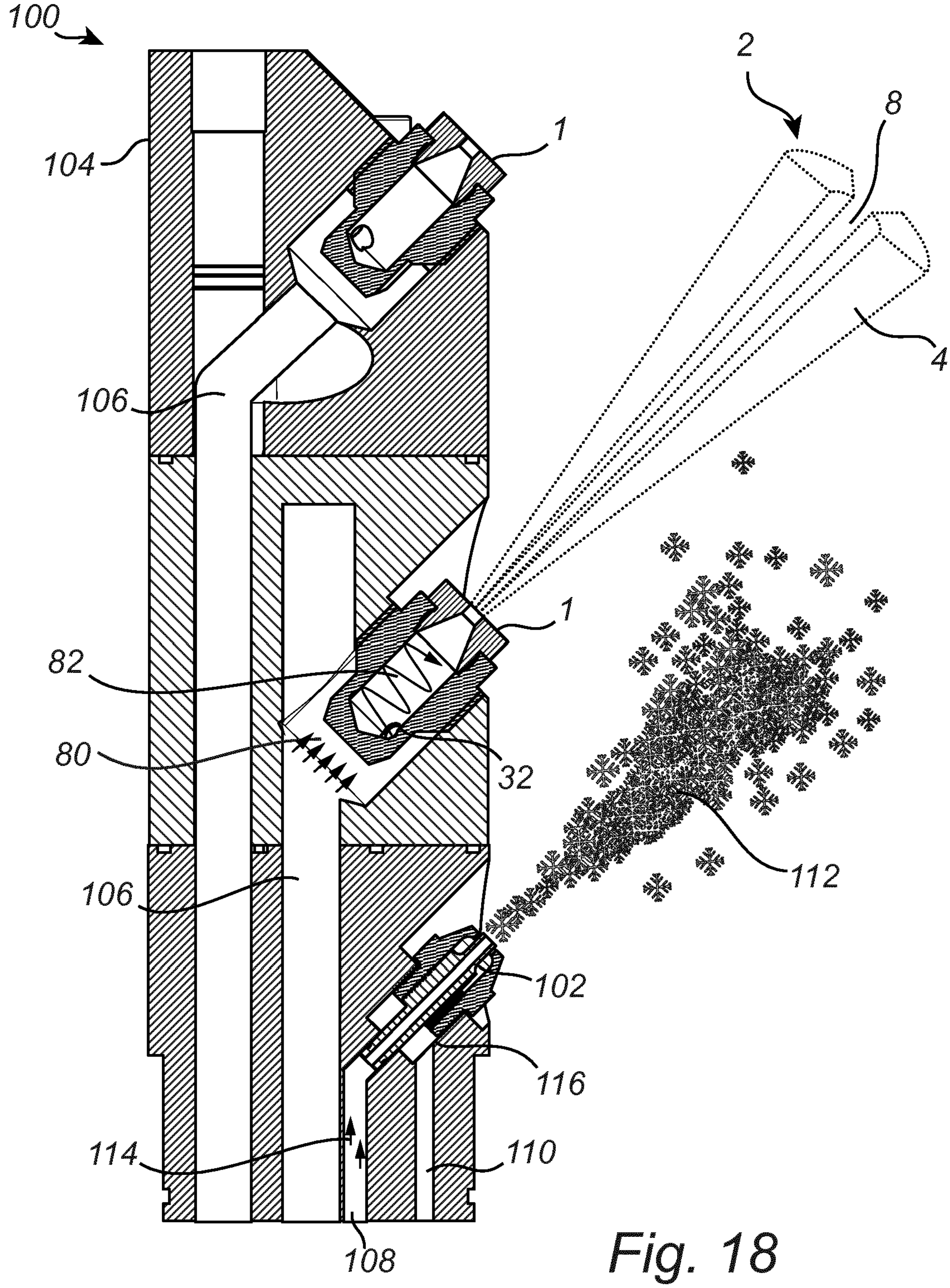

Fig. 18

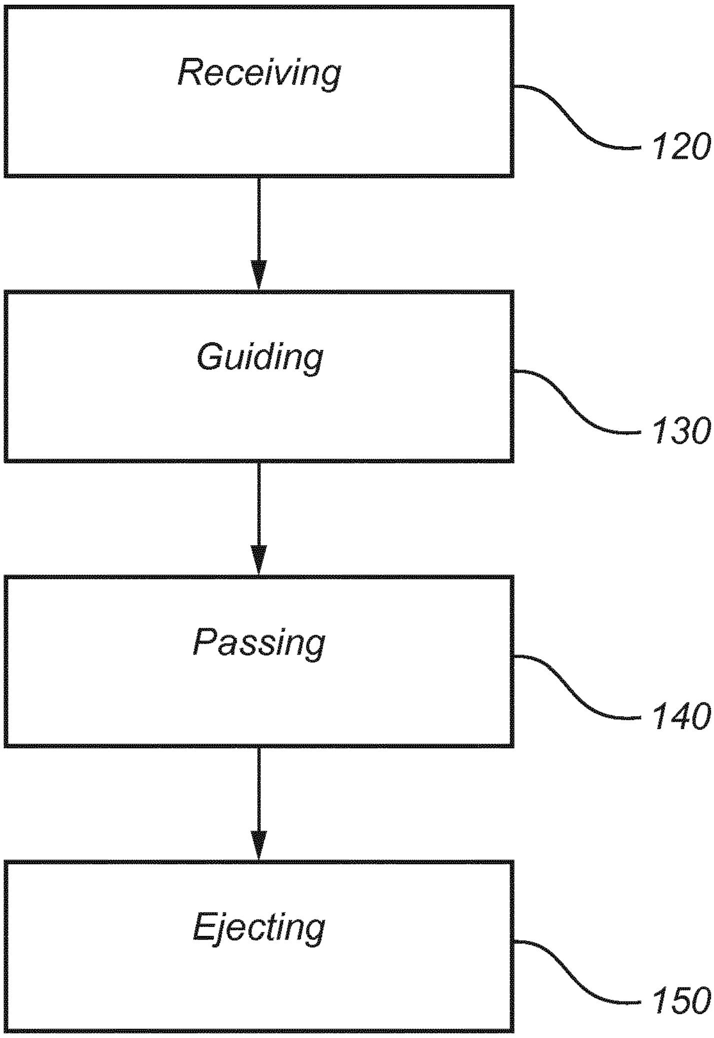

Fig. 19

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EUROPEAN SEARCH REPORT

Application Number
EP 18 19 0217

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X	EP 1 486 257 A2 (KYORITSU GOKIN CO LTD [JP]; ISHIKAWAJIMA HARIMA HEAVY IND [JP]) 15 December 2004 (2004-12-15) * paragraph [0046]; figure 7 *	1-4,12,14,15	
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	23 January 2019	Vigilante, Marco

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