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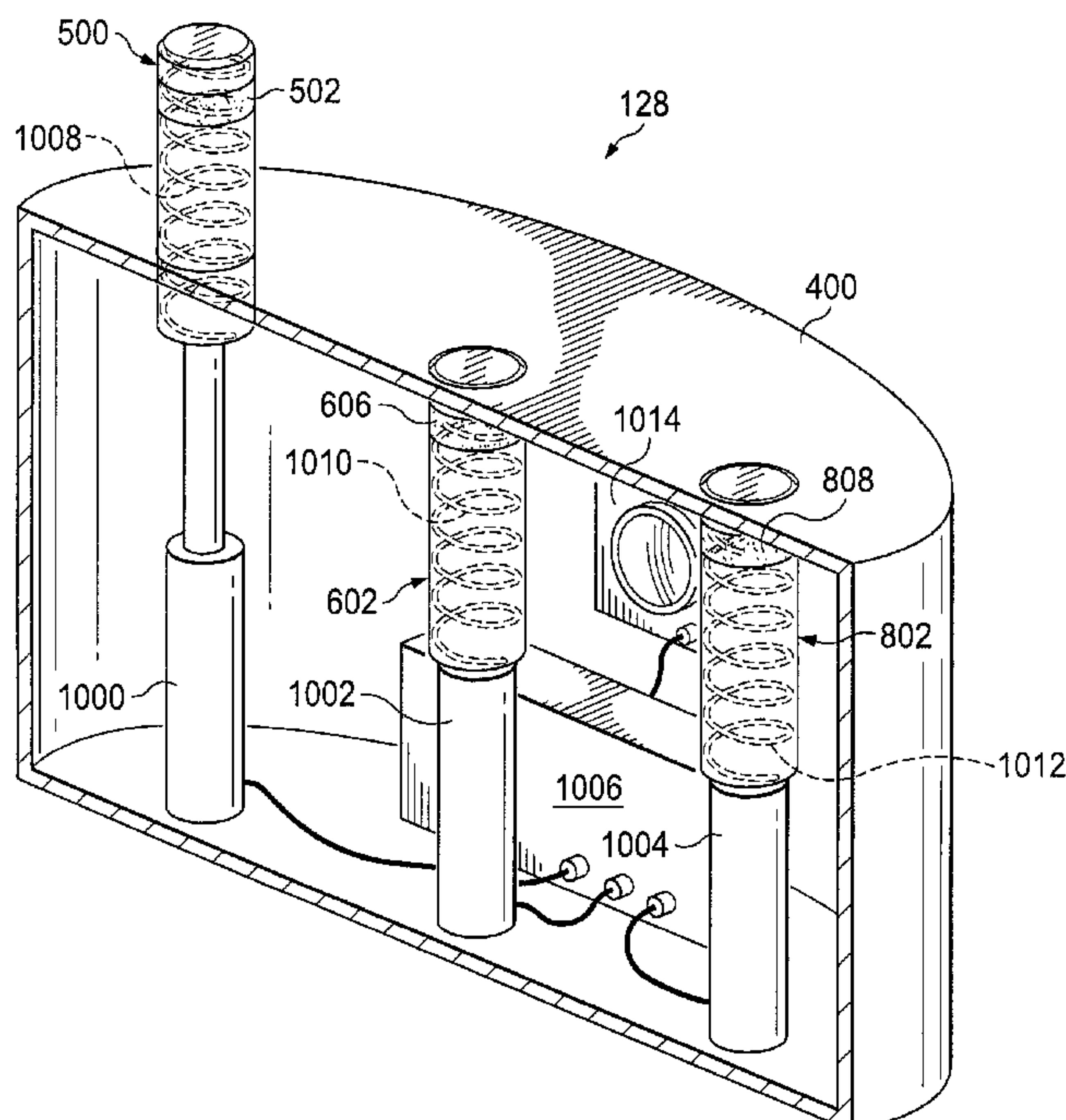
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(54) Titre : **SYSTEME DE MESURE DE GOUTTE D'EAU ET DE DETECTION DE GIVRAGE AUTOMATISE**

(54) Title: **AUTOMATED WATER DROP MEASUREMENT AND ICE DETECTION SYSTEM**



**ABSTRACT**

5 A method and apparatus for detecting an icing condition. The apparatus comprises a sensor system and an icing condition detector. The sensor system is configured to collect drops of water from air on an exterior of an aircraft and generate a number of images of the drops of water collected. The icing condition detector is configured to detect a presence of a number of types of icing conditions for the aircraft using the number of images from the sensor.

**AUTOMATED WATER DROP MEASUREMENT AND ICE DETECTION SYSTEM****BACKGROUND INFORMATION****5 Field:**

The present disclosure relates generally to detecting icing conditions and, in particular, to detecting icing conditions for an aircraft. Still more particularly, the present disclosure relates to detecting supercooled drops of water, including supercooled large drops (SLD) for aircraft.

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**Background:**

In aviation, icing on an aircraft may occur when atmospheric conditions lead to the formation of ice on the surfaces of the aircraft. Further, this ice also may occur within the engine. Ice forming on the surfaces of the aircraft, on inlets of an engine, and on other 15 locations is undesirable and potentially unsafe for operating the aircraft.

Icing conditions may occur when drops of supercooled liquid water are present. In these illustrative examples, water is considered to be supercooled when the water is cooled below the stated freezing point for water but is still in a liquid form. Icing conditions may be 20 characterized by the size of the drops, the liquid water content, air temperature, and other parameters. These parameters may affect the rate and extent at which ice forms on an aircraft.

When icing occurs, the aircraft does not operate as desired. For example, ice on the 25 wing of an aircraft will cause the aircraft to stall at a lower angle of attack and have an increased drag.

Aircraft may have mechanisms to prevent icing, remove ice, or some combination thereof to handle these icing conditions. For example, aircraft may include icing detection, 30 prevention, and removal systems. Ice may be removed using deicing fluid, infrared heating, and other suitable mechanisms.

Aircraft may be certified for operation during different types of icing conditions. Some aircraft may be certified to operate in normal icing conditions, but not those that include supercooled large drops. Currently used sensor systems are unable to differentiate between normal and supercooled large drop icing conditions. Therefore, it would be desirable to have a method and apparatus that takes into account at least some of the issues discussed above, as well as other possible issues.

## SUMMARY

10 The disclosure describes an apparatus including a sensor system configured to collect drops of water from air on an exterior of an aircraft and generate a number of images of the collected drops of water. The apparatus also includes an icing condition detector configured to detect, using the number of images from the sensor system, a presence within the collected drops of water of at least one of a first number of drops of water having a first number of sizes associated with a first 15 type of icing condition for the aircraft, and a second number of drops of water having a second number of sizes associated with a second type of icing condition for the aircraft.

20 The icing condition detector may be further configured to perform an operation in response to detecting the presence of at least one of the first type of icing condition and the second type of icing condition.

The operation may be selected from at least one of generating an alert, activating an anti-icing system, generating a log entry, and sending a report.

25 The sensor system may include a number of probes configured to collect the drops of water from the air on the exterior of the aircraft. The sensor system may also include a camera system configured to generate the number of images of the collected drops of water.

30 The number of probes may be configured to extend into the air on the exterior of the aircraft. The number of probes may also be configured to retract out of the air on the exterior of the aircraft into an interior of the aircraft.

The number of probes may be configured to periodically extend into the air on the exterior of the aircraft and retract out of the air on the exterior of the aircraft.

5 The apparatus may further include a housing. The camera system may be located within the housing and the number of probes may be configured to extend into the air on the exterior of the aircraft from the housing and retract out of the air on the exterior of the aircraft into the housing. The apparatus may also include a motor system configured to cause the number of probes to extend into the air on the exterior of the aircraft from the housing and to retract out of the air on the exterior of 10 the aircraft back into the housing.

The icing condition detector may be configured to detect the presence of at least one of the first type of icing condition and the second type of icing condition by analyzing the number of images of the collected drops of water, when the collected drops of water includes at least one of the 15 first number of drops of water having a first number of sizes and the second number of drops of water having the second number of sizes. The icing condition detector may also be configured to detect the presence of at least one of the first type of icing condition and the second type of icing condition by comparing at least one of the first number of sizes and the second number of sizes represented in the number of images with drop sizes stored in a drop database of frozen drops of 20 water.

The icing condition detector may be located in at least one of the camera system, a housing, and a computer system in the aircraft.

25 The first type of icing condition may be caused by the first number of frozen drops having the first number of sizes from 0.00465 millimeters in diameter to 0.111 millimeters in diameter and the second type of icing condition may be caused by the second number of frozen drops having the second number of sizes from 0.112 millimeters in diameter to 2.2 millimeters in diameter

30 The second type of icing condition may be a supercooled large drop type of icing condition.

The sensor system may further include a first probe, a second probe and a third probe, each configured to collect the drops of water from the air on the exterior of the aircraft. The sensor system may also include a motor system configured to automatically and periodically cause the first probe, the second probe and the third probe to extend into the air on the exterior of the aircraft and retract back from the air on the exterior of the aircraft into the housing. The sensor system may also include a camera system located within the housing configured to generate the number of images of the collected drops of water when at least one of the first probe, the second probe, and the third probe is retracted into the housing.

10

The first probe, the second probe and the third probe may each have a viscous portion that collects the drops of water from the air on the exterior of the aircraft.

15 The viscous portion may include at least one of silicon rubber, polytetrafluoroethylene, an oily resin and a waxy resin.

The disclosure also describes an icing condition detection system including a plurality of sensor units configured to generate information about at least one of a first type of icing condition and a second type of icing condition outside of an aircraft. Each sensor unit in the plurality of sensor units includes a number of probes configured to collect drops of water from air on an exterior of the aircraft and a camera system configured to generate a number of images of the collected drops of water. The icing condition detection system also includes an icing condition detector configured to detect, using the number of images generated by the camera system, a presence within the collected drops of water of at least one of a first number of drops of water having a first number of sizes associated with the first type of icing condition of the aircraft and a second number of drops of water having a number of second sizes associated with the second type of icing condition of the aircraft.

30 The icing condition detection system may further include an anti-icing system configured to remove ice from a surface of the aircraft when the presence of at least one of the first type of icing condition and second type of icing condition is detected.

The disclosure also describes a method for detecting an icing condition, the method involving collecting drops of water from air on an exterior of an aircraft and generating a number of images of the collected drops of water. The method also involves determining, using the number of images generated, a presence within the collected drops of water of at least one of a first number of 5 drops of water having a first number of sizes associated with a first type of icing condition for the aircraft, and a second number of drops of water having a second number of sizes associated with a second type of icing condition for the aircraft.

10 The method may further involve performing an operation when the presence of at least one of the first type of icing condition and the second type of icing condition is determined.

15 Collecting the drops of water may involve causing a number of probes to extend into the air on the exterior of the aircraft and retract out of the air on the exterior of the aircraft into an interior of the aircraft. Generating the number of images may involve generating the number of images of the collected drops of water as frozen drops of water when the number of probes are retracted out of 20 the air on the exterior of the aircraft into the interior of the aircraft.

25 Collecting the drops of water may further involve melting the frozen drops of water after generating the images and prior to causing the number of probes to extend back into the air on the exterior of the aircraft.

The features and functions can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

25

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

30 The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and features thereof, will best be understood by reference to the following detailed

description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

**Figure 1** is an illustration of an aircraft in accordance with an illustrative embodiment;

5      **Figure 2** is an illustration of a block diagram of an icing condition detection environment in accordance with an illustrative embodiment;

**Figure 3** is an illustration of a block diagram of a sensor unit in accordance with an illustrative embodiment;

**Figure 4** is an illustration of a sensor unit on an aircraft in accordance with an illustrative embodiment;

10     **Figure 5** is an illustration of a sensor unit in accordance with an illustrative embodiment;

**Figure 6** is another illustration of a sensor unit in accordance with an illustrative embodiment;

**Figure 7** is another illustration of a sensor unit in accordance with an illustrative embodiment;

5       **Figure 8** is yet another illustration of a sensor unit in accordance with an illustrative embodiment;

**Figure 9** is another illustration of a sensor unit in accordance with an illustrative embodiment;

10      **Figure 10** is an illustration of a cross-sectional view of a sensor unit in accordance with an illustrative embodiment;

**Figure 11** is an illustration of an isometric view of a sensor unit in accordance with an illustrative embodiment;

**Figure 12** is an illustration of a flowchart of a process for detecting an icing condition in accordance with an illustrative embodiment; and

15      **Figure 13** is an illustration of a timing diagram for detecting a number of types of icing conditions in accordance with an illustrative embodiment.

## DETAILED DESCRIPTION

20      The illustrative embodiments recognize and take into account a number of different considerations. For example, the different illustrative embodiments recognize and take into account that currently used systems for detecting icing conditions on an aircraft are unable to detect all of the different types of icing conditions that may occur. For example, the different illustrative embodiments recognize and take into account that as the size of the drops of 25 water increase, currently used sensors may not detect icing caused by those drops of water. The different illustrative embodiments recognize and take into account that the locations at which different sizes of drops will collide with an airfoil during operation of an aircraft change depending on the size of the drops.

30      The illustrative embodiments recognize and take into account that it is desirable to detect different types of icing conditions that may be caused by different sizes of drops of

water. In particular, the illustrative embodiments recognize and take into account that it may be desirable to detect drops of supercooled liquid water. These drops may take the form of supercooled large drops (SLD).

5 Thus, the illustrative embodiments provide a method and apparatus for detecting different types of icing conditions. In one illustrative embodiment, a method and apparatus are present for detecting an icing condition. Drops of water are collected from the air on the exterior of an aircraft. A number of images of the drops of water collected are generated. A determination is made as to whether a number of types of icing conditions for the aircraft is 10 present using the images. In these illustrative examples, the phrase “number of” when used with reference with items mean one or more items. For example, number of images is one or more images.

15 With reference now to the figures and, in particular, with reference to **Figure 1**, an illustration of an aircraft is depicted in accordance with an illustrative embodiment. In this illustrative example, aircraft **100** has wing **102** and wing **104** attached to fuselage **106**. Aircraft **100** also includes engine **108** attached to wing **102** and engine **110** attached to wing **104**.

20 Fuselage **106** has nose section **112** and tail section **114**. Nose section **112** is the forward part of aircraft **100**, while tail section **114** is the aft part of aircraft **100**. Horizontal stabilizer **116**, horizontal stabilizer **118**, and vertical stabilizer **120** are attached to tail section **114** of fuselage **106**.

25 Aircraft **100** is an example of a vehicle in which icing condition detection system **122** may be implemented. In this illustrative example, icing condition detection system **122** includes sensor units **124** located on surface **126** of aircraft **100**.

30 In this particular example, sensor units **124** include sensor unit **128** and sensor unit **130**. Sensor unit **128** is located on side **132** of aircraft **100**. Sensor unit **130** is located on side **134** of aircraft **100**. In this illustrative example, sensor unit **134** is substantially opposite of sensor unit **128** and is shown in phantom. In one illustrative example, sensor unit **128** and

sensor unit **130** may be located substantially at horizontal center line **136** in aircraft **100**. A more detailed illustration of sensor unit **128** in location **138** on fuselage **106** is described in more detail below.

5 In these illustrative examples, sensor units **124** are configured to collect drops of water that may be present in the air around surface **126** of aircraft **100**. These drops of water may be analyzed to determine a presence of a number of types of icing conditions. In these illustrative examples, sensor units **124** may generate images of the drops of water for analysis. The analysis may indicate whether the drops of water are frozen drops of water, the  
10 size of the drops of water, and other suitable information that may be used to identify a presence of a number of types of icing conditions.

In these illustrative examples, these icing conditions may occur at different altitudes and temperatures that cause the formation of ice on aircraft **100**. For example, icing  
15 conditions may be present at an altitude from about sea level to about **30,000** feet when the temperature is from about **-40** degrees Celsius to about **0** degrees Celsius. Of course, other altitudes and temperatures may be present at which ice may be formed from water that contacts surface **126** of aircraft **100**. Icing conditions also may be present when the liquid water content in the drops is from about **0.4** to about **2.8** grams/cubic meter at the altitude  
20 and temperature range described above.

In particular, the number of types of icing conditions may include a first type of icing condition and a second type of icing condition. In these illustrative examples, the first type of icing condition and the second type of icing condition are caused by drops of water of  
25 different sizes. Although the altitude, temperature, and liquid water content ranges may be the same, one difference between the first and second types of icing conditions is the drop size.

In the illustrative examples, the first type of icing condition may be referred to as a  
30 normal icing condition. The second type of icing condition may be referred to as a supercooled large drop icing condition.

In these illustrative examples, the first type of icing condition may be present when the size of the drops is from about **0.00465** millimeters in diameter to about **0.111** millimeters in diameter. Drops with these sizes may be referred to as normal drops. The 5 second type of icing condition may be present when the size of the drops includes drops that have a diameter greater than about **0.111** millimeters. Drops having a size greater than about **0.111** millimeters may be referred to as large drops and, in particular, may be called supercooled large drops under the altitude, temperature, and liquid water content conditions described above. For example, the drops may have a diameter of a range from about **0.112** 10 millimeters to about **2.2** millimeters. In addition, the second type of icing condition may include drops that are **0.111** millimeters or less when drops greater than **0.111** millimeters are present.

As depicted, sensor units **124** are configured to detect drops of water in a first number 15 of sizes. Further, sensor units **124** also are configured to detect drops of water having a second number of sizes. These drops of water may be in a liquid state, a frozen state, or some combination thereof. In these illustrative examples, the first number of sizes is smaller than the second number of sizes.

20 For example, the first number of sizes may be from about **0.00465** millimeters in diameter to about **0.111** millimeters in diameter. The second number of sizes may be from about **0.112** millimeters to about **2.2** millimeters in diameter. The second number of sizes of the drops of water may be drops of water that are considered to be drops of supercooled water. These drops of supercooled water may be supercooled large drops.

25

The illustration of sensor units **124** are not meant to imply limitations to the manner in which sensor units may be implemented in other illustrative examples for aircraft **100** and other aircraft or vehicles in which detection of icing conditions is desired. For example, other numbers of sensor units may be used in addition to sensor unit **128** and sensor unit **130** 30 in sensor units **124**. For example, in other illustrative examples, five sensor units, twelve sensor units, or some other suitable number of sensor units may be employed.

These sensor units also may be placed in other locations such as on vertical stabilizer 120, on engine 110, and other suitable locations. As another example, sensor units 124 also may be positioned above horizontal center line 136 on aircraft 100.

5

Turning now to **Figure 2**, an illustration of a block diagram of an icing condition detection environment is depicted in accordance with an illustrative embodiment. Icing condition detection environment 200 is an environment in which ice detection may be performed for vehicle 202. In this illustrative example, vehicle 202 may be aircraft 100 in 10 **Figure 1**.

Icing condition detection system 204 may be associated with vehicle 202. When one component is “associated” with another component, the association is a physical association in these depicted examples. For example, a first component, icing condition detection 15 system 204, may be considered to be associated with a second component, vehicle 202, by being secured to the second component, bonded to the second component, mounted to the second component, welded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component using a third component. The 20 first component may also be considered to be associated with the second component by being formed as part of and/or an extension of the second component.

In this illustrative example, icing condition detection system 204 includes sensor system 206 and icing condition detector 208. Icing condition detection system 204 is 25 configured to detect a number of types of icing conditions 210.

In particular, icing condition detection system 204 may be configured to detect whether the number of types of icing conditions 210 are present where ice 212 may be formed on surface 214 of vehicle 202. In this illustrative example, vehicle 202 may take a 30 number of different forms including aircraft 100 in **Figure 1**.

In the illustrative examples, sensor system **206** is a hardware system and may include software. In these illustrative examples, sensor system **206** is comprised of a number of sensor units **216**.

5 Each sensor unit in the number of sensor units **216** is associated with surface **214** of vehicle **202**. In particular, number of sensor units **216** may be in locations that are exposed to air **218**. In particular, the number of sensor units **216** may be positioned to be within airstream **220** in air **218** around vehicle **202**.

10 Sensor system **206** is configured to detect drops of water **222**. In particular, the number of sensor units **216** in sensor system **206** may be configured to collect drops of water **222** from air **218** on the exterior of vehicle **202**. A number of drops of water **222** may be in a liquid state, a frozen state, or some combination thereof. In other words, the number of drops of water **222** may include frozen drops of water **228**. Drops of water **222** may freeze 15 during the collection process performed by sensor system **206** to collect drops of water **222** for analysis.

20 Additionally, sensor system **206** is configured to generate a number of images **224** of drops of water **222** collected by sensor system **206**. The number of images **224** of drops of water **222** may be analyzed by icing condition detector **208**.

As depicted, icing condition detector **208** is configured to detect a presence of the number of types of icing conditions **210** for vehicle **202** using the number of images **224** generated by sensor system **206**. Icing condition detector **208** may be implemented using 25 hardware, software, or some combination thereof. When software is used, the operations performed by icing condition detector **208** may be implemented in program code configured to run on a processor unit. When hardware is employed, the hardware may include circuits that operate to perform the operations in icing condition detector **208**.

30 In the illustrative examples, the hardware may take the form of a circuit system, an integrated circuit, an application specific integrated circuit (ASIC), a programmable logic

device, or some other suitable type of hardware configured to perform a number of operations. With a programmable logic device, the device is configured to perform the number of operations. The device may be reconfigured at a later time or may be permanently configured to perform the number of operations. Examples of programmable 5 logic devices include, for example, a programmable logic array, a programmable array logic, a field programmable logic array, a field programmable gate array, and other suitable hardware devices. Additionally, the processes may be implemented in organic components integrated with inorganic components and/or may be comprised entirely of organic components excluding a human being. For example, the processes may be implemented as 10 circuits in organic semiconductors.

In one illustrative example, icing condition detector **208** is configured to generate information **230** about drops of water **222** from images **224**. In particular, information **230** may include drop sizes **232** for drops of water **222**. Drop sizes **232** identified for drops of 15 water **222** may be compared to drop sizes **234** in drop database **236**. Drop sizes **234** in drop database **236** are sizes for drops of water for different icing conditions in types of icing conditions **210**.

In these illustrative examples, drop sizes **232** may be identified from empirical data. 20 The empirical data may be generated from using drops with known sizes that are collected by sensor system **206**. For example, the measurements may be images of drops of water **222** collected by sensor system **206** from air **218**. Drops of water **222** have drop sizes **225**, which are known when generating drop database **236**.

25 For example, drop sizes **232** for drops of water **222** collected on devices such as probes may be different from drops sizes **225** for drops of water **222** in air **218**. In other words, drops of water **222** in the air may have a different size from when drops of water **222** adhere or land on a surface of a device, such as a probe. Drop sizes **232** may be correlated to drop sizes **225** when drop sizes **225** are known. This information may be used to create drop 30 database **236** for identifying types of icing conditions **210**.

The comparison of drop sizes **232** for drops of water **222** to drop sizes **234** in drop database **236** may be performed in substantially real time. In other words, as icing condition detector **208** detects drops of water **222** with drop sizes **232**, drop sizes **232** are compared to drop sizes **234** in drop database **236** as fast as possible without intentional delay. In this manner, information **230** may be generated in substantially real time.

The comparison of drop sizes **232** for drops of water **222** to drop sizes **234** in drop database **236** may be used to identify a presence of a number of types of icing conditions **210** around vehicle **202**. In particular, the type of icing condition or types of icing conditions in types of icing conditions **210** may be identified from this comparison.

Additionally, icing condition detector **208** is configured to perform an operation in response to detecting a presence of one or more types of icing conditions **210**. In particular, types of icing conditions **210** may include a first type of icing condition and a second type of icing condition as described above.

The operation that may be performed by icing condition detector **208** may include activating anti-icing system **226**. In this illustrative example, anti-icing system **226** may take a number of different forms. For example, anti-icing system **226** may include at least one of an infrared heater, an electrical resistive heater, a de-icer boot, and other suitable types of anti-icing devices. Anti-icing system **226** may be used for at least one of reducing the formation of icing, preventing the formation of ice, and removing ice from the surfaces of vehicle **202** in these illustrative examples.

As used herein, the phrase “at least one of”, when used with a list of items, means different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, “at least one of item A, item B, and item C” may include, without limitation, item A or item A and item B. This example also may include item A, item B, and item C or item B and item C. In other examples, “at least one of” may be, for example, without limitation, two of item A, one of item B, and ten of item C; four of item B and seven of item C; and other suitable combinations.

Additionally, icing condition detector **208** also may perform other operations in place of or in addition to activating anti-icing system **226**. For example, the other operations may include at least one of generating an alert, generating a log entry, sending a report, or other 5 suitable types of operations.

In this manner, icing condition detection system **204** is configured to detect different types of icing conditions **210**. In these illustrative examples, icing condition detection system **204** may provide for automated, real time water drop measurement and for ice 10 detection based on a number of types of icing conditions **210** that may be identified.

Turning now to **Figure 3**, an illustration of a block diagram of a sensor unit is depicted in accordance with an illustrative embodiment. Sensor unit **300** is an example of one implementation of a sensor unit in sensor units **216** for sensor system **206** in **Figure 2**.  
15

Sensor unit **300** includes a number of different types of components in this illustrative example. As depicted, sensor unit **300** includes housing **302**, probes **304**, actuator system **306**, camera system **308**, drop remover **310**, and controller **312**.

20 Housing **302** is a physical structure in which the other components in sensor unit **300** may be associated. In particular, housing **302** may contain or hold the other components in sensor unit **300**.

25 In these illustrative examples, housing **302** may take a number of different forms. For example, housing **302** may have a shape such as a cylinder, a cube, a cuboid, a frustum, and other suitable shapes. Housing **302** may be comprised of one or more different types of materials. For example, housing **302** may be comprised of at least one of a metal, a plastic, aluminum, titanium, a composite material, and other suitable types of materials.  
30

Probes **304** are physical structures configured to collect drops of water from the air around the vehicle. In these illustrative examples, probes **304** may extend into the air on the

exterior of the vehicle and retract out of the air on the exterior of the vehicle to collect drops of water that may be present in the air around the exterior of the vehicle. In particular, probes **304** may extend into the air on the exterior of the vehicle from the housing and retract out of the air on the exterior of the vehicle into the housing.

5

Actuator system **306** is configured to move probes **304** to extend into the air and retract from the air. In other words, actuator system **306** may cause probes **304** to move out of housing **302** and back into housing **302**. In particular, the movement of probes **304** may be such that only a portion of probes **304** are extended into the air outside of housing **302** 10 while another portion of probes **304** are retracted out of the air inside of housing **302**.

Actuator system **306** is a hardware system and may be implemented using a number of different types of actuators. For example, actuator system **306** may include components selected from a motor system such as at least one of an electric motor, a pneumatic motor, 15 and other suitable types of components.

Camera system **308** is a hardware system and is configured to generate images of drops of water that may be collected on probes **304**. In particular, camera system **308** may generate images of the drops of water when on the portion of probes **304** that are located 20 within housing **302**.

Camera system **308** may be implemented using one or more cameras. In these illustrative examples, camera system **308** may be implemented using visible light cameras. When camera system **308** includes one or more visible light cameras, camera system **308** 25 may include a light source such as a light emitting diode or a flash. This light source provides light for images of drops of water taken by camera system **308** in conditions where the amount of ambient light is insufficient for generating images for analysis. For example, probes **304** may be operated during a night flight of an aircraft with sensor unit **300**. The light or flash may be needed to generate images of drops of water captured by probes **304** in 30 this example.

In other illustrative examples, other types of camera systems may be used. For example, camera system **308** may include an infrared camera.

Drop remover **310** is a hardware system and is configured to remove frozen, liquid, or both frozen and liquid drops of water that may be on probes **304**. The removal of the frozen drops of water may occur after camera system **308** has generated the images. Drop remover **310** removes frozen drops of water on probes **304** prior to probes **304** being extended back into the air on the exterior of the vehicle outside of housing **302** in these illustrative examples.

10

Drop remover **310** may be implemented using a number of different types of de-icing systems. For example, drop remover **310** may be a heater configured to melt any drops of water that are frozen on probes **304**. This heater may also be configured to evaporate the drops of water on probes **304** that are not yet frozen. Additionally, drop remover **310** may be a mechanical structure that scrapes frozen drops of water off of probes **304**. In still other illustrative examples, drop remover **310** may scrape liquid drops of water off of probes **304**. In other words, drop remover **310** may be a de-icing system, a mechanical drop removal system, or a combination thereof.

20

Controller **312** is a hardware device configured to control the operation of sensor unit **300**. In these illustrative examples, controller **312** may be implemented as a circuit and may be an integrated circuit, a processor unit, a programmable logic array, an application specific integrated circuit, or some other suitable type of hardware.

25

As depicted, controller **312** may control the operation of actuator system **306** to move probes **304** into and out of housing **302**. Further, controller **312** also may be configured to control the operation of camera system **308** to generate images of drops of water on probes **304**. Controller **312** also may be configured to control the operation of drop remover **310** to remove frozen drops of water or other ice from probes **304** prior to probes **304** being moved back outside of housing **302** to collect additional drops of water.

The illustration of icing condition detection environment **200** and the different components in icing condition detection environment **200** in **Figure 2** and **Figure 3** are not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be unnecessary. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

For example, although icing condition detector **208** is shown as a separate component from sensor system **206**, icing condition detector **208** may be distributed in sensor units **216** in addition to being a separate component or in place of being a separate component. Icing condition detector **208** may be located in a camera system, a housing, a computer system, or in some other suitable location in aircraft **100**. In still other illustrative examples, sensor system **206** may include other types of sensors configured to detect the presence of ice **212** on surface **214** of vehicle **202**, or to detect types of icing conditions **210** that may be present around vehicle **202**.

In another illustrative example, vehicle **202** may take other forms other than aircraft **100**. For example, vehicle **202** may be selected from one of, for example, without limitation, a personnel carrier, a tank, a train, an automobile, a bus, a spacecraft, a surface ship, and other suitable vehicles.

Turning now to **Figure 4**, an illustration of a sensor unit on an aircraft is depicted in accordance with an illustrative embodiment. As depicted, a more detailed illustration of sensor unit **128** at location **138** in **Figure 1** is shown.

In this view, sensor unit **128** has housing **400**, which is substantially flush to surface **126** of fuselage **106** in aircraft **100**. As depicted, housing **400** includes ports **402**. In particular, ports **402** include port **404**, port **406**, and port **408**.

In these illustrative examples, ports **402** provide an ability for probes (not shown) to extend from housing **400** to the exterior of aircraft **100** and to retract into housing **400** into the interior of aircraft **100**. These probes may extend and retract to collect drops of water in these illustrative examples.

5

Although the components in **Figure 4** are shown in a particular configuration, other configurations of housing **400** and ports **402** may be implemented in an illustrative embodiment. The design of sensor unit **128** may be based on unique aircraft configurations in some illustrative examples.

10

Turning now to **Figure 5**, an illustration of a sensor unit is depicted in accordance with an illustrative embodiment. In this example, probe **500** extends from port **404**. Probe **500** may collect drops of water from air around aircraft **100** when in this extended state on the exterior of housing **400** and aircraft **100**.

15

As depicted, probe **500** has viscous portion **502**. Viscous portion **502** may be a coating on the surface of probe **500**, an attachment to probe **500**, or attached to probe **500** in some other suitable fashion. Viscous portion **502** may be comprised of a different type of material than probe **500**. For example, viscous portion **502** of probe **500** may be comprised of a smooth but erosion-resistant material such as silicon rubber, polytetrafluoroethylene, an oily or waxy resin, or other suitable types of material. The material selected for viscous portion **502** of probe **500** may be selected such that viscous portion **502** collects drops of water.

25

In these illustrative examples, viscous portion **502** of probe **500** is configured such that all of viscous portion **502** may retract into housing **400** through port **404**. In this manner, viscous portion **502** with drops of water may be photographed and images generated may be analyzed by sensor unit **128**.

30

Although the depicted example shows viscous portion **502** as a small portion of probe **500**, viscous portion **502** may be larger depending on the particular implementation. For

example, viscous portion **502** may be configured to cover the entire surface of probe **500**. In still other illustrative examples, viscous portion **502** of probe **500** may be smaller than depicted in this figure.

5       Turning now to **Figure 6**, another illustration of a sensor unit is depicted in accordance with an illustrative embodiment. In this view, probe **500** moves in the direction of arrow **600** to retract into housing **400** through port **404**. Additionally, probe **602** moves in the direction of arrow **604** to extend outwards to the exterior of housing **400** through port **406**.

10      In this illustrative example, probe **602** has viscous portion **606**. Viscous portion **606** of probe **602** is similar to viscous portion **502** of probe **500**. Viscous portion **606** is comprised of a material configured to collect drops of water on the surface of viscous portion **606**.

15      As depicted, viscous portion **606** of probe **602** is configured such that all of viscous portion **606** may retract into housing **400** through port **406**. In this manner, viscous portion **606** with drops of water may be photographed and analyzed by sensor unit **128**. In some illustrative examples, viscous portion **606** may be smaller or larger than shown in this figure, 20 depending on the particular implementation.

25      Next, in **Figure 7**, another illustration of a sensor unit is depicted in accordance with an illustrative embodiment. In this view, probe **602** is shown in a fully extended state outside of housing **400** and probe **500** has been fully retracted into the interior of housing **400**.

30      With reference now to **Figure 8**, yet another illustration of a sensor unit is depicted in accordance with an illustrative embodiment. In this example, probe **602** moves in the direction of arrow **800** to retract into the interior of housing **400** through port **406**. Probe **802** moves in the direction of arrow **804** to extend outwards to the exterior of housing **400** through port **408**.

As depicted, probe **802** has viscous portion **808**. Viscous portion **808** of probe **802** is similar to viscous portion **502** of probe **500** and viscous portion **606** of probe **602**. Viscous portion **808** is comprised of a material configured to collect drops of water on the surface of 5 viscous portion **808**.

As depicted, viscous portion **808** of probe **802** is configured such that all of viscous portion **808** may retract into housing **400** through port **408**. In this manner, viscous portion **808** with drops of water may be photographed and analyzed by sensor unit **128**. In some 10 illustrative examples, viscous portion **808** may be smaller or larger than shown in this figure, depending on the particular implementation.

In **Figure 9**, another illustration of a sensor unit is depicted in accordance with an 15 illustrative embodiment. In this illustrative example, probe **802** is shown as being fully extended on the exterior of housing **400** and probe **602** has been fully retracted into the interior of housing **400**.

In the illustrative examples depicted in **Figures 4-9**, probes, such as probe **500**, probe **602**, and probe **802**, may move in a manner such that one of the probes may always be 20 extended to collect drops of water when the sensor unit **128** is used to detect a presence of a number of types of icing conditions. In some examples, a first probe such as probe **500** may be fully retracted before a second probe, such as probe **602**, is extended. In other words, when viscous portion **502** of probe **500** reaches the interior of housing **400** in sensor unit **128** to be analyzed, probe **602** with viscous portion **606** may be extended. In other illustrative 25 examples, more than one probe may be extended from housing **400** substantially concurrently.

Turning now to **Figure 10**, an illustration of a cross-sectional view of a sensor unit is 30 depicted in accordance with an illustrative embodiment. In this illustrative example, a cross-sectional view of sensor unit **128** is shown taken along lines **10-10** in **Figure 4**.

As depicted, probe **500** with viscous portion **502**, probe **602** with viscous portion **606**, and probe **802** with viscous portion **808** are shown fully retracted into the interior of housing **400**. Probe **500** is operated by actuator **1000**, probe **602** is operated by actuator **1002**, and probe **802** is operated by actuator **1004** in these illustrative examples. Actuator **1000**, actuator **1002**, and actuator **1004** may be physical implementations for actuator system **306** in **Figure 3**.

Actuator **1000**, actuator **1002**, and actuator **1004** are configured to move probe **500**, probe **602**, and probe **802**, respectively, into the air and retract probe **500**, probe **602**, and probe **802** into housing **400**. Actuator **1000**, actuator **1002**, and actuator **1004** are controlled by controller **1006**. Controller **1006** may be a physical implementation for controller **312** in **Figure 3**.

In this example, drop remover **1008** is associated with probe **500**, drop remover **1010** is associated with probe **602**, and drop remover **1012** is associated with probe **802**. Drop remover **1008**, drop remover **1010**, and drop remover **1012** may be physical implementations for drop remover **310** in **Figure 3**.

In this illustrative example, drop remover **1008**, drop remover **1010**, and drop remover **1012** are shown as internal coils in this example. In other illustrative examples, drop remover **1008**, drop remover **1010**, and drop remover **1012** may be external heaters or associated with the surface of drop remover **1008**, drop remover **1010**, and drop remover **1012**.

In still other illustrative examples, drop remover **1008**, drop remover **1010**, and drop remover **1012** may be mechanical devices. These mechanical devices may be configured to scrape ice or drops of water off of the surfaces of probe **500**, probe **602**, and probe **802**.

As depicted, camera system **1014** is present in housing **400**. Camera system **1014** is an example of a physical implementation for camera system **308** in **Figure 3**. Camera system **1014** is configured to generate images of probe **500**, probe **602**, and probe **802** when

at least one of probe **500**, probe **602**, and probe **802** is retracted in housing **400**. Camera system **1014** is also operated by controller **1006** in these illustrative examples.

Turning now to **Figure 11**, an illustration of an isometric view of a sensor unit is 5 depicted in accordance with an illustrative embodiment. In this example, sensor unit **128** is shown such that probe **500**, probe **602**, probe **802**, and the components in housing **400** are visible.

In this view, actuator **1000** has extended probe **500** into the air. Viscous portion **502** is collecting drops of water in this illustrative example. Probe **602** and probe **802** remain in 10 the interior of housing **400**.

The illustrations of sensor unit **128** in **Figure 1**, and **Figures 4-11** are not meant to imply limitations to the manner in which sensor unit **300** may be implemented. For example, other sensor units may have other numbers of probes other than the three probes shown for 15 sensor unit **128**. For example, a sensor unit may include only a single probe, four probes, or some other suitable number of probes. Further, the probes also may have other shapes. For example, a probe may have a cross section that is oval, rectangular, square, hexagonal, or some shape other than the circular shape shown for probe **500**, probe **602**, and probe **802**.

20 Turning now to **Figure 12**, an illustration of a flowchart of a process for detecting an icing condition is depicted in accordance with an illustrative embodiment. The process illustrated in **Figure 12** may be implemented in icing condition detection environment **200** in **Figure 2**. In particular, this process may be implemented using icing condition detection system **204**.

25

The process begins by collecting drops of water from air on an exterior of a vehicle (operation **1200**). A number of images of the drops of water collected are generated (operation **1202**). The process then determines whether a number of types of icing conditions is present using the number of images (operation **1204**).

30

If a number of types of icing conditions is present, an operation is performed (operation **1206**) with the process then returning to operation **1200**. If a number of types of icing conditions is not present, the process also returns to operation **1200**. This process may be repeated as long as monitoring for one or more icing conditions is desired.

5

The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent a module, a segment, a function, and/or a portion of an operation or step. For example, one or more of the blocks may be implemented as program code, in hardware, or a combination of the program code and hardware. When implemented in hardware, the hardware may, for example, take the form of integrated circuits that are manufactured or configured to perform one or more operations in the flowcharts or block diagrams.

15

In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

Turning now to **Figure 13**, an illustration of a timing diagram for detecting a number of types of icing conditions is depicted in accordance with an illustrative embodiment. In this illustrative example, timing diagram **1300** shows the timing of a cycle of movement of the probes in sensor unit **128** in **Figures 4-11**. Timing diagram **1300** includes scale **1302** with elapsed time measured in seconds.

As depicted, timing diagram **1300** includes line **1304**, line **1306**, and line **1308**. Line **1304** tracks the movement over time of “probe A,” line **1306** tracks the movement over time of “probe B,” and line **1308** tracks the movement over time of “probe C.” Probe A may

correspond to probe **500**, probe B may correspond to probe **602**, and probe C may correspond to probe **802** in **Figures 4-11**.

In this illustrative example, the cycle time for probe A depicted by line **1304** consists 5 of five seconds in the air stream to sample drops of water in the air during time period **1310**, **20** seconds inside the housing to photograph and measure the drops during time period **1312**, and **35** seconds to heat or otherwise remove the drops of water from the probe during time period **1314**. After the photograph of probe A is taken, an icing measurement signal is latched for sixty seconds as shown during time period **1316**. A latched signal may be a 10 signal that is continuously transmitted. The signal may be latched in order to minimize nuisance cycling of ice protection systems. The cycle during time period **1310**, time period **1312**, and time period **1314** may repeat for any number of times for probe A.

In this depicted example, line **1317** indicates the signal being sent by probe A in 15 sensor unit **128**. This signal may be sent to the flight deck of the aircraft or to other suitable locations to be used in initiating operation of an anti-icing system or other suitable anti-icing measures. This signal may be sent continuously between cycles of probe A.

As depicted, probe B follows the same cycle as probe A but the cycle is offset by **15** 20 seconds. Line **1306** shows the collection, image generation, and drop removal portions of this cycle over time. Line **1318** indicates a signal being sent to the flight deck from probe B in sensor unit **128**.

In this example, probe C also follows the same cycle as probe A and probe B. The 25 cycle time for probe C depicted by line **1306** is delayed by **30** seconds in this illustrative example. Line **1320** indicates a signal being sent to the flight deck from probe C.

In this manner, sensor unit **128** continuously provides information to the flight deck about icing conditions for the aircraft. As a result, the aircraft may prevent or remove ice, 30 water, or both ice and water from the surface of the aircraft in substantially real time such that the aircraft operates as desired when icing conditions are present.

Thus, the illustrative embodiments provide a method and apparatus for detecting different types of icing conditions. With the use of an illustrative embodiment, the icing condition detection system may differentiate between types of icing conditions. Thus, the 5 illustrative embodiments provide more-detailed information about icing conditions than currently used icing detection systems that are unable to differentiate between normal and supercooled large drop icing conditions.

Further, the illustrative embodiments can accurately measure drop size. These 10 measurements may be made by comparing images of the drops of water collected on the probes to images stored in a database. Moreover, the illustrative embodiments may be operated using less power than currently used icing detection systems. For example, the sensor unit may be placed on “stand-by” until icing conditions are present.

15 Additionally, with the use of an illustrative embodiment, aircraft operators do not have to rely on the temperature of the aircraft to determine icing conditions. As ice accumulates on the probe, the icing condition detection system analyzes and classifies the type of icing condition present in the environment around the aircraft. This process alerts the flight deck of icing conditions much more quickly than using other techniques and provides 20 real time updates of the icing conditions surrounding the aircraft.

The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the 25 embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art.

Further, different illustrative embodiments may provide different features as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical 30 application, and to enable others of ordinary skill in the art to understand the disclosure for

various embodiments with various modifications as are suited to the particular use contemplated.

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY  
OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

1. An apparatus comprising:

5 a sensor system configured to collect drops of water from air on an exterior of an aircraft and to generate a number of images of the collected drops of water; and

an icing condition detector configured to detect, using the number of images from the sensor system, a presence within the collected drops of water of at least one of:

10 a first number of drops of water having a first number of sizes associated with a first type of icing condition for the aircraft; and

a second number of drops of water having a second number of sizes associated with a second type of icing condition for the aircraft.

2. The apparatus of claim 1, wherein the icing condition detector is further configured to perform an operation in response to detecting the presence of at least one of the first type of icing condition and the second type of icing condition.

15 3. The apparatus of claim 1 or 2, wherein the operation is selected from at least one of generating an alert, activating an anti-icing system, generating a log entry, and sending a report.

4. The apparatus of any one of claims 1 – 3, wherein the sensor system comprises:

20 a number of probes configured to collect the drops of water from the air on the exterior of the aircraft; and

a camera system configured to generate the number of images of the collected drops of water.

5. The apparatus of claim 4, wherein the number of probes is configured to extend into the air on the exterior of the aircraft and to retract out of the air on the exterior of the aircraft into an interior of the aircraft.

6. The apparatus of claim 4 or 5, wherein the number of probes is configured to periodically extend into the air on the exterior of the aircraft and retract out of the air on the exterior of the aircraft.

7. The apparatus of claim 4 further comprising:

5 a housing, wherein the camera system is located within the housing and the number of probes is configured to extend into the air on the exterior of the aircraft from the housing and retract out of the air on the exterior of the aircraft into the housing; and

10 a motor system configured to cause the number of probes to extend into the air on the exterior of the aircraft from the housing and to retract out of the air on the exterior of the aircraft back into the housing.

8. The apparatus of any one of claims 1-7, wherein the icing condition detector is configured to detect the presence of at least one of the first type of icing condition and the second type of icing condition by:

15 analyzing the number of images of the collected drops of water, when the collected drops of water include at least one of:

the first number of drops of water having a first number of sizes; and

the second number of drops of water having the second number of sizes; and

20 comparing at least one of the first number of sizes and the second number of sizes represented in the number of images with drop sizes stored in a drop database of frozen drops of water.

9. The apparatus of any one of claims 4-8, wherein the icing condition detector is located in at least one of the camera system, a housing, and a computer system in the aircraft.

10. The apparatus of any one of claims 1-9, wherein the first type of icing condition is caused by the first number of frozen drops having the first number of sizes from **0.00465** millimeters in diameter to **0.111** millimeters in diameter and the second type of icing condition is caused by

the second number of frozen drops having the second number of sizes from **0.112** millimeters in diameter to **2.2** millimeters in diameter

11. The apparatus of any one of claims **1-10**, wherein the second type of icing condition is a supercooled large drop type of icing condition.
- 5 12. The apparatus of claim **1**, wherein the sensor system further comprises:

a first probe, a second probe and a third probe, each configured to collect the drops of water from the air on the exterior of the aircraft;

10 a motor system configured to automatically and periodically cause the first probe, the second probe and the third probe to extend into the air on the exterior of the aircraft and retract back from the air on the exterior of the aircraft into the housing; and

a camera system located within the housing configured to generate the number of images of the collected drops of water when at least one of the first probe, the second probe, and the third probe is retracted into the housing.

15 13. The apparatus of claim **12**, wherein the first probe, the second probe and the third probe each have a viscous portion that collects the drops of water from the air on the exterior of the aircraft.

14. The apparatus of claim **13**, wherein the vicious portion includes at least one of silicon rubber, polytetrafluoroethylene, an oily resin and a waxy resin.

20 15. An icing condition detection system comprising:

a plurality of sensor units configured to generate information about at least one of a first type of icing condition and a second type of icing condition outside of an aircraft, wherein each sensor unit in the plurality of sensor units comprises:

25 a number of probes configured to collect drops of water from air on an exterior of the aircraft;

a camera system configured to generate a number of images of the collected drops of water;

an icing condition detector configured to detect, using the number of images generated by the camera system, a presence within the collected drops of water of at least one of:

a first number of drops of water having a first number of sizes associated with the first type of icing condition of the aircraft; and

a second number of drops of water having a number of second sizes associated with the second type of icing condition of the aircraft.

10 16. The icing condition detection system of claim 12 further comprising:

an anti-icing system configured to remove ice from a surface of the aircraft when the presence of at least one of the first type of icing condition and second type of icing condition is detected.

17. A method for detecting an icing condition, the method comprising:

15 collecting drops of water from air on an exterior of an aircraft;

generating a number of images of the collected drops of water; and

determining, using the number of images generated, a presence within the collected drops of water of at least one of:

a first number of drops of water having a first number of sizes associated with a first type of icing condition for the aircraft; and

a second number of drops of water having a second number of size associated with a second type of icing condition for the aircraft.

20 18. The method of claim 17 further comprising:

performing an operation when the presence of at least one of the first type of icing condition and the second type of icing condition is determined.

19. The method of claim **17 or 18**, wherein:

5 collecting the drops of water comprises causing a number of probes to extend into the air on the exterior of the aircraft and retract out of the air on the exterior of the aircraft into an interior of the aircraft; and

generating the number of images comprises generating the number of images of the collected drops of water as frozen drops of water when the number of probes are retracted out of the air on the exterior of the aircraft into the interior of the aircraft.

10 20. The method of claim **19**, wherein collecting the drops of water further comprises:

melting the frozen drops of water after generating the images and prior to causing the number of probes to extend back into the air on the exterior of the aircraft.

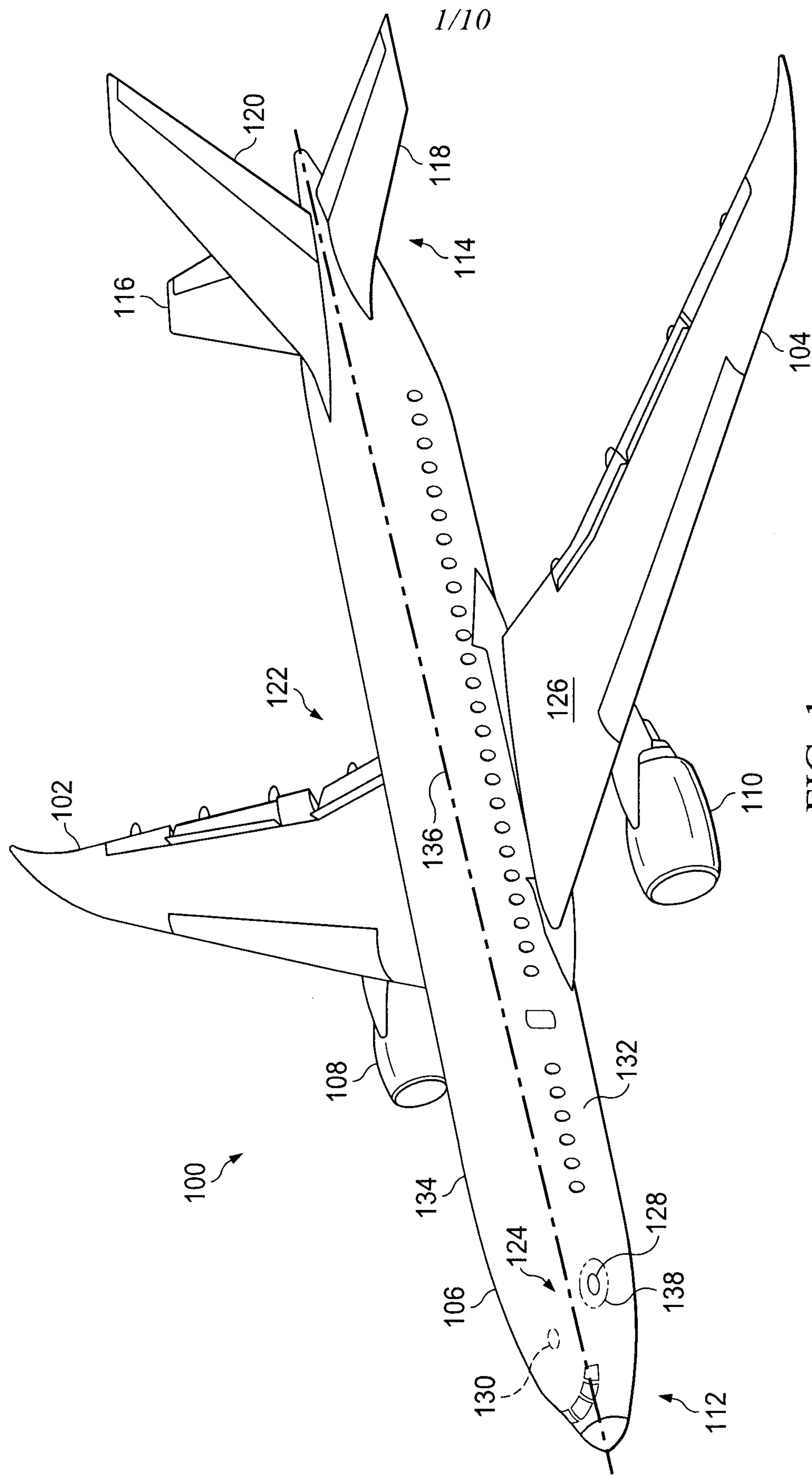


FIG. 1

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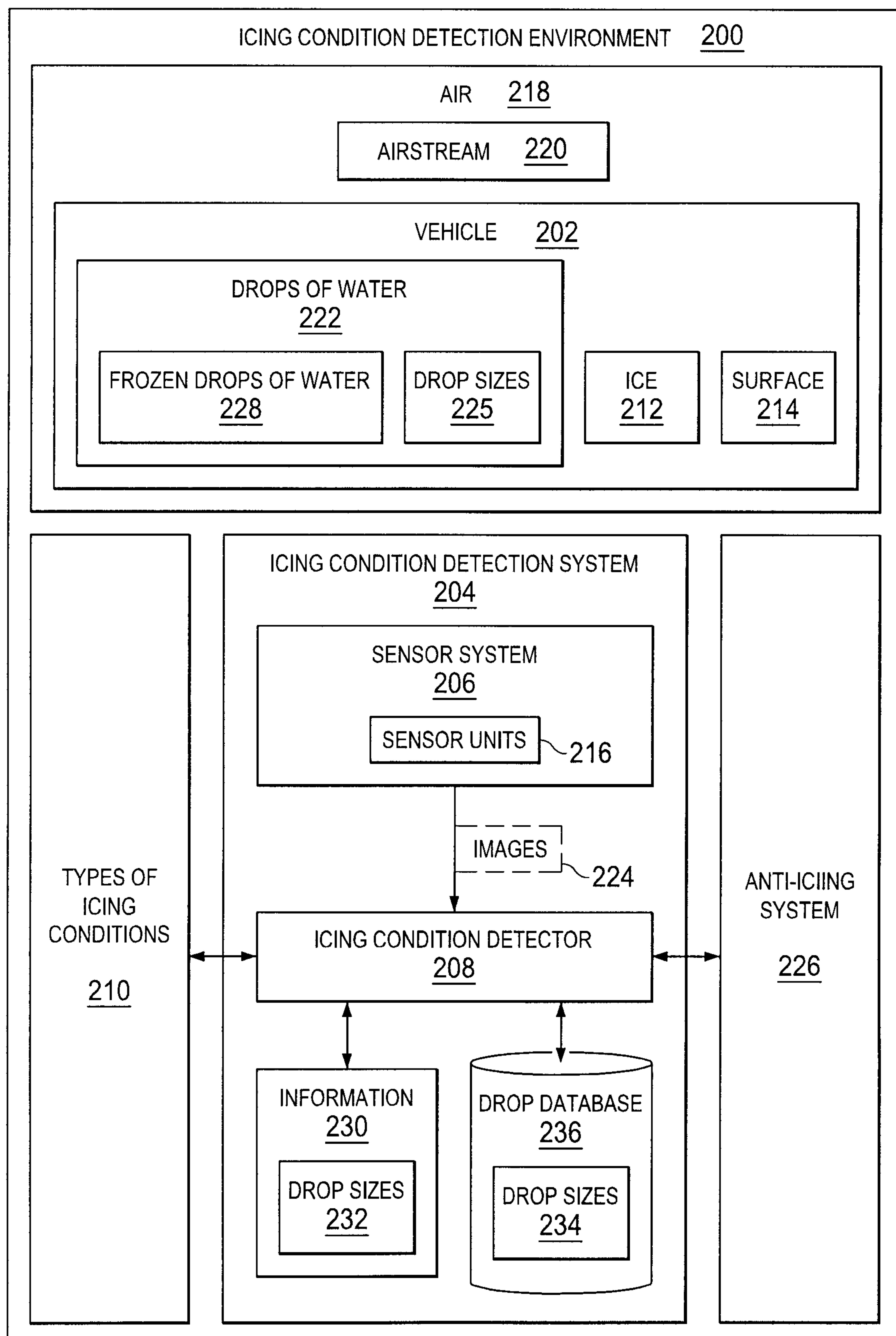


FIG. 2

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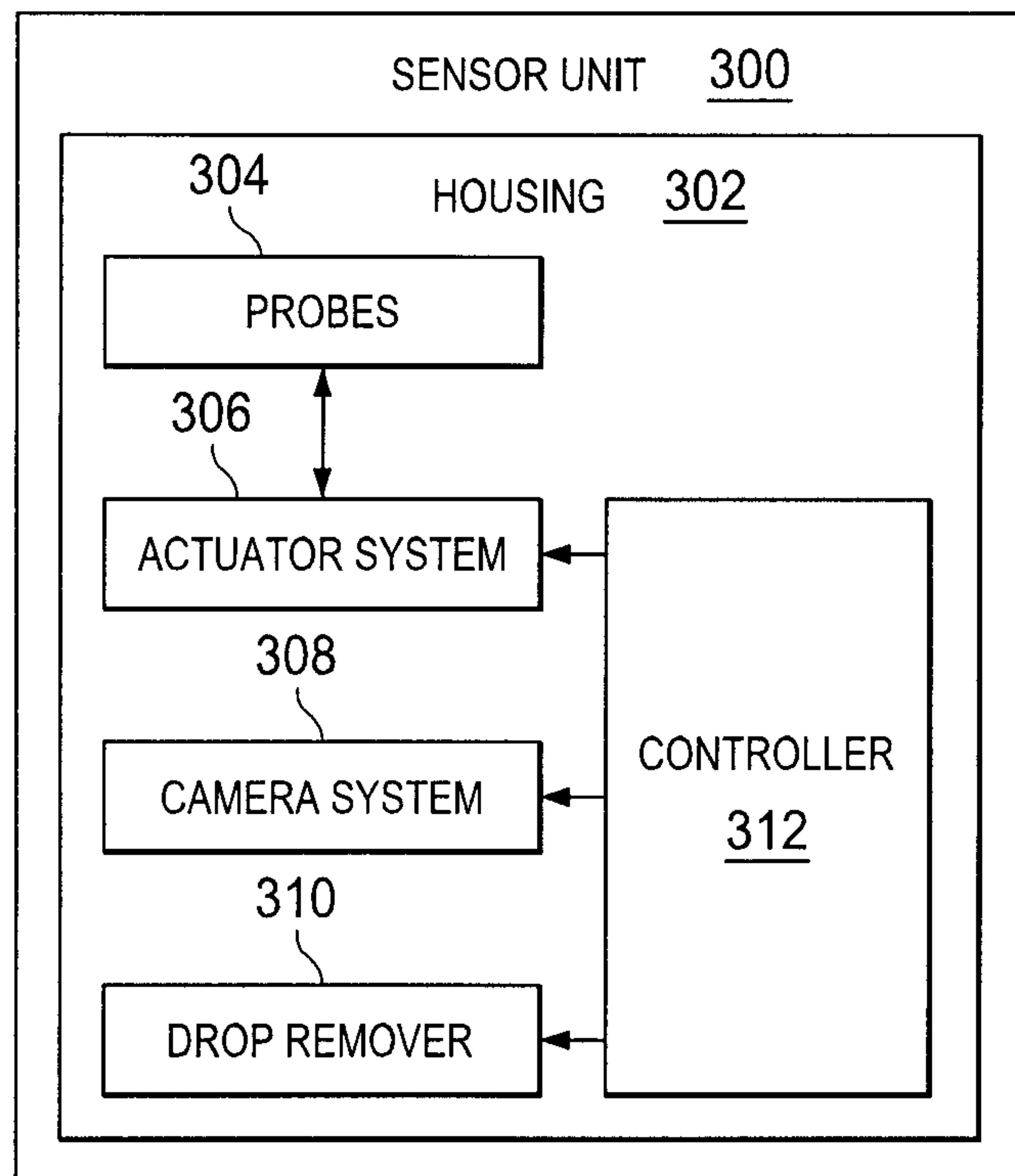


FIG. 3

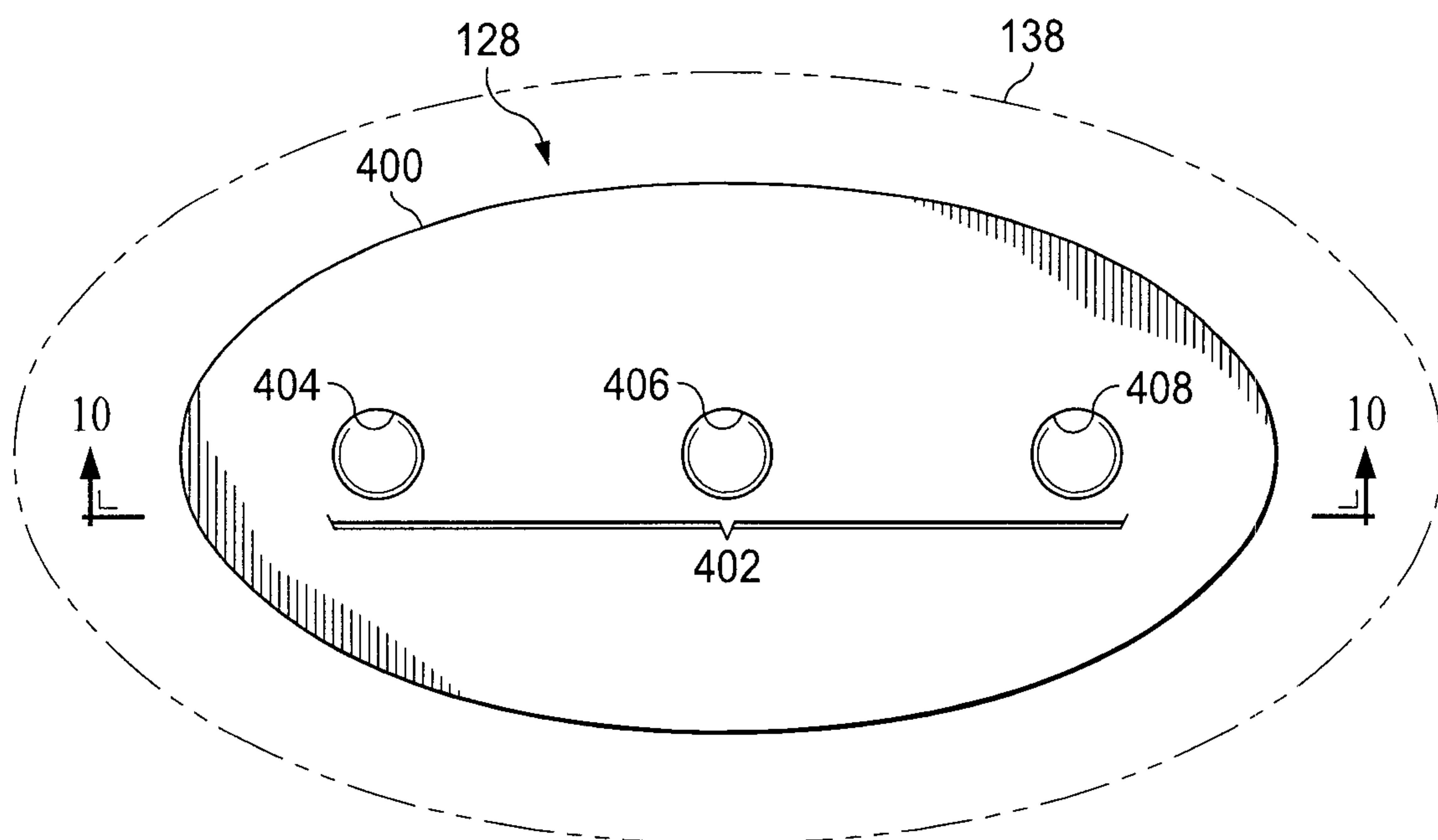


FIG. 4

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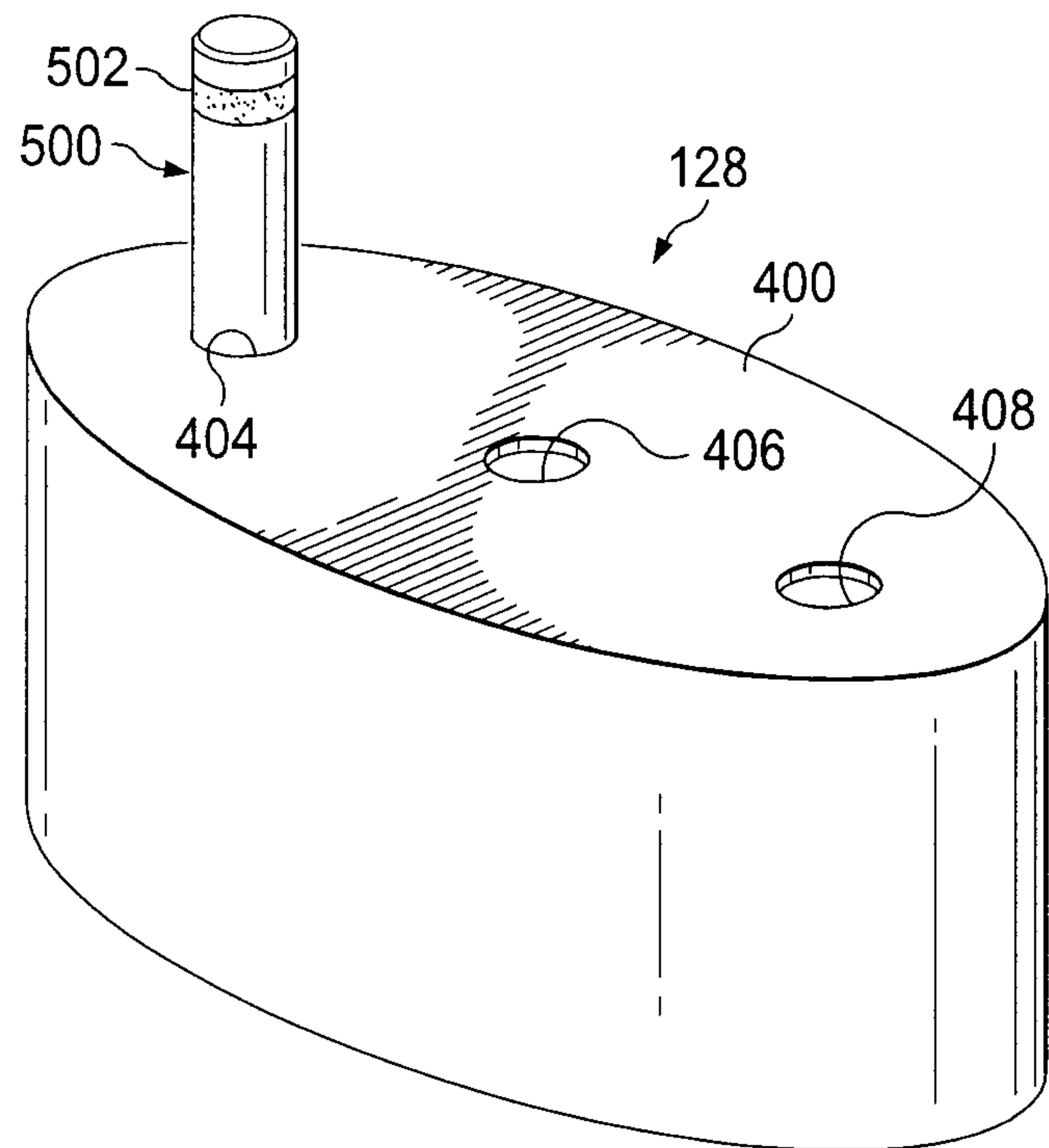


FIG. 5

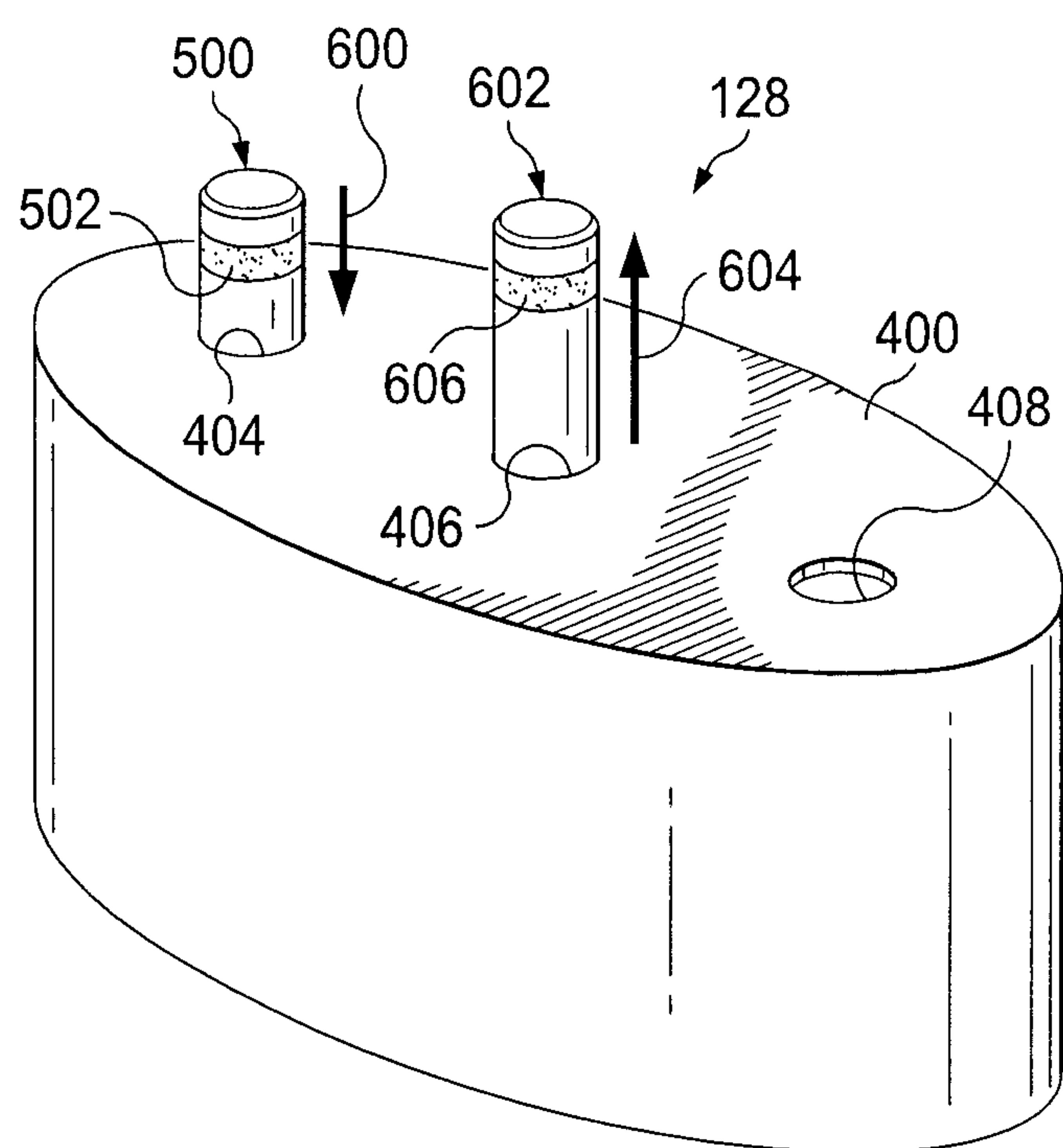


FIG. 6

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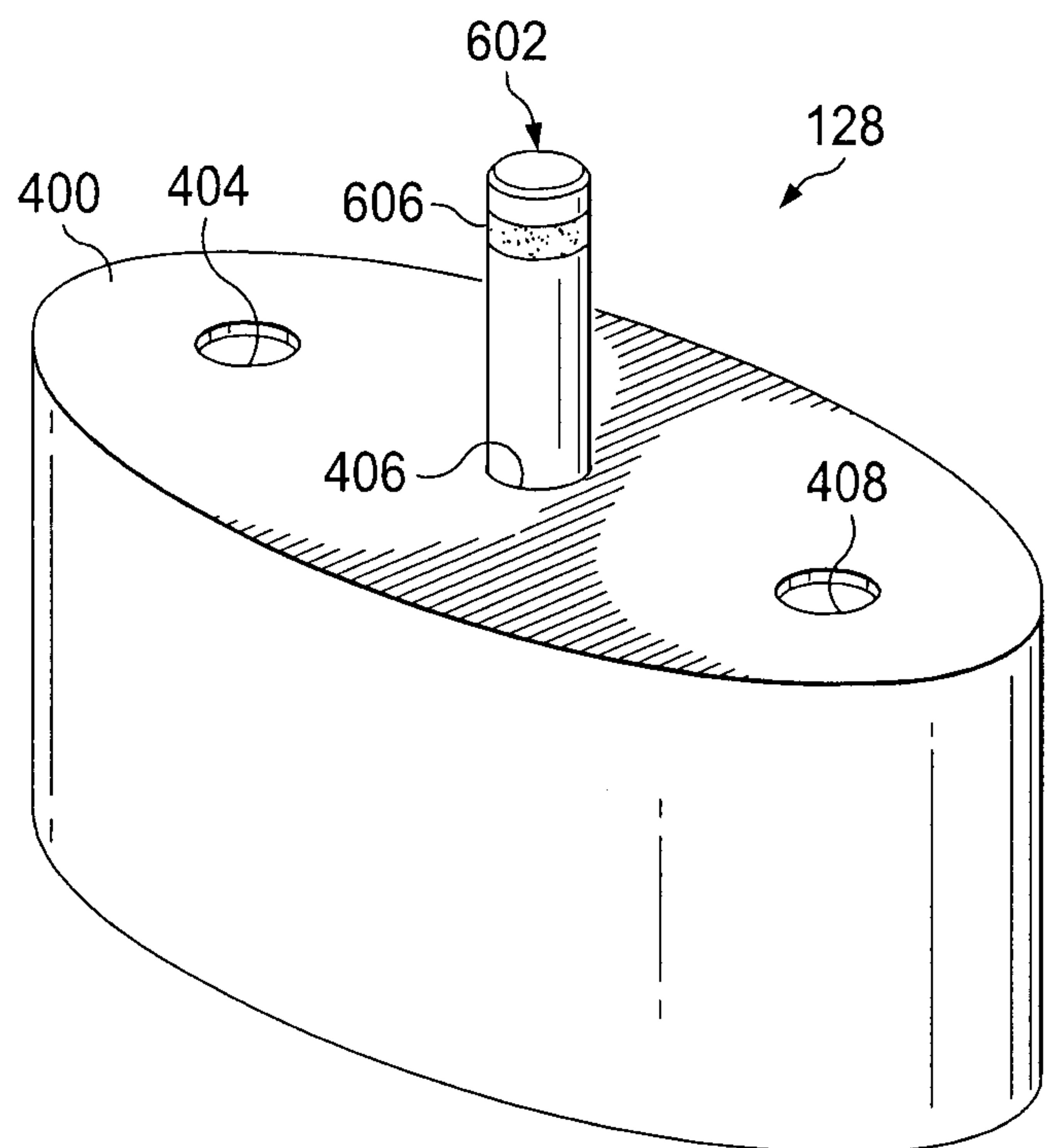


FIG. 7

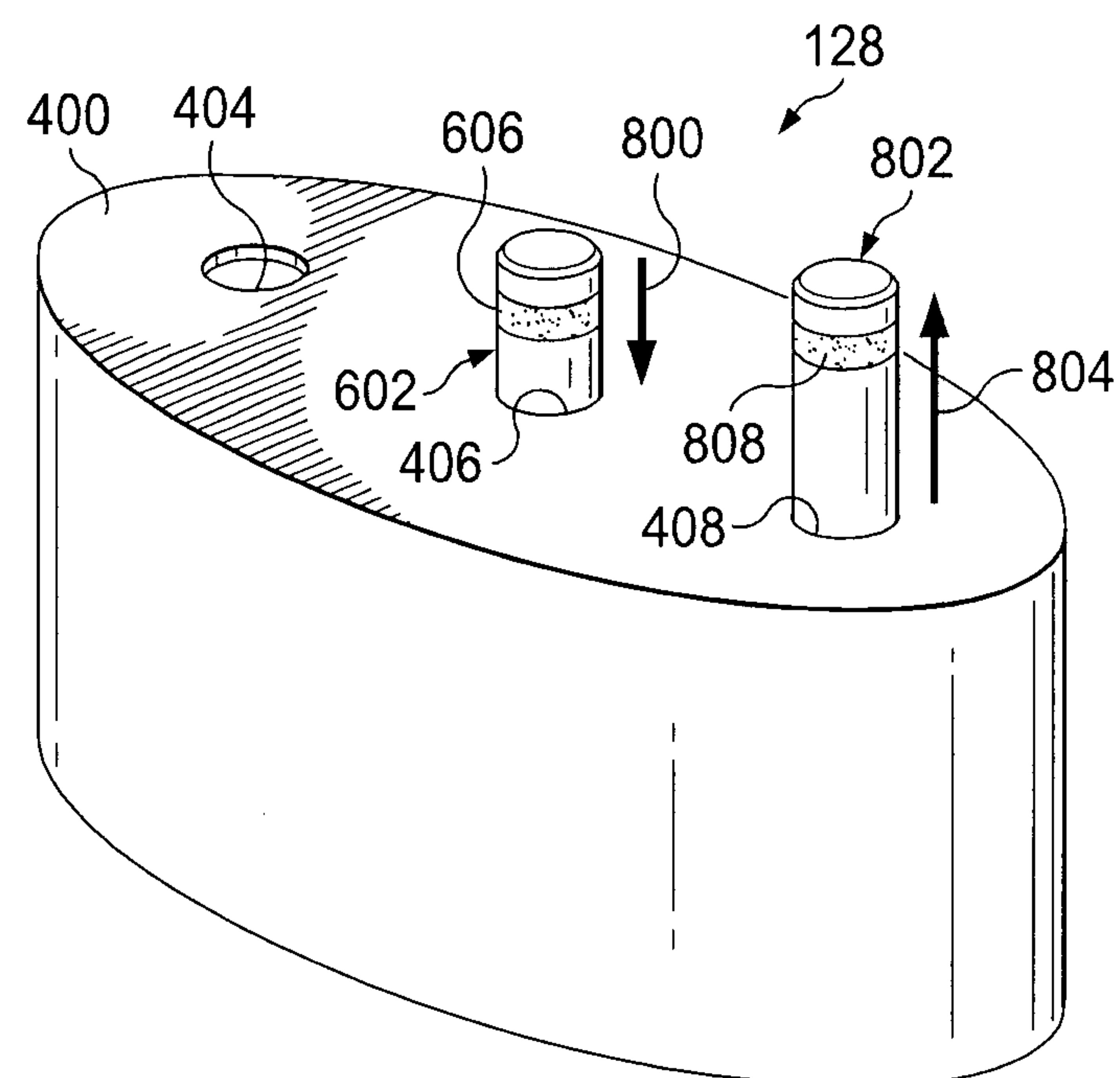


FIG. 8

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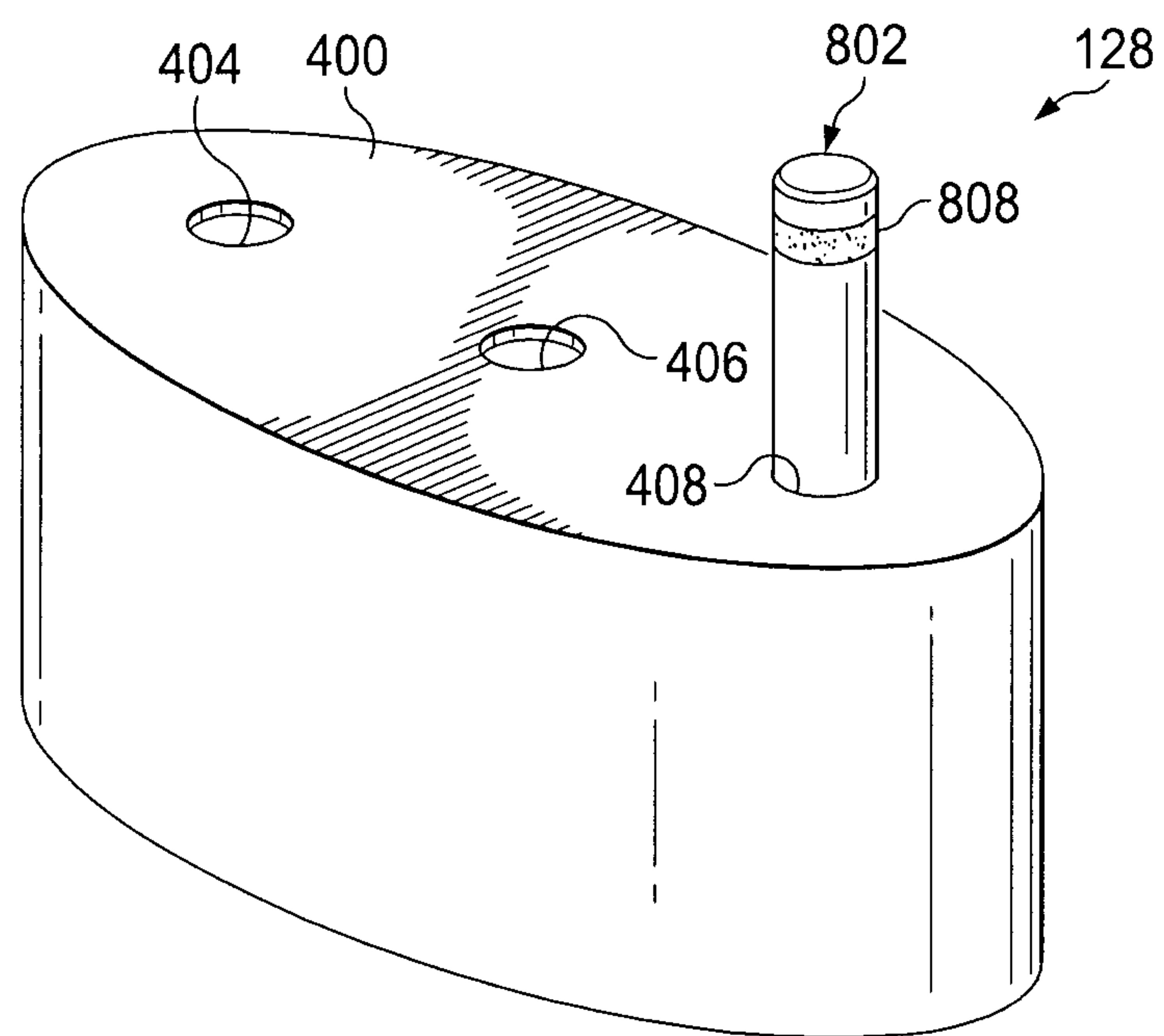


FIG. 9

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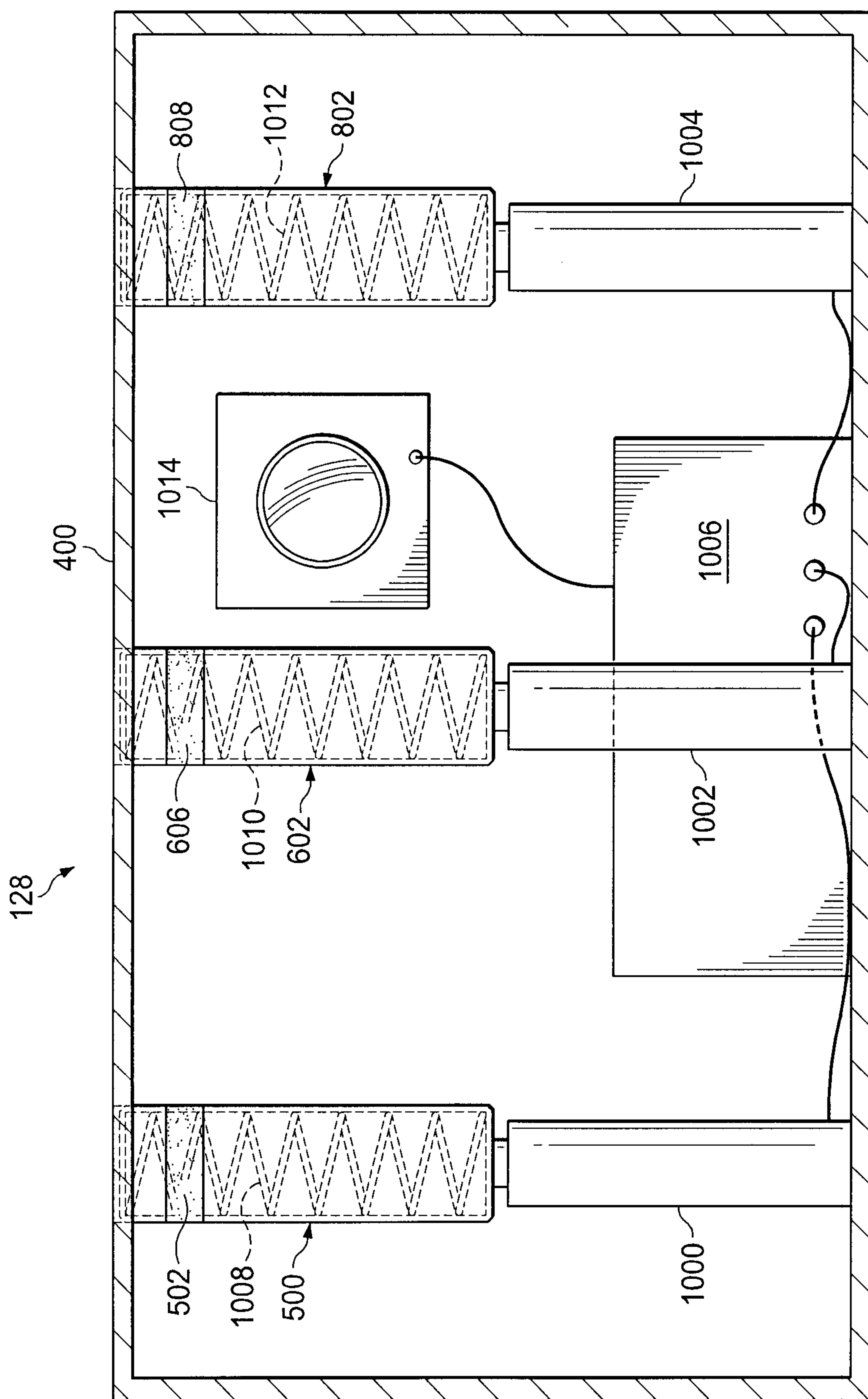
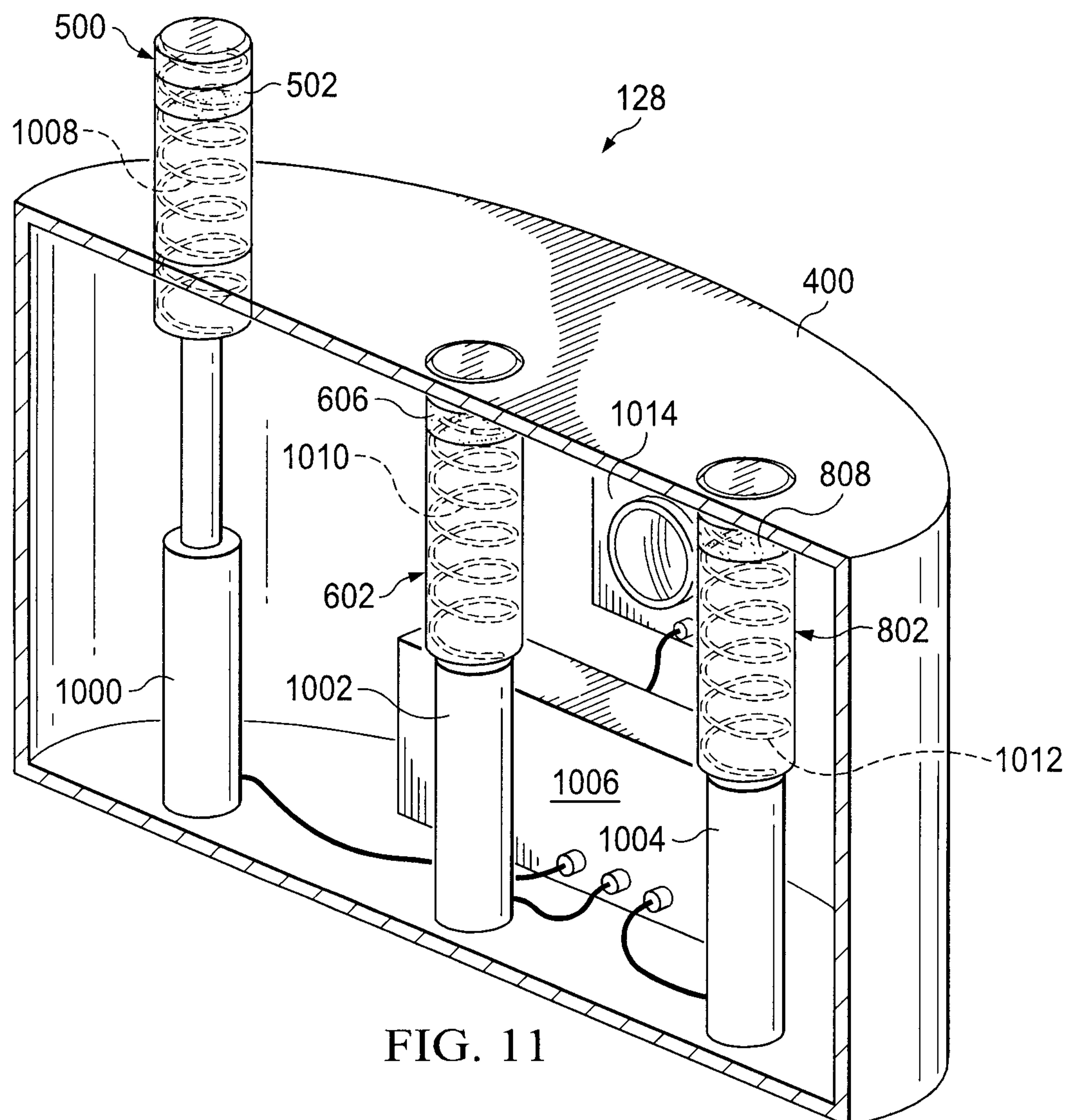


FIG. 10

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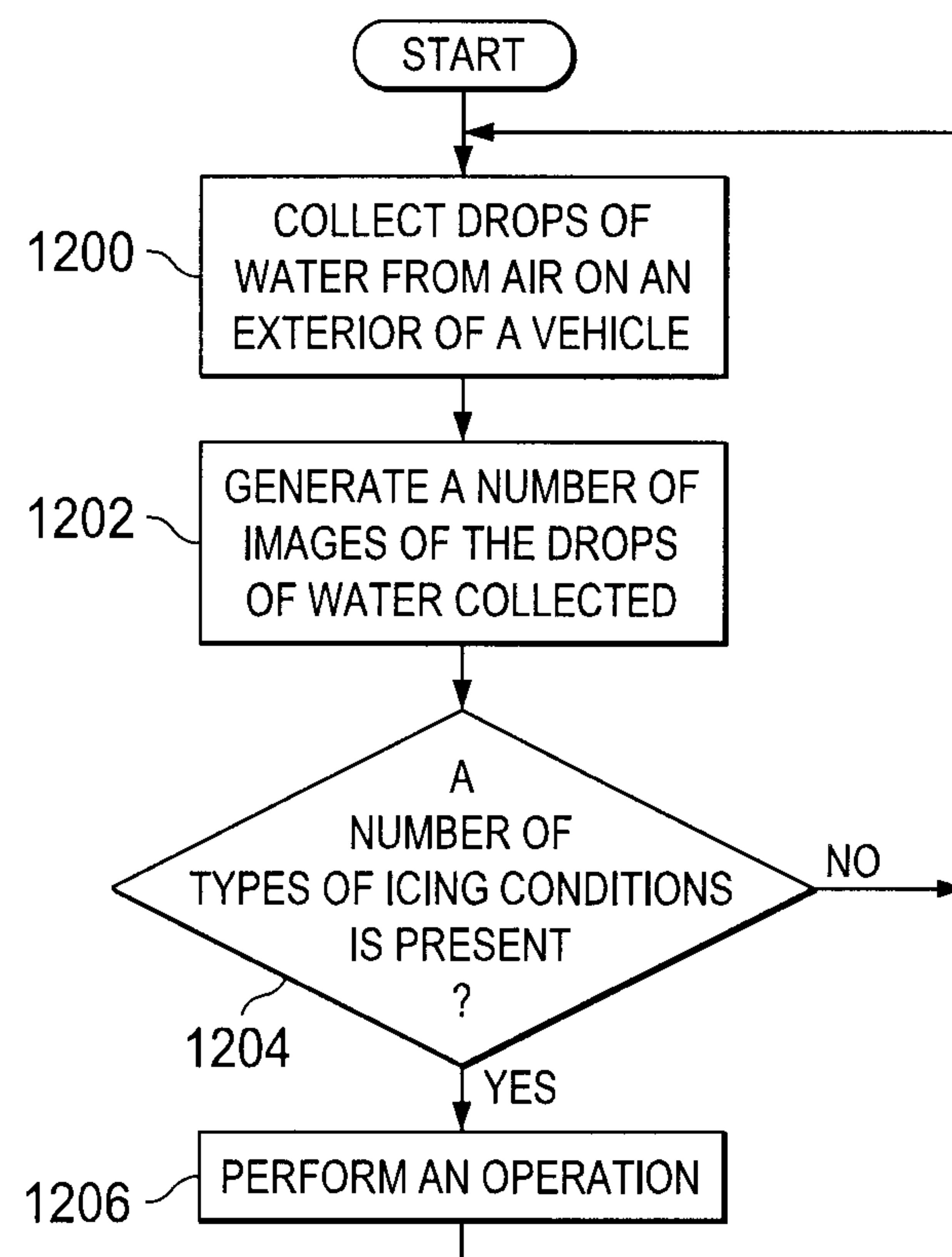


FIG. 12

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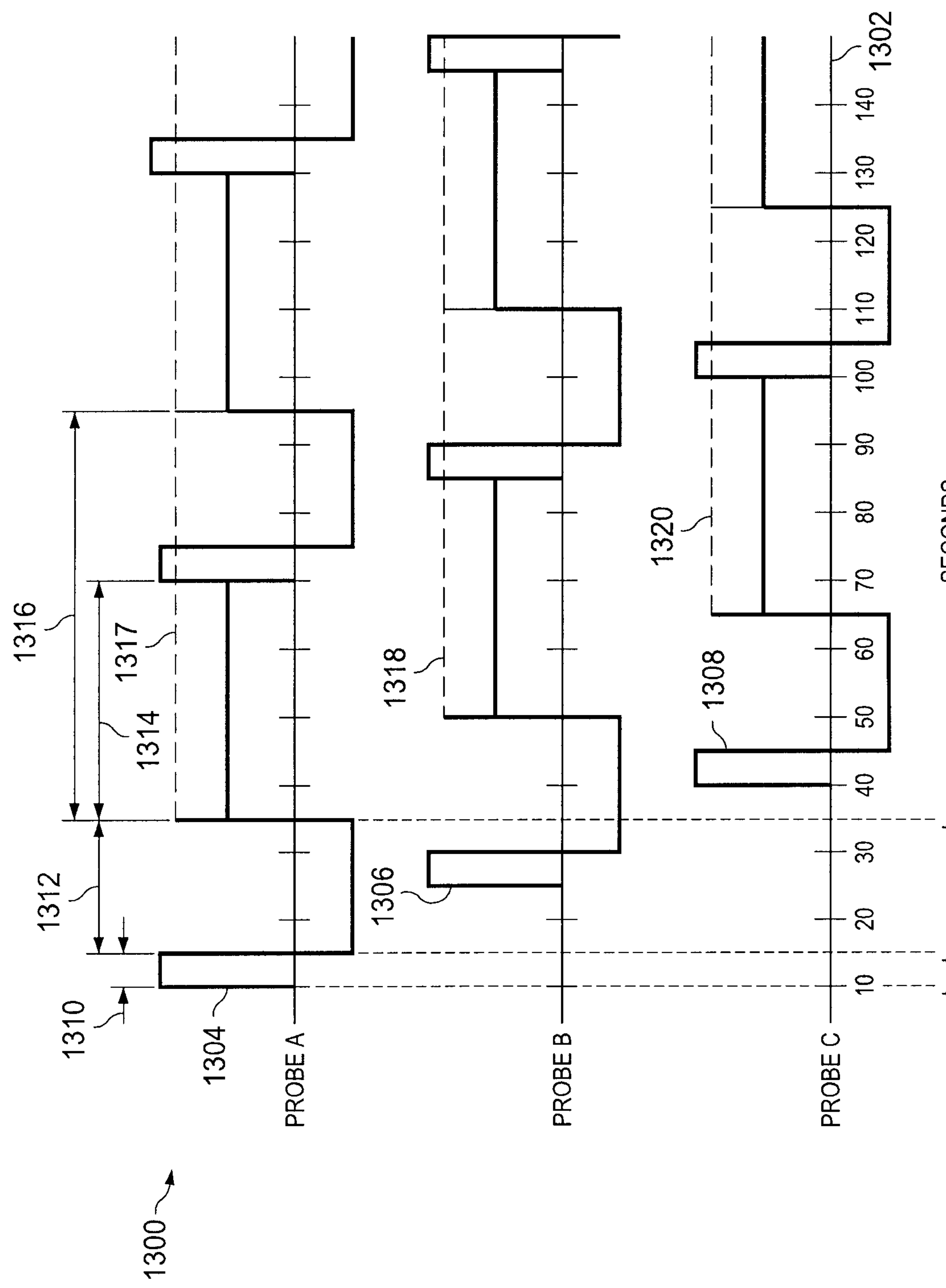


FIG. 13

