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(54) **SENSOR ARRANGEMENT AND CATHETER COMPRISING A SENSOR ARRANGEMENT**

SENSORANORDNUNG UND KATHETER MIT EINER SENSORANORDNUNG

AGENCEMENT DE CAPTEUR ET CATHÉTER COMPRENANT UN AGENCEMENT DE CAPTEUR

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EP 3 410 930 B1

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Description

[0001] The present disclosure generally relates to the field of sensor technology. More specifically, the present disclosure relates to a sensor arrangement and a catheter comprising a sensor arrangement.

[0002] A sensor able to measure a velocity of a fluid flow along two directions may be needed in certain cardiovascular procedures. In the state of the art, as described for example in WO 2011/101813 A1 and WO2014/186912 A1, this is obtained by using two perpendicular sensors in order to obtain the direction of the fluid flow, often described by an incidence angle ϑ .

[0003] Another configuration using a pair of parallel temperature sensors separated by a heating transistor is disclosed in US4637253.

[0004] In order to measure the velocity of the fluid flow in three dimensions, three orthogonal displaced sensors are needed. A measurement of the velocity of the fluid flow in two dimensions requires a sensor arrangement with two orthogonal displaced sensors.

[0005] In order to correctly measure the velocity of the fluid flow, the two sensors should be subject to the same velocity and the fluid flow should exchange the same amount of heat with the sensor.

[0006] In case a hot film or hot wire is used with a catheter, the catheter should be linked to a round surface of the sensor and it is possible that the surface of the two sensors being exposed to the flow will be different. For example, the horizontal sensor could be placed around the catheter while the vertical sensor could lie on one side. With this configuration both sensors cannot be exposed to the same flow when the sensor touches a vessel wall and only a part of the sensor is covered by the fluid flow.

[0007] A possible solution would be to minimize the sensor's surface, but this would also minimize the sensor's sensibility.

[0008] Therefore, a space-saving solution for a sensor arrangement is needed ideally not limiting the sensor's sensibility.

[0009] Accordingly, there is a need for an improved sensor arrangement and a catheter comprising such a sensor arrangement.

[0010] The present invention is set out in the appended claims. According to a first aspect, a sensor arrangement is provided. The sensor arrangement comprises at least two displaced first sensors and a control unit. The at least two displaced first sensors are arranged in parallel in a first plane and are adapted to measure a quantity of a fluid flow. The control unit is adapted to determine, from the measured quantity of the fluid flow, information indicating at least a range of directions of the fluid flow in two dimensions.

[0011] In other words, the at least two sensors are arranged parallel to one another / in parallel to each other. Further, the at least two sensors are displaced from each other. The term fluid flow can be understood as flow of

a/the fluid.

[0012] The term at least a range of directions of the fluid flow may relate to one single direction. The one single direction may correspond to the correct or actual direction of the fluid flow. In this case, the correct or actual direction of the fluid flow can be unambiguously determined. Thus, in this case, the control unit may be adapted to determine, from the measured quantity of the fluid flow, information indicating the correct or actual direction of the fluid flow in two dimensions.

[0013] The term at least a range of directions of the fluid flow may relate to two or more direction candidates (candidates of directions) lying within the range of directions. The two or more direction candidates may comprise the correct or actual direction of the fluid flow. In this case, an approximation or estimation of the correct or actual direction of the fluid flow can be determined. This approximation or estimation may be specified more accurately by appropriate measures or configurations as explained in more detail below. Thus, in this case, the control unit may be adapted to determine, from the measured quantity of the fluid flow, information indicating a range of directions of the fluid flow, the range of directions including the correct or actual direction of the fluid flow in two dimensions.

[0014] In this way, a space-saving solution is achieved. The two-dimensional sensor arrangement according to the first aspect includes displaced sensors that are arranged in parallel rather than displaced sensors that are arranged orthogonally to each other. The sensors' output is then processed in such a way that bi-dimensional flow information can be derived. Bi-dimensional (flow) information may be understood as (flow) information with only two values, e.g. one value for one direction, respectively.

[0015] This configuration solves the current limitation of the state of the art, because if, for example, the two sensors were displaced and arranged in parallel to a longitudinal direction of a catheter, it may improve the bi-dimensional fluid flow velocity measurement, which was limited by cases in which two perpendicular sensors were not exposed to the same flow pattern. The parallel arrangement may ensure that the sensors are exposed to at least approximately the same flow pattern.

[0016] The at least two displaced first sensors are spaced parallel to each other. The at least two displaced first sensors may be spaced apart from each other, in particular transverse to or orthogonal to a common direction or common orientation of the at least two displaced first sensors. The common direction or common orientation of the at least two displaced first sensors may be defined by a lengthwise/longitudinal direction of each of the at least two displaced first sensors. The at least two displaced first sensors are arranged next to each other, in particular abreast or alongside, transverse to or orthogonal to the lengthwise/longitudinal direction of each of the at least two displaced first sensors. The common direction or common orientation of the at least two displaced first sensors may be defined by the parallel

arrangement of the at least two displaced first sensors.

[0017] The control unit is adapted to determine, from the measured quantity of the fluid flow, information indicating a direction of the fluid flow in two dimensions. The determined direction may lie within the range of directions. The range of directions may comprise a first and fourth, or a second and third quadrant of a two-dimensional coordinate system of the first plane. In this case, the determined direction may lie in an area formed by a first and fourth, or a second and third quadrant of a two-dimensional coordinate system of the first plane. For example, the range of directions may correspond to the first and fourth quadrant of the two-dimensional coordinate system or to the second and third quadrant of the two-dimensional coordinate system.

[0018] For example, the control unit may be adapted to determine, from the measured quantity of the fluid flow, information indicating a direction of the fluid flow in two dimensions, wherein the information may indicate that the direction lies in an area formed by a first and fourth, or a second and third quadrant of a two-dimensional coordinate system of the first plane.

[0019] The quadrants may be defined by a two-dimensional coordinate system comprising x- and y-axes, wherein the sensors are arranged in parallel to the y-axis. The coordinate system is not part of the sensor arrangement, but can be regarded as a virtual reference used herein to describe the direction of the fluid flow in the coordinate system. The quadrants of the two-dimensional coordinate system may be described as follows.

[0020] In geometry, the axes of a two-dimensional Cartesian system divide the plane into four infinite regions, called quadrants, each bounded by two half-axes. These quadrants are often numbered from first to fourth and denoted by Roman numerals: I (where the signs of the two coordinates are (+,+)), II (-,+), III (-,-), and IV (+,-). When the axes are drawn according to the mathematical custom, the numbering goes counter-clockwise starting from the upper right ("northeast") quadrant.

[0021] In other words, the first quadrant may be established by positive values of x and y, the second quadrant may be drawn up by a positive value of y and a negative value of x, the third quadrant may be drawn up by negative values of x and y and the fourth quadrant may be drawn up by a negative value of y and a positive value of x. The combination of the first and fourth quadrant may form the right half of the coordinate system and the second and third quadrant may form the left half of the coordinate system.

[0022] In consequence, the information indicating at least the range of directions of the fluid flow may indicate a distinction between right and left half of the sensor arrangement with respect to the y-axis of the coordinate system. The first quadrant of the two-dimensional coordinate system may be described by a respective angle $0 \leq \alpha \leq 90^\circ$ of the coordinate system starting at the positive x-axis ($\alpha = 0^\circ$) rotating in a counter-clockwise direction or the incidence angle $180^\circ \geq \vartheta \geq 90^\circ$ (the incidence angle

normally starts on the negative side of the x-axis and rotates clockwise). The second quadrant of the two-dimensional coordinate system may be described by a respective angle $90^\circ \leq \alpha \leq 180^\circ$ of the coordinate system starting at the y-axis ($\alpha = 90^\circ$) rotating in a counter-clockwise direction or the incidence angle $90^\circ \geq \vartheta \geq 0^\circ$. The third quadrant of the two-dimensional coordinate system may be described by a respective angle $180^\circ \leq \alpha \leq 270^\circ$ of the coordinate system starting at the negative x-axis ($\alpha = 180^\circ$) rotating in a counter-clockwise direction or the incidence angle $360^\circ \geq \vartheta \geq 270^\circ$. The fourth quadrant of the two-dimensional coordinate system may be described by a respective angle $270^\circ \leq \alpha \leq 360^\circ$ of the coordinate system starting at the negative y-axis ($\alpha = 270^\circ$) rotating in a counter-clockwise direction or the incidence angle $270^\circ \geq \vartheta \geq 180^\circ$.

[0023] The information regarding the indication of at least a range of directions of the fluid flow may indicate a trend of the direction of the fluid flow in a certain region, e.g. one or more quadrants as explained above.

[0024] The first sensors of the sensor arrangement according to the first aspect may be thermal sensors or flow sensors, for example hot wire, hot plate, constant temperature or constant current anemometers. Thermal sensors may be referred to as temperature sensors and flow sensors may be referred to as anemometric sensors.

[0025] The sensor arrangement according to the first aspect may further comprise at least two displaced second sensors, i.e. at least two second sensors that are displaced from one another. The at least two displaced second sensors may be arranged in parallel in the first plane and may be adapted to measure the quantity of the fluid flow. The at least two displaced second sensors may be spaced parallel to each other. The at least two displaced second sensors may be spaced apart from each other, in particular transverse to or orthogonal to the common direction or common orientation of the at least two displaced first sensors. The common direction or common orientation of the at least two displaced second sensors may be defined by the lengthwise/longitudinal direction of each of the at least two displaced first sensors. Each of the at least two displaced first sensors may be arranged next to one of the at least two displaced second sensors, in particular abreast or alongside, transverse to or orthogonal to the lengthwise/longitudinal direction of each of the at least two displaced first sensors. The common direction or common orientation of the at least two displaced second sensors may be defined by the parallel arrangement of the at least two displaced first sensors. The control unit may be adapted to determine the information indicating at least the range of directions of the fluid flow in two dimensions by further considering the quantity of the fluid flow measured by the at least two displaced second sensors. In other words, the control unit may further be adapted to determine, from the measured quantity of the fluid flow (as measured by the first and second sensors), the information indicating at least the range of directions of the fluid flow in two dimensions.

[0026] For example, the control unit may be adapted to determine, by further considering the quantity of the fluid flow measured by the at least two displaced second sensors, the information indicating the direction of the fluid flow in two dimensions, wherein the direction lies in the first, second, third or fourth quadrant of the two-dimensional coordinate system of the first plane. In other words, the control unit may further be adapted to determine, from the measured quantity of the fluid flow (as measured by the first and second sensors), information indicating the direction of the fluid flow in two dimensions, wherein the direction lies in the first, second, third or fourth quadrant of the two-dimensional coordinate system of the first plane. In this way, the information regarding the indication of at least the range of directions of the fluid flow may indicate a more accurate trend of the direction of the fluid flow in a certain region, e.g. one or more quadrants as explained above.

[0027] The at least two displaced second sensors may have a different size and/or length than the at least two displaced first sensors. For example, the at least two displaced second sensors may be shorter or longer in size and/or length than the at least two displaced first sensors. The term size may relate to the size in the longitudinal direction of the respective sensor.

[0028] The sensor arrangement according to the first aspect may further comprise at least two displaced third sensors, i.e. at least two third sensors that are displaced from each other. The at least two displaced third sensors may be arranged in parallel in a second plane, perpendicular to the first plane, and adapted to measure the quantity of the fluid flow. The at least two displaced third sensors may be spaced parallel to each other. The at least two displaced third sensors may be spaced apart from each other, in particular transverse to or orthogonal to a common direction or common orientation of the at least two displaced third sensors. The common direction or common orientation of the at least two displaced third sensors may be defined by a lengthwise/longitudinal direction of each of the at least two displaced third sensors. The at least two displaced third sensors may be arranged next to each other, in particular abreast or alongside, transverse to or orthogonal to the lengthwise/longitudinal direction of each of the at least two displaced third sensors. The common direction or common orientation of the at least two displaced third sensors may be defined by the parallel arrangement of the at least two displaced third sensors. The control unit may be further adapted to determine information indicating at least a range of directions of the fluid flow in three dimensions by further considering the quantity measured by the at least two third sensors.

[0029] The sensor arrangement may further comprise at least two displaced fourth sensors arranged in parallel to the third sensors in the second plane. The at least two fourth sensors may have a different size and/or length than the at least two third sensors. The at least two displaced fourth sensors may be spaced parallel to each

other. The at least two displaced fourth sensors may be spaced apart from each other, in particular transverse to or orthogonal to the common direction or common orientation of the at least two displaced third sensors. The common direction or common orientation of the at least two displaced fourth sensors may be defined by the lengthwise/longitudinal direction of each of the at least two displaced third sensors. Each of the at least two displaced third sensors may be arranged next to one of the at least two displaced fourth sensors, in particular abreast or alongside, transverse to or orthogonal to the lengthwise/longitudinal direction of each of the at least two displaced third sensors. The common direction or common orientation of the at least two displaced fourth sensors may be defined by the parallel arrangement of the at least two displaced third sensors. In this respect, the fourth sensors may be considered to correspond to the second sensors and the third sensors may be considered to correspond to the first sensors.

[0030] The at least two displaced first, second, third and/or fourth sensors of the sensor arrangement may be arranged in parallel to each other.

[0031] The measured quantity of the fluid flow may comprise or be a velocity of the fluid flow, an acceleration of the fluid flow or the like.

[0032] The velocity of the fluid flow may be determined by a lookup table, an analytical solution and/or a numerical solution of the heat transfer convection governing equation.

[0033] According to a second aspect, a catheter is provided. The catheter comprises a sensor arrangement according to the first aspect, wherein the sensor arrangement is arranged on the catheter for measuring a fluid flow, e.g. the blood flow.

[0034] The sensor arrangement may be arranged in longitudinal direction of the catheter. In this arrangement the at least two first sensors may lie parallel to the longitudinal direction of the catheter.

[0035] In this way, the space required by the sensor arrangement in the longitudinal direction on the catheter can be reduced. The perpendicular sensor arrangement of the state of the art requires more space in the longitudinal direction of the catheter, as one sensor has to be placed, in the longitudinal direction of the catheter, next to the other, perpendicular sensor. On the contrary, the sensor arrangement according to the first aspect requires less space in the longitudinal direction of the catheter, namely space at least similar to or corresponding to the length of one sensor.

[0036] The catheter may comprise or be formed as a tube. In this case, the longitudinal direction may be the longitudinal direction of the tube.

[0037] In the following, the present disclosure will further be described with reference to exemplary embodiments illustrated in the Figures, in which:

Fig.1 is a schematic illustration of two prior art sensor arrangements;

Fig.2A is a schematic illustration of a sensor arrangement with a parallel sensor configuration;

Fig.2B is a schematic illustration of a sensor arrangement with a parallel sensor configuration and a fluid flow indication;

Fig.2C is a schematic illustration of a two-dimensional coordinate system with indicated first, second, third and fourth quadrants, and an indicated fluid flow;

Fig.3A is a schematic illustration of a sensor arrangement with a parallel sensor configuration and an exemplary temperature distribution, when the incidence angle of the fluid flow is $\vartheta = 0^\circ$ ($\alpha = 180^\circ$);

Fig.3B is a schematic illustration of measurement values, when the incidence angle of the fluid flow is $\vartheta = 0^\circ$ ($\alpha = 180^\circ$);

Fig.3C is a schematic illustration of a sensor arrangement with a parallel sensor configuration and an exemplary temperature distribution, when the incidence angle of the fluid flow is $\vartheta = 90^\circ$ ($\alpha = 90^\circ$);

Fig.3D is a schematic illustration of measurement values, when the incidence angle of the fluid flow is $\vartheta = 90^\circ$ ($\alpha = 90^\circ$);

Fig.3E is a schematic illustration of a sensor arrangement with a parallel sensor configuration and an exemplary temperature distribution, when the incidence angle of the fluid flow is $\vartheta = 30^\circ$ ($\alpha = 150^\circ$);

Fig.3F is a schematic illustration of measurement values, when the incidence angle of the fluid flow is $\vartheta = 30^\circ$ ($\alpha = 150^\circ$);

Fig.3G is a schematic illustration of a sensor arrangement with a parallel sensor configuration and an exemplary temperature distribution, when the incidence angle of the fluid flow is $\vartheta = 60^\circ$ ($\alpha = 120^\circ$);

Fig.3H is a schematic illustration of measurement values, when the incidence angle of the fluid flow is $\vartheta = 60^\circ$ ($\alpha = 120^\circ$);

Fig.4 is a schematic illustration of a sensor arrangement with a parallel sensor configuration and two additional parallel sensors;

Fig.5A is a schematic illustration of a sensor arrangement for a fluid flow measurement in three di-

mensions;

Fig.5B is a schematic illustration of a sensor arrangement for a fluid flow measurement in three dimensions with additional sensors; and

Fig.6 is a schematic illustration of an example lookup table for solving the heat transfer convection governing equation.

[0038] In the following description, for purposes of explanation and not limitation, specific details are set forth, such as specific sensor and geometry details, in order to provide a thorough understanding of the present disclosure. It will be apparent to one skilled in the art that the present disclosure may be practiced in other embodiments that depart from these specific details. For example, even if the present disclosure is described with reference to specific angles to illustrate directions of the fluid flow, the present disclosure may be practiced with all angles (0° to and including 360°). All of the calculations described herein may be carried out by a suitable control unit (mentioned above) e.g. using individual hardware circuitry, using software functioning in conjunction with a programmed microprocessor or a general purpose computer, using an Application Specific Integrated Circuit (ASIC) and/or using one or more Digital Signal Processors (DSPs). The control unit can be suitably connected in wireless and/or wired manner to one or more sensors and one or more sensor arrangements described herein to exchange data such as measurement values. The control unit may be arranged on a catheter on which the sensor arrangement(s) described herein is/are arranged or may be arranged separately from the catheter.

[0039] Fig. 1 shows a schematic illustration of two prior art sensor arrangements 3 based on hot-wires and hot-films. Three orthogonal displaced sensors are shown, which are required for measuring a velocity of a three dimensional fluid flow. For the measurement of the velocity of the fluid flow in two dimensions a sensor arrangement with two orthogonal displaced sensors is required.

[0040] Fig. 2A shows a schematic illustration of a sensor arrangement 1 with a parallel sensor configuration comprising two parallel sensors 5. The two sensors 5 are arranged in parallel in a common plane. In the example of Fig. 2A the sensors 5 of the sensor arrangement 1 have a rectangular geometry, but they may also be implemented as parallel wires or have a different geometry, e.g. circular or elliptical. This configuration is built to measure a direction of the fluid flow, which may be originating from the left or right of a sensor plane, as described in more detail below.

[0041] Fig. 2B shows a schematic illustration of the sensor arrangement 1 of Fig. 2A and a fluid flow 10 indication. The additionally indicated fluid flow 10 describes a direction having an incidence angle ϑ with respect the negative side of the x-axis 20. In this scenario, the incident fluid flow 10 is exemplarily indicated to originate from the

left and thus to be on the left hand side of the sensors plane. The sensor plane is, in the present example, formed by the two axes in y-direction 15 and x-direction 20. In other words, the incident fluid flow 10 is exemplarily indicated to originate from the left hand side with respect to the y-axis 15 and to end in the origin of the coordinate system.

[0042] Fig.2C shows a schematic illustration of a two-dimensional coordinate system 2 illustrated in Fig. 2B in more detail. That is, the two-dimensional coordinate system 2 of Fig. 2C has a first 25, a second 26, a third 27 and a fourth 28 quadrant. Further, a fluid flow 10 is indicated in the coordinate system. The sensor arrangement 1 is adapted to determine at least a range of directions of the fluid flow 10 within the coordinate system. For example, the sensor arrangement 1 may determine that the direction of the fluid flow 10 lies within one or more quadrants of the two-dimensional coordinate system 2. In the scenario of two parallel sensors 5, the information is bi-dimensional and indicates a direction coming from a left hand side or a right hand side with respect to the y-axis 15. In other words, the sensor arrangement 1 is configured to determine that the direction lies in the second 26 and third 27 quadrant (left side), or the first 25 and fourth 28 quadrant (right side), respectively. In the example of Fig. 2C, the sensor arrangement can determine, for example, that the direction of the fluid flow 10 lies within the area formed by the second quadrant 26 and third quadrant 27.

[0043] Fig.3A shows a schematic illustration of further details of the sensor arrangement 1 of Fig. 2A. Fig. 3A illustrates an exemplary temperature distribution 30, 35 of the fluid, when the incidence angle of the fluid flow is $\vartheta = 0^\circ$ ($\alpha = 180^\circ$). In case of a flow (and flow velocity) with an incidence angle of $\vartheta = 0^\circ$ ($\alpha = 180^\circ$), the left sensor is working normally and is not affected by the right sensor. The right sensor measures, however, a slightly warmed fluid, as shown by the isothermal area 30, so its measurement will be of a lowered magnitude with respect to the one measured by the left sensor.

[0044] Fig.3B shows a schematic illustration of the measurement values 31, 36 measured by the sensors 5 in the example of Fig. 3A, when the incidence angle of the fluid flow is $\vartheta = 0^\circ$ ($\alpha = 180^\circ$) as illustrated in Fig.3A. As described above with respect to Fig. 3A, the first measurement value 31 as measured by the left sensor is higher than the second measurement value 36 measured by the right sensor. As the first measurement value 31 is higher than the second measurement value 36, the sensor arrangement 1 can derive that the direction of the fluid flow lies in the second or third quadrant. There is still some ambiguity as to where exactly in the second and third quadrant the direction lies. The sensor arrangement 1 can be suitably calibrated to lower or even nullify this ambiguity. For example, the sensor arrangement 1 can be calibrated such that the difference between the measurement values 31, 36 is a maximum difference value when the incidence angle of the fluid flow is $\vartheta = 0^\circ$ (α

$= 180^\circ$). Thus, when determining measurement values 31, 36 and thus deriving a difference value between these measurement values 31, 36, the sensor arrangement sensor 1 can detect that the determined difference value corresponds to the calibrated maximum difference value. Thus, the sensor arrangement 1 can determine that the direction of the fluid flow is along the x-axis 20 without knowing whether the direction is pointing into the left or right direction. By further considering whether the left or right sensor returned the lower measurement value, the sensor arrangement 1 can further determine whether the direction is pointing into the left or right direction. If the left sensor returns the higher measurement value 31, then the sensor arrangement 1 determines that the direction points to the right $\vartheta = 0^\circ$ ($\alpha = 180^\circ$), i.e. the fluid flow is from left to right. If the left sensor returns the lower measurement value 36, then the sensor arrangement 1 determines that the direction points to the left $\vartheta = 180^\circ$ ($\alpha = 0^\circ$), i.e. the fluid flow is from right to left.

[0045] Fig.3C shows a schematic illustration of the sensor arrangement 1 of Fig. 2A. Fig. 3C further shows an exemplary temperature distribution 30, 35, when the incidence angle of the fluid flow is $\vartheta = 90^\circ$ ($\alpha = 90^\circ$). The left sensor and the right sensor are either not affecting each other or they are affecting each other in an equal manner, which depends on the distance between the sensors 5 and the magnitude of the flow velocity.

[0046] Fig.3D shows a schematic illustration of the measurement values 31, 36 measured by the sensors 5 in the example of Fig. 3C, when the incidence angle of the fluid flow is $\vartheta = 90^\circ$ ($\alpha = 90^\circ$). In this case, both sensors 5 return the same measurement values 31, 36. Thus, the sensor arrangement 1 can derive, as the sensors 5 are either not affected by each other or affected in an equal manner, that the direction of the fluid flow is along the y-axis 15, e.g. either up or down in this illustration. Since this scenario usually describes the primary direction in a catheter comprising a sensor arrangement arranged in longitudinal direction of the catheter, the direction indicates the usual blood flow.

[0047] Fig.3E shows a schematic illustration of the sensor arrangement 1 of Fig. 2A. Fig. 3E further illustrates an exemplary temperature distribution 30, 35, when the incidence angle of the fluid flow is $\vartheta = 30^\circ$ ($\alpha = 150^\circ$). The left sensor is affecting the measurement of the right sensor similar to the case of $\vartheta = 0^\circ$ ($\alpha = 180^\circ$). However, the difference between the measurement values 31, 36 of the two sensors 5 is lower because the influence of the left sensor will affect only a part of the area of the right sensor.

[0048] Fig.3F shows a schematic illustration of the measured difference 31, 36, when the incidence angle of the fluid flow is $\vartheta = 30^\circ$ ($\alpha = 150^\circ$). As explained above with respect to Figs. 3A and 3B, the sensor arrangement 1 determines, by comparing the measurement values 31, 36, that the direction lies in the second or third quadrant in the example of Fig. 3E. There is remaining ambiguity regarding the distinction between the second or third

quadrant. Also in this case the effect described above with respect to Figs. 3A and 3B will be present, i.e. the right sensor will be less sensible to the fluid flow due to the influence of the left sensor on the right sensor. In other words, the left sensor will return the higher measurement value 31. However, the difference between the measurement values 31, 36 is lower than in Fig. 3B, as the right sensor is influenced less by the left sensor than in Fig. 3A. If the sensor arrangement is suitably calibrated as explained above, it can determine that the direction is in the second or third quadrant, but not on the x-axis 20.

[0049] Fig.3G shows a schematic illustration of the sensor arrangement 1 of Fig. 2A. Further, Fig. 3G shows an exemplary temperature distribution 30, 35, when the incidence angle of the fluid flow is $\vartheta = 60^\circ$ ($\alpha = 120^\circ$). Again, the left sensor is affecting the measurement of the right sensor similar to the case of $\vartheta = 0^\circ$ ($\alpha = 180^\circ$) and $\vartheta = 30^\circ$ ($\alpha = 150^\circ$). However, the difference between the measurement values 31, 36 of the two sensors 5 is lower than in the other two cases because the influence of the left sensor will affect only a smaller part of the area of the right sensor.

[0050] Fig.3H shows a schematic illustration of the measurement values 31, 36 measured by the sensors 5, when the incidence angle of the fluid flow is $\vartheta = 60^\circ$ ($\alpha = 120^\circ$). As explained above, the sensor arrangement 1 can determine that the direction lies in the second or third quadrant, because the left sensor returned the higher measurement value 36. There remains the ambiguity as to where exactly the direction lies within the second or third quadrant. If suitably calibrated in the way explained above, the sensor arrangement 1 may even determine that the direction of the fluid is closer to the y-axis 15 than in the case of $\vartheta = 30^\circ$ ($\alpha = 150^\circ$) as the difference between the measurement values 31, 36 is smaller.

[0051] Fig.4 shows a schematic illustration of the sensor arrangement 1 having the parallel sensor configuration comprising the two parallel sensors 5 as illustrated in Figs. 2A to 3H and explained above and two additional parallel sensors 6. This configuration allows distinguishing between the first, second, third and fourth quadrant of a two-dimensional plane, wherein the two parallel sensors 5 and the additional two parallel sensors 6 are aligned in parallel in the same plane. The disambiguation between $0^\circ \leq \vartheta \leq 90^\circ$ (second quadrant, $180^\circ \geq \alpha \geq 90^\circ$) and $270^\circ \leq \vartheta \leq 360^\circ$ (third quadrant, $270^\circ \geq \alpha \geq 180^\circ$) is performed by adding the two parallel sensors 6 for example as an anemometric sensor or a temperature sensor, respectively.

[0052] If the two parallel sensors 6 are anemometric sensors, and:

if the right sensor of the two sensors 6 records a lower value with respect to the left sensor of the two sensors 6, it means that the sensor is working in the region $270^\circ \leq \vartheta \leq 360^\circ$ ($270^\circ \geq \alpha \geq 180^\circ$);

if the left sensor of the two sensors 6 records an equal value with respect to the right sensor of the

two sensors 6, and the flow is going from left to right as determined by the sensors 5, then it means that the direction is in the region $0^\circ \leq \vartheta \leq 90^\circ$ ($180^\circ \geq \alpha \geq 90^\circ$);

if both left and right sensors of the two sensors 6 record a reduced fluid flow velocity with respect to the normal fluid flow velocity measured by the left and right sensor of the two sensors 5, it means that the flow is going in the direction of $\vartheta = 270^\circ$ ($\alpha = 270^\circ$); and

if both left and right sensors of the two sensors 6 record an equal fluid flow velocity with respect to the normal fluid flow velocity measured by the left and right sensors of the two sensors 5, it means that the flow is going in the direction of $\vartheta = 90^\circ$ ($\alpha = 90^\circ$).

[0053] If the two parallel sensors 6 are temperature sensors, and:

if the right sensor of the two sensors 6 records a higher value with respect to the left sensor of the two sensors 6, then the sensor is working in the region $0^\circ \leq \vartheta \leq 90^\circ$ ($180^\circ \geq \alpha \geq 90^\circ$);

if the left sensor of the two sensors 6 records an equal value with respect to the right sensor of the two sensors 6, and the flow is going from left to right as determined by sensors 5, then it means that the direction is in the region $270^\circ \leq \vartheta \leq 360^\circ$ ($270^\circ \geq \alpha \geq 180^\circ$);

if both left and right sensors of the two sensors 6 record a higher temperature with respect to the fluid temperature than the sensors 5, it means that the flow is going in the direction of $\vartheta = 270^\circ$ ($\alpha = 270^\circ$); and

if both left and right sensors 6 record an equal temperature with respect to the fluid temperature as sensors 5, it means that the flow is going in the direction of $\vartheta = 90^\circ$ ($\alpha = 90^\circ$).

[0054] Similarly, the disambiguation between $180^\circ \geq \vartheta \geq 90^\circ$ (first quadrant, $0 \leq \alpha \leq 90^\circ$) and $270^\circ \geq \vartheta \geq 180^\circ$ (fourth quadrant, $270^\circ \leq \alpha \leq 360^\circ$) can be performed.

[0055] Fig.5A shows a schematic illustration of a sensor arrangement 1 for a fluid flow measurement in three dimensions with first sensors 5 and second sensors 7, wherein the sensors 5, 7 are arranged in parallel, but the first sensors 5 and the second sensors 7 are placed along two non-parallel axes, e.g. two perpendicular axes as illustrated in Fig.5A, whereby a three-dimensional information according to a direction of the fluid flow can be gathered.

[0056] Fig.5B shows a schematic illustration of a sensor arrangement 1 for a fluid flow measurement in three dimensions, wherein additional sensors 6 are added to the sensor arrangement 1 of Fig.5A to more precisely gather information regarding the three-dimensional case as explained above with respect to Figure 4. This extension may lead to information indicating a direction, which

correspond to octants of a three-dimensional coordinate system.

[0057] Fig.6 shows a schematic illustration of an example lookup table for solving the heat transfer convection governing equation in order to implement the concept of comparing measurement values to derive the fluid flow direction as explained above. When a moving fluid with temperature T_f encounters a warmer body at a temperature T_s , there is a heat transfer between the two bodies known as convective heat transfer. The governing equation of this physical phenomenon is:

$$\rho c \left[\frac{\partial T}{\partial t} + v_i \frac{\partial T}{\partial x_i} \right] - \frac{\partial}{\partial x_i} \left(k \frac{\partial T}{\partial x_i} \right) - q = 0$$

Where T is the temperature, q is the volumetric heat source, ρ is the material's density, k the thermal conductivity, c the specific heat. v_i is the fluid's velocity in direction x_i . The equation describes the temperature distribution into a fluid domain where the fluid is moving.

[0058] The convective effect is used for building anemometers, a resistive sensor R_s is heated at a temperature T_s above fluid's temperature T_f and the power transferred to the fluids by the sensor, when the fluid is moving, is described by the following equation:

$$I^2 R_s = h A_s (T_s - T_f)$$

where I is the current flowing into the sensor, h is a convective coefficient and A_s is the area of the sensor. Anemometric sensors are also sensitive to the direction of the fluid with respect to the geometrical dimension of the sensor.

[0059] If the two measurements of S1 (left sensor) and S2 (right sensor) are defined as:

- ES_{min} is the value measured by the sensor (S1 or S2) measuring the lower value, and
- ES_{max} is the value measured by the sensor (S1 or S2) measuring the higher value.

[0060] The following equation may be written:

$$ES_{max} = f_k(U_{eff}),$$

where f_k is a function that relates the measured velocity with an electrical output of the sensor, e.g. the well-known King's Law. In a bi-dimensional space the "effective cooling velocity" or U_{eff} is defined as:

$$U_{eff}^2 = U^2 (\cos^2 \vartheta + k^2 \sin^2 \vartheta)$$

[0061] This equation describes the relation between a

measured U_{eff} with the real fluid's velocity U , where ϑ is the angle (orientation of the velocity) between the sensor's transverse direction and the fluid's velocity and k is a sensor's coefficient (geometrical coefficient specific for each sensor) that quantifies a sensor's sensibility to the velocity direction perpendicular to the main direction.

[0062] The measurement performed by the S_{min} (sensor (S1 or S2) measuring the lower value) may be in general written as:

$$ES_{min} = f_{FSmax}(v, \vartheta) - f_{shade}(v, \vartheta, T_s)$$

where f_{shade} is the function describing the loss in sensitivity of the sensor S measuring the lower value that is a function of the fluid's velocity, the velocity orientation and the known sensor's temperature (T_s). By coupling the measurements ES_{max} and ES_{min} , it is possible to establish a relationship between the two measurements that may identify the two values of v and ϑ , when $0^\circ \leq \vartheta \leq 90^\circ$ ($180^\circ \geq \alpha \geq 90^\circ$) or $270^\circ \leq \vartheta \leq 360^\circ$ ($270^\circ \geq \alpha \geq 180^\circ$) (Fig.3A-3H), assuming that the flow goes from the left sensor to the right sensor (the system behaves symmetrically when the flow goes from the right sensor to the left sensor).

[0063] A function g

$$[v, \vartheta] = g(ES_{max}, ES_{min})$$

may be formulated using different methods:

- Empirical definition, through test bench experiments. In this case, g is then formulated as a look up table;
- Analytical solution of the heat transfer convection governing equation;
- Numerical solution of the heat transfer convection governing equation; or
- Use of reduced and simplified formulas derived from the heat transfer convection governing equation.

Claims

1. A sensor arrangement (1) comprising:

at least two displaced first sensors (5) arranged in parallel in a first plane and next to each other, and adapted to measure a quantity of a fluid flow (10); and

a control unit adapted to determine, from the measured quantity of the fluid flow (10), information indicating at least a range of directions of the fluid flow (10) in two dimensions, wherein the first sensors (5) are hot wire, hot plate, constant temperature or constant current anemometers.

2. The sensor arrangement (1) according to claim 1, wherein the control unit is adapted to determine, from the measured quantity of the fluid flow (10), information indicating a direction of the fluid flow (10) in two dimensions, wherein the information indicates that the direction lies in an area formed by a first (25) and fourth (28), or a second (26) and third (27) quadrant of a two-dimensional coordinate system (2) of the first plane.
3. The sensor arrangement (1) according to claim 1 or 2, further comprising at least two displaced second sensors (6) arranged in parallel in the first plane and adapted to measure the quantity of the fluid flow (10), wherein the control unit is adapted to determine the information indicating at least the range of directions of the fluid flow (10) in two dimensions by further considering the quantity of the fluid flow (10) measured by the at least two displaced second sensors (6).
4. The sensor arrangement (1) according to claim 3, wherein the control unit is further adapted to determine information indicating the direction of the fluid flow (10) in two dimensions by further considering the quantity of the fluid flow (10) measured by the at least two displaced second sensors.
5. The sensor arrangement (1) according to any of claims 1 to 4, further comprising at least two displaced third sensors (7) arranged in parallel in a second plane, perpendicular to the first plane, and adapted to measure the quantity of the fluid flow (10), wherein the control unit is further adapted to determine information indicating at least a range of directions of the fluid flow (10) in three dimensions by further considering the quantity measured by the at least two third sensors (7).
6. The sensor arrangement (1) according to claim 5, wherein the at least two displaced first (5), second (6) and third (7) sensors are arranged in parallel.
7. The sensor arrangement (1) according to any of claims 1 to 6, wherein the quantity comprises a velocity of the fluid flow.
8. The sensor arrangement (1) according to claim 7, wherein the velocity of the fluid flow is determined by a lookup table, an analytical solution or a numerical solution of the heat transfer convection governing equation.
9. A catheter comprising a sensor arrangement (1) according to any of claims 1 to 8, wherein the sensor arrangement (1) is arranged on the catheter for measuring a fluid flow, for example a blood flow.

10. The catheter according to claim 9, wherein the sensor arrangement (1) is arranged in longitudinal direction of the catheter.

Patentansprüche

1. Sensoranordnung (1), umfassend:
 - zumindest zwei versetzte erste Sensoren (5), die parallel in einer ersten Ebene und nebeneinander angeordnet sind, und die eingerichtet sind, um eine Größe eines Fluidstroms (10) zu messen; und
 - eine Steuereinheit, die eingerichtet ist, um aus der gemessenen Größe des Fluidstroms (10) Informationen zu bestimmen, die zumindest einen Bereich von Richtungen des Fluidstroms (10) in zwei Dimensionen angeben, wobei die ersten Sensoren (5) Hitzdrahtanemometer, Heizplattenanemometer, Konstanttemperaturanemometer oder Konstantstromanemometer sind.
2. Sensoranordnung (1) gemäß Anspruch 1, wobei die Steuereinheit eingerichtet ist, um aus der gemessenen Größe des Fluidstroms (10) Informationen zu bestimmen, die eine Richtung des Fluidstroms (10) in zwei Dimensionen angeben, wobei die Informationen angeben, dass die Richtung in einer Fläche liegt, die durch einen ersten (25) und vierten (28) oder einen zweiten (26) und dritten (27) Quadranten eines zweidimensionalen Koordinatensystems (4) der ersten Ebene ausgebildet ist.
3. Sensoranordnung (1) gemäß Anspruch 1 oder 2, weiterhin umfassend zumindest zwei versetzte zweite Sensoren (6), die parallel in der ersten Ebene angeordnet sind und eingerichtet sind, um die Größe des Fluidstroms (10) zu messen, wobei die Steuereinheit eingerichtet ist, um die Informationen, die zumindest den Bereich der Richtungen des Fluidstroms (10) in zwei Dimensionen angeben, durch weiteres Berücksichtigen der Größe des Fluidstroms (10) zu bestimmen, der durch die zumindest zwei versetzten zweiten Sensoren (6) gemessen ist.
4. Sensoranordnung (1) gemäß Anspruch 3, wobei die Steuereinheit weiterhin eingerichtet ist, um Informationen, die die Richtung des Fluidstroms (10) in zwei Dimensionen angeben, durch weiteres Berücksichtigen der Größe des Fluidstroms (10) zu bestimmen, die durch die zumindest zwei versetzten zweiten Sensoren gemessen ist.
5. Sensoranordnung (1) gemäß zumindest einem der Ansprüche 1 bis 4, weiterhin umfassend zumindest zwei versetzte dritte Sensoren (7), die parallel in ei-

ner zweiten Ebene lotrecht zu der ersten Ebene angeordnet sind, und eingerichtet sind, um die Größe des Fluidstroms (10) zu messen, wobei die Steuereinheit weiterhin eingerichtet ist, um Informationen, die zumindest einen Bereich der Richtungen des Fluidstroms (10) in drei Dimensionen angeben, durch weiteres Berücksichtigen der Größe zu bestimmen, die durch die zumindest zwei dritten Sensoren (7) gemessen ist.

6. Sensoranordnung (1) gemäß Anspruch 5, wobei die zumindest zwei versetzten ersten (5), zweiten (6) und dritten (7) Sensoren parallel angeordnet sind.
7. Sensoranordnung (1) gemäß zumindest einem der Ansprüche 1 bis 6, wobei die Größe eine Geschwindigkeit des Fluidstroms umfasst.
8. Sensoranordnung (1) gemäß Anspruch 7, wobei die Geschwindigkeit des Fluidstroms durch eine Nachschlagetabelle, eine analytische Lösung oder eine numerische Lösung der Grundgleichung des konvektiven Wärmetransfers bestimmt wird.
9. Katheter, der eine Sensoranordnung (1) gemäß zumindest einem der Ansprüche 1 bis 8 umfasst, wobei die Sensoranordnung (1) bei dem Katheter zum Messen eines Fluidstroms, zum Beispiel eines Blutstroms, eingerichtet ist.
10. Katheter gemäß Anspruch 9, wobei die Sensoranordnung (1) in einer Längsrichtung des Katheters angeordnet ist.

Revendications

1. Agencement (1) de capteurs comprenant :

au moins deux premiers capteurs décalés (5) agencés en parallèle dans un premier plan et à côté l'un de l'autre, et adaptés à mesurer une quantité d'un écoulement de fluide (10) ; et une unité de commande adaptée à déterminer, à partir de la quantité mesurée de l'écoulement de fluide (10), des informations indiquant au moins une plage de directions de l'écoulement de fluide (10) dans deux dimensions, dans lequel les premiers capteurs (5) sont des anémomètres à fil chaud, à plaque chaude, à température constante ou à courant constant.

2. Agencement (1) de capteurs selon la revendication 1, dans lequel l'unité de commande est adaptée à déterminer, à partir de la quantité mesurée de l'écoulement de fluide (10), des informations indiquant une direction de l'écoulement de fluide (10) dans deux dimensions, dans lequel les informations indiquent

que la direction se trouve dans une zone formée par un premier (25) et un quatrième (28), ou un deuxième (26) et un troisième (27) quadrants d'un système de coordonnées bidimensionnelles (2) du premier plan.

3. Agencement (1) de capteurs selon la revendication 1 ou 2, comprenant en outre au moins deux deuxième capteurs décalés (6) agencés en parallèle dans le premier plan et adaptés à mesurer la quantité de l'écoulement de fluide (10), dans lequel l'unité de commande est adaptée à déterminer les informations indiquant au moins la plage de directions de l'écoulement de fluide (10) dans deux dimensions en prenant en outre en compte la quantité de l'écoulement de fluide (10) mesurée par les au moins deux deuxième capteurs décalés (6).
4. Agencement (1) de capteurs selon la revendication 3, dans lequel l'unité de commande est en outre adaptée à déterminer des informations indiquant la direction de l'écoulement de fluide (10) dans deux dimensions en prenant en outre en compte la quantité de l'écoulement de fluide (10) mesurée par les au moins deux deuxième capteurs décalés.
5. Agencement (1) de capteurs selon l'une quelconque des revendications 1 à 4, comprenant en outre au moins deux troisième capteurs décalés (7) agencés en parallèle dans un deuxième plan, perpendiculaire au premier plan, et adaptés à mesurer la quantité de l'écoulement de fluide (10), dans lequel l'unité de commande est en outre adaptée à déterminer des informations indiquant au moins une plage de directions de l'écoulement de fluide (10) dans trois dimensions en prenant en outre en compte la quantité mesurée par les au moins deux troisième capteurs décalés (7).
6. Agencement (1) de capteurs selon la revendication 5, dans lequel les au moins deux premiers (5), deuxième (6) et troisième (7) capteurs décalés sont agencés en parallèle.
7. Agencement (1) de capteurs selon l'une quelconque des revendications 1 à 6, dans lequel la quantité comprend une vitesse de l'écoulement de fluide.
8. Agencement (1) de capteurs selon la revendication 7, dans lequel la vitesse de l'écoulement de fluide est déterminée par une table de recherche, une solution analytique ou une solution numérique de l'équation régissant une convection par transfert de chaleur.
9. Cathéter comprenant un agencement (1) de capteurs selon l'une quelconque des revendications 1 à 8, dans lequel l'agencement (1) de capteurs est agencé sur le cathéter pour mesurer un écoulement

de fluide, par exemple un écoulement de sang.

10. Cathéter selon la revendication 9, dans lequel dans lequel l'agencement (1) de capteurs est agencé dans un sens longitudinal du cathéter.

5

10

15

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45

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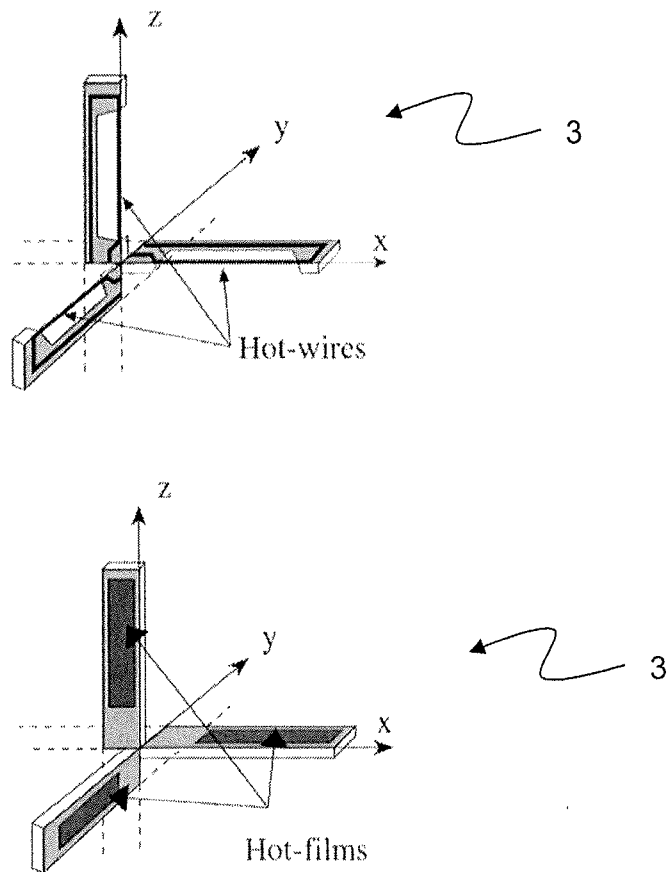


Fig.1

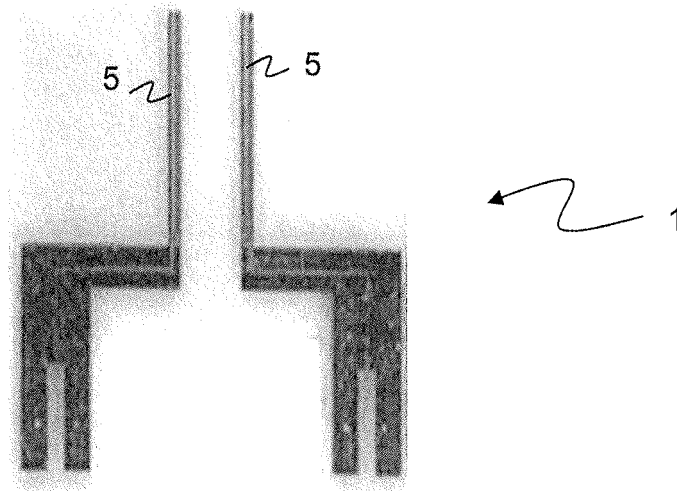


Fig.2A

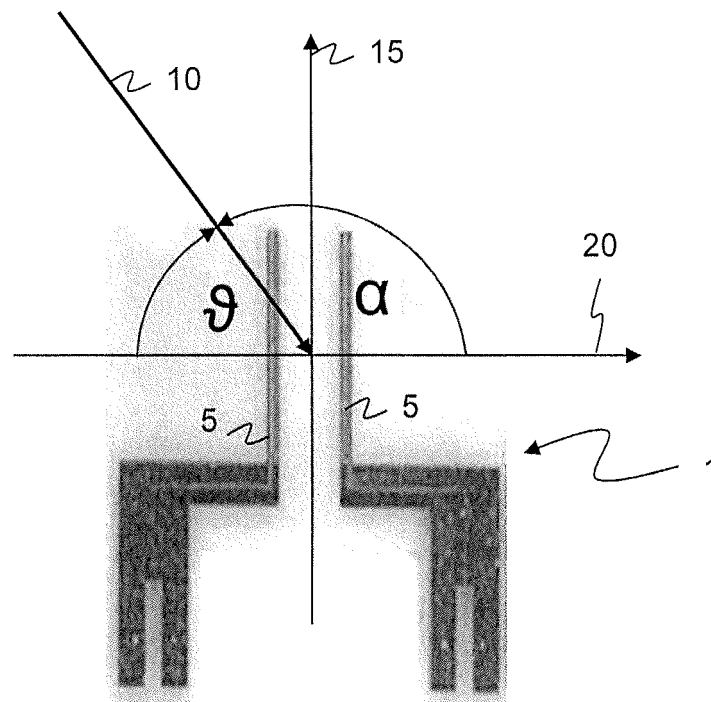


Fig.2B

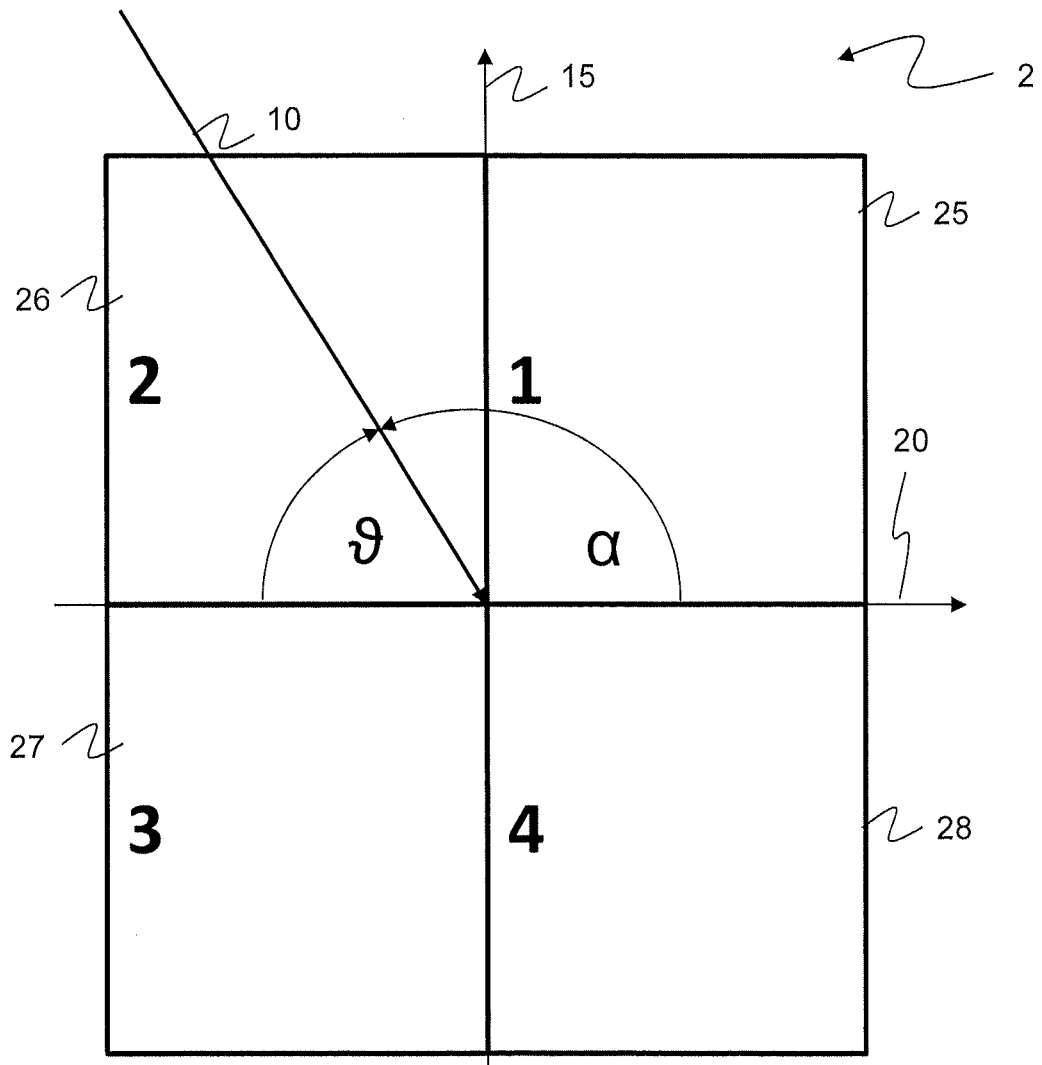


Fig.2C

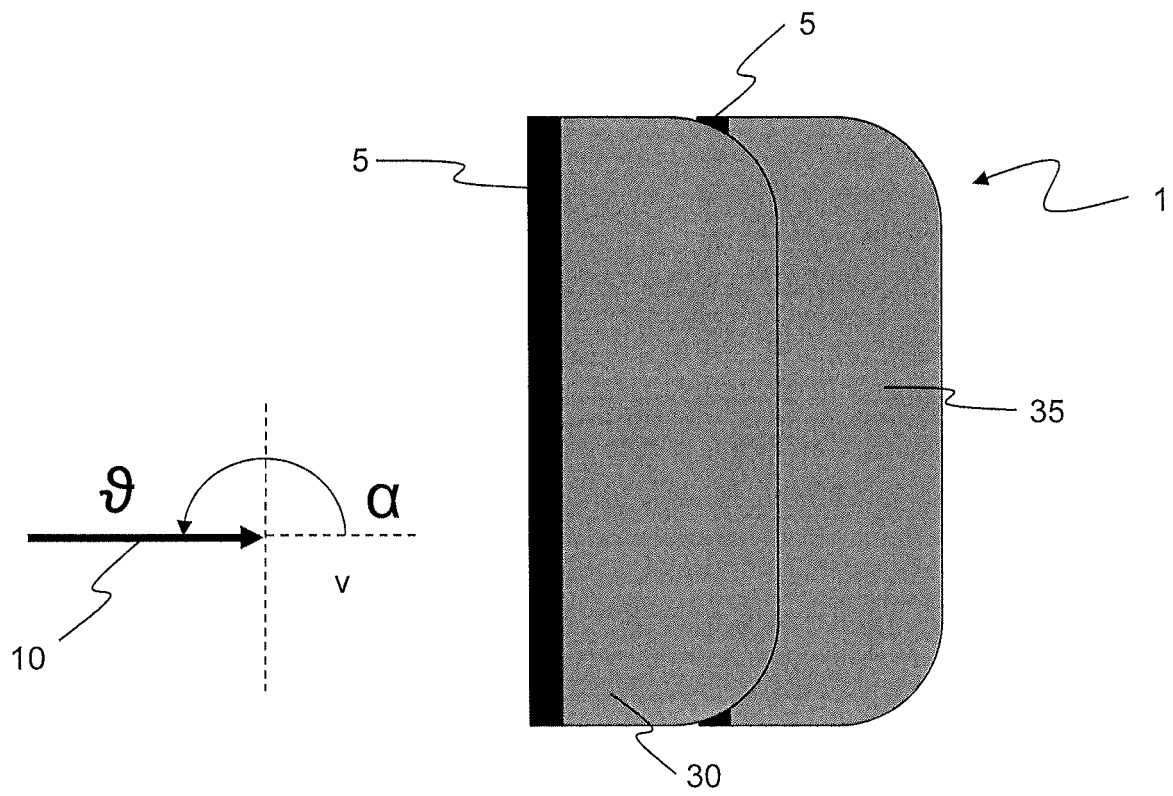


Fig.3A

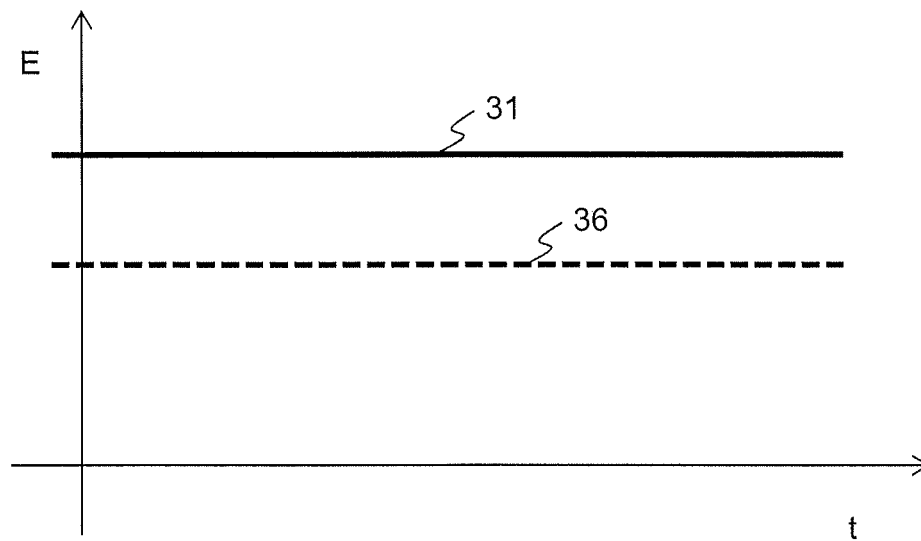


Fig.3B

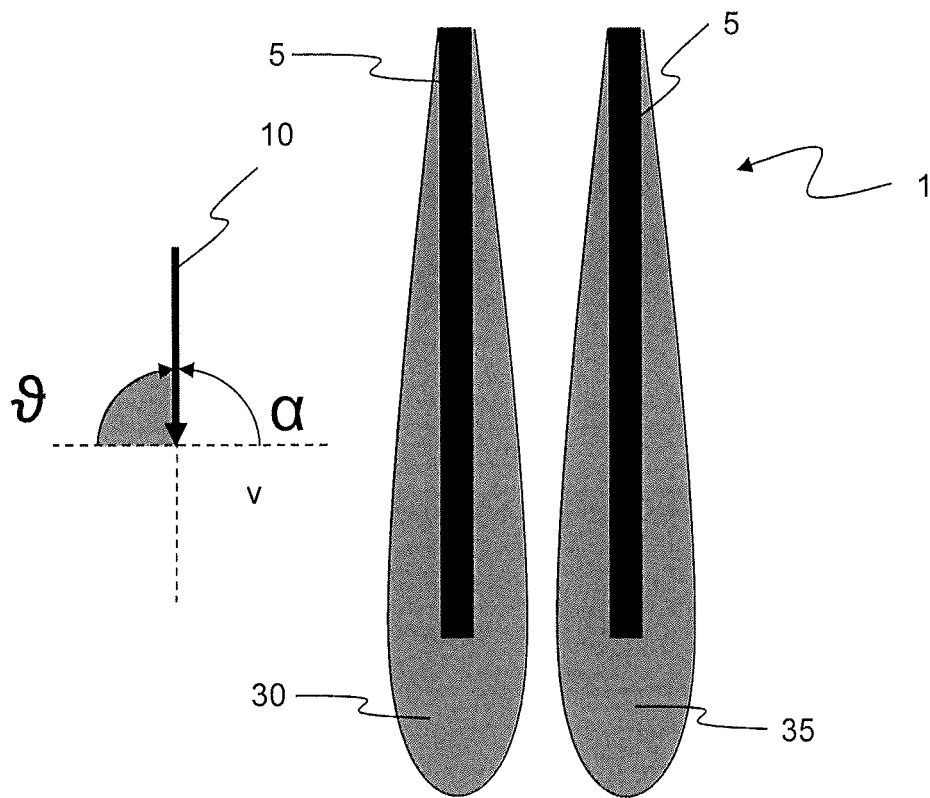


Fig.3C

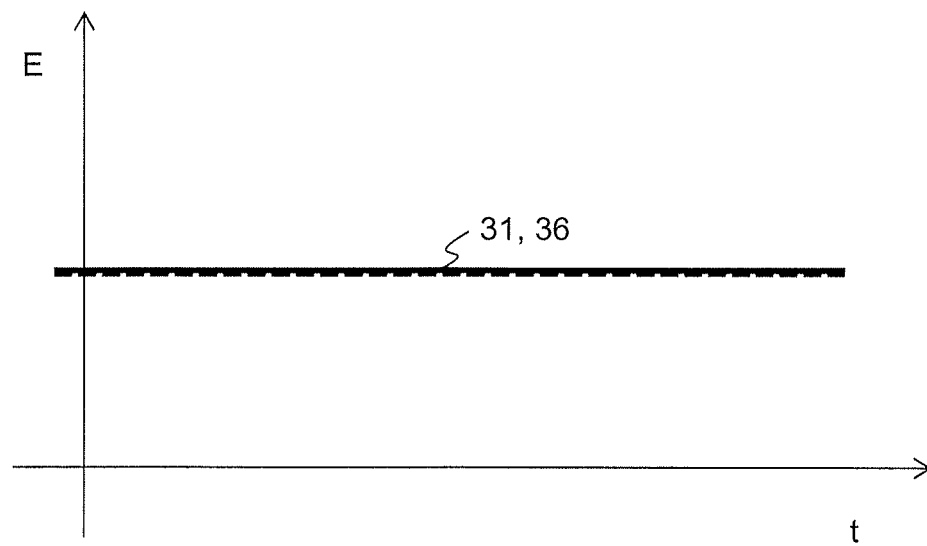


Fig.3D

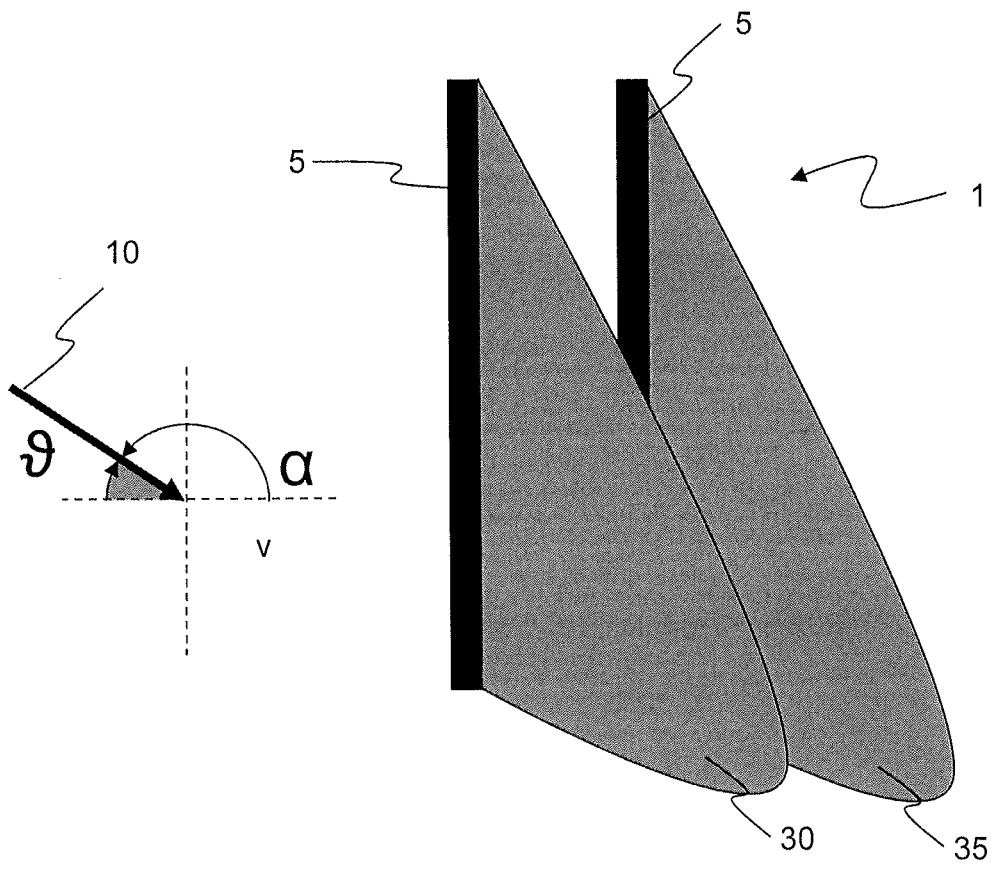


Fig. 3E

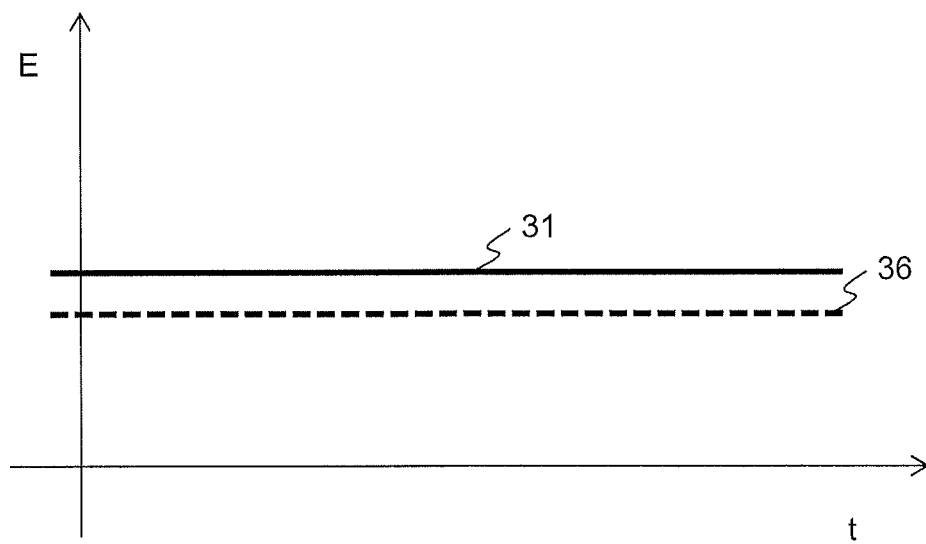


Fig. 3F

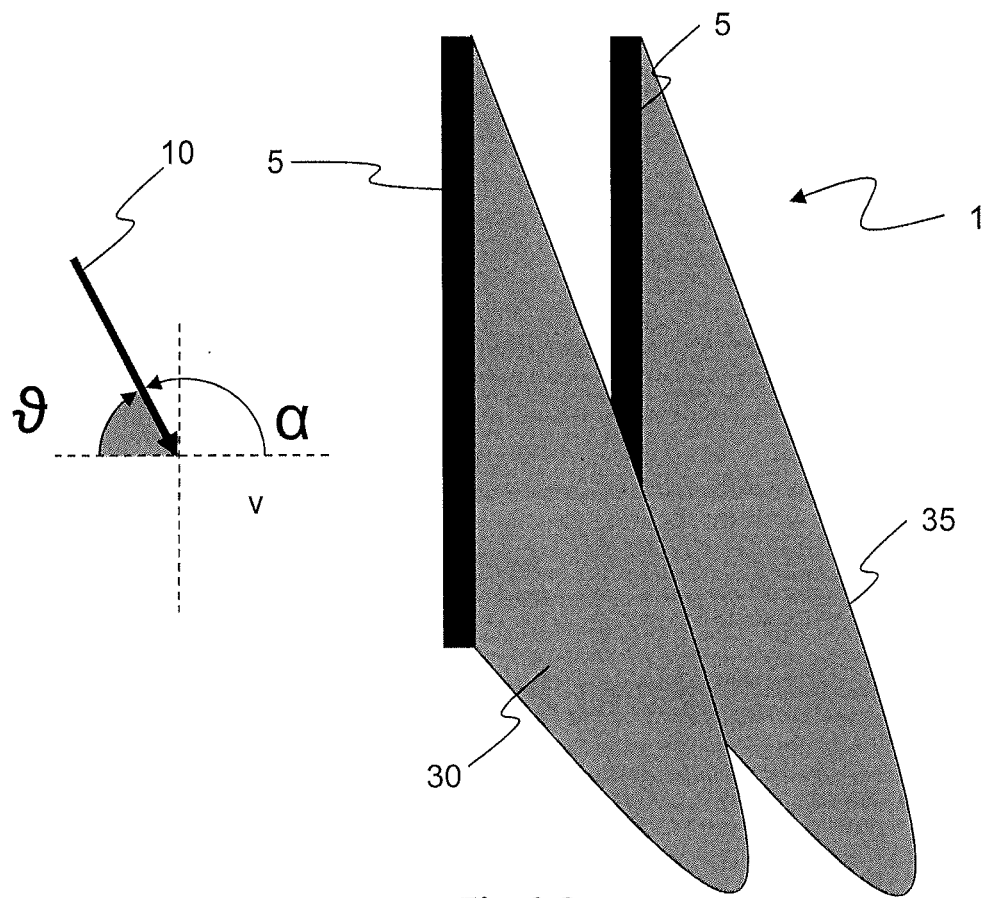


Fig.3G

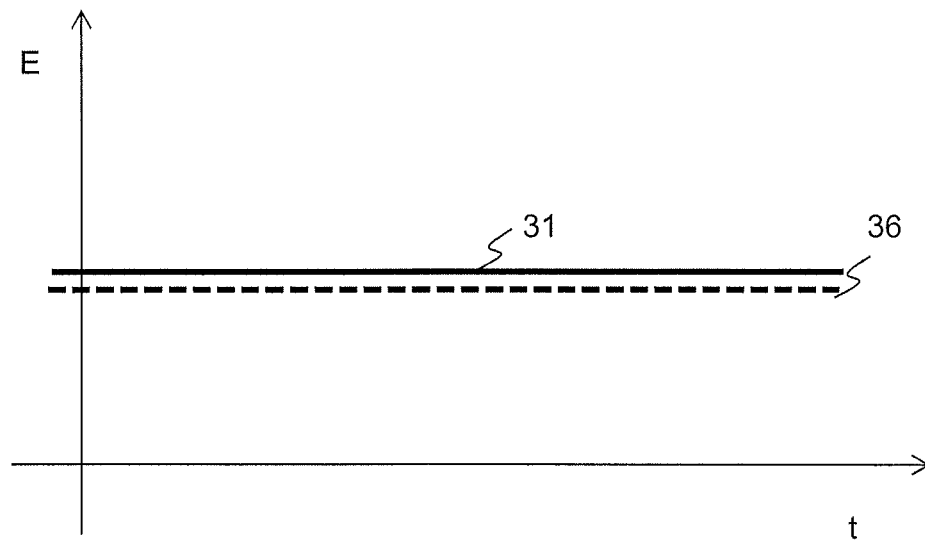


Fig.3H

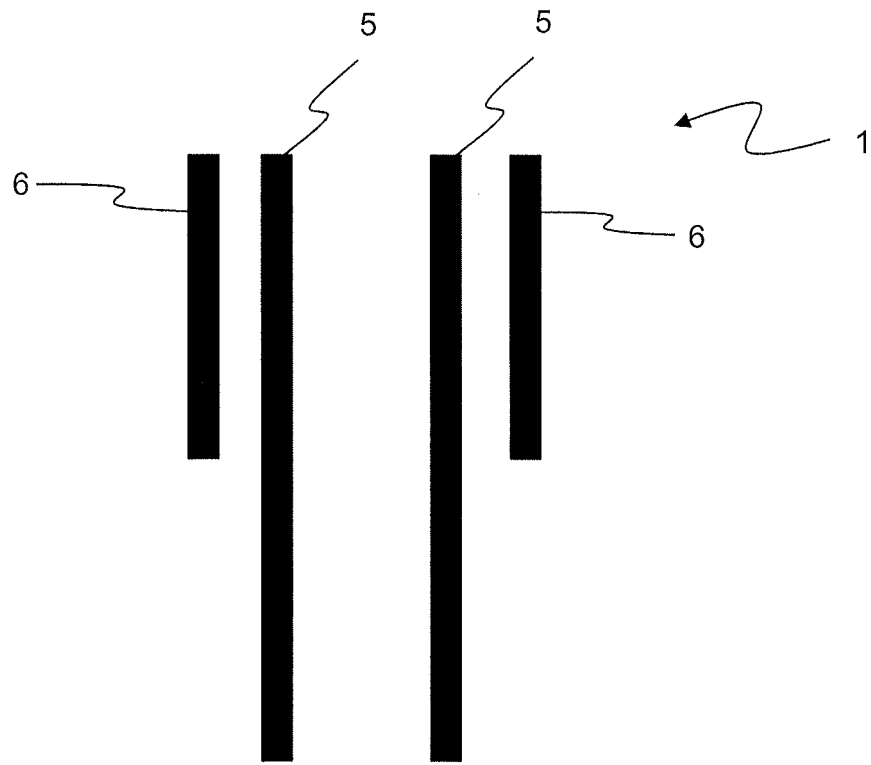


Fig.4

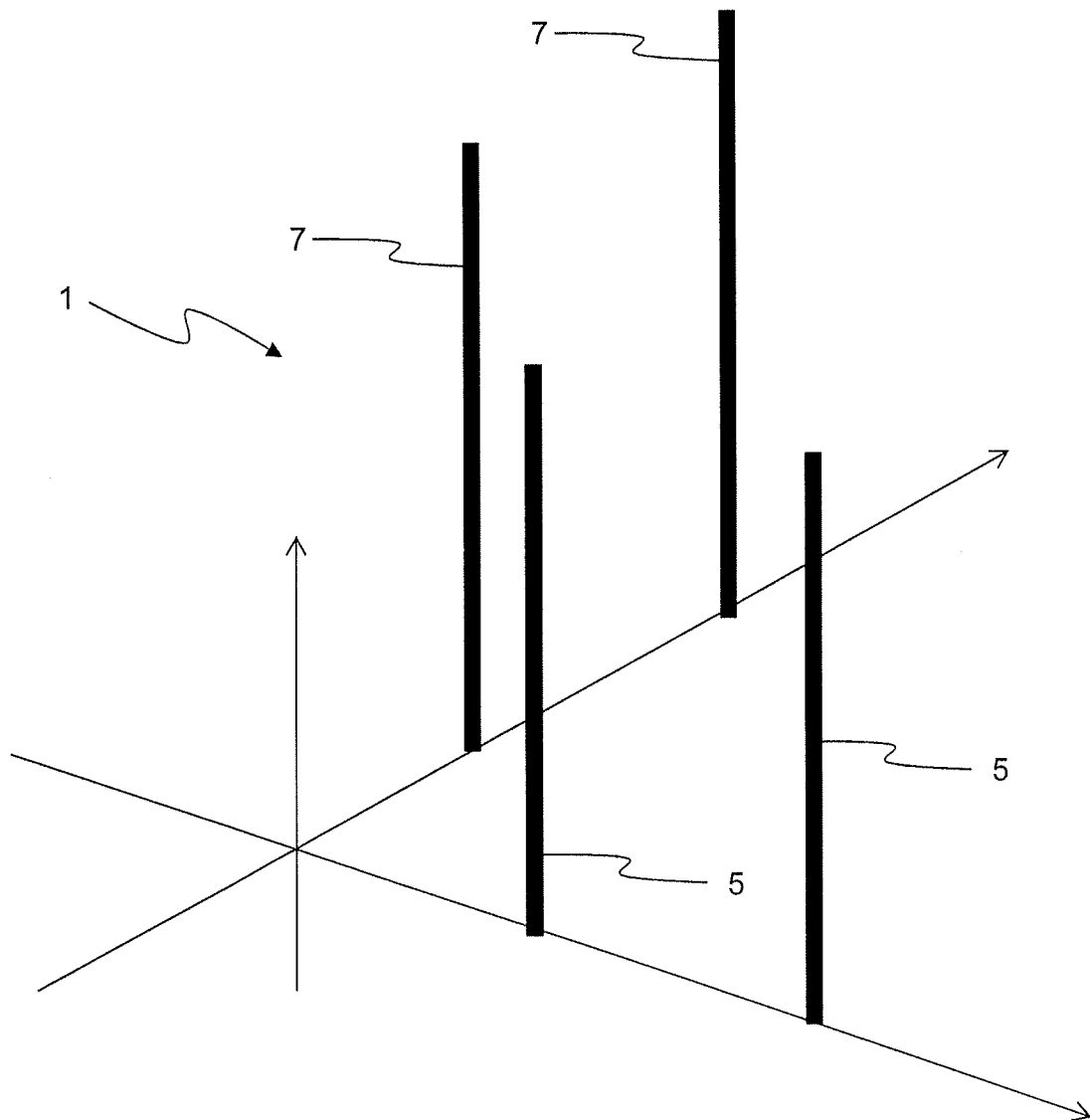


Fig.5A

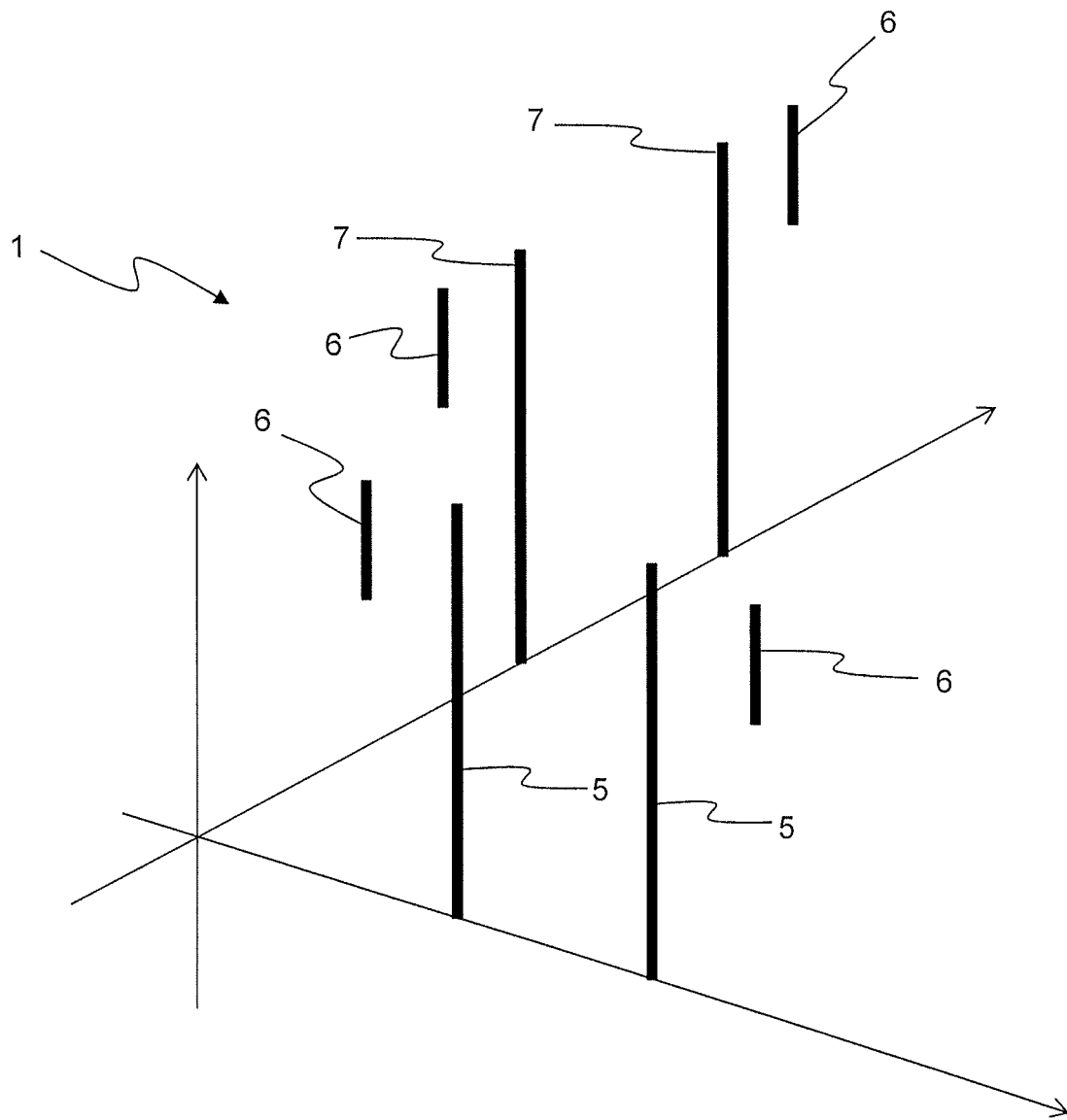


Fig.5B

$g(ES_{max}, ES_{min})$	U		
	V_1	V_2	V_3
ϑ_1	$(ES_{max}, ES_{min})_{1,1}$	$(ES_{max}, ES_{min})_{1,2}$	$(ES_{max}, ES_{min})_{1,3}$
ϑ_2	$(ES_{max}, ES_{min})_{2,1}$	$(ES_{max}, ES_{min})_{2,2}$	$(ES_{max}, ES_{min})_{2,3}$
ϑ_3	$(ES_{max}, ES_{min})_{3,1}$	$(ES_{max}, ES_{min})_{3,2}$	$(ES_{max}, ES_{min})_{3,3}$

Fig.6

REFERENCES CITED IN THE DESCRIPTION

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- US 4637253 A [0003]

专利名称(译)	传感器布置和带有传感器布置的导管		
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申请(专利权)人(译)	MEDYRIA AG		
当前申请(专利权)人(译)	MEDYRIA AG		
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发明人	SETTE, MAURO MASSIMO DI IASIO, ANITA		
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摘要(译)

本公开总体上涉及传感器技术领域。更具体地，本公开涉及传感器装置和包括这种传感器装置的导管。传感器装置的一个实施例包括：至少两个在第一平面内平行布置并适于测量流体流量的第一传感器；控制单元，其适于从所测量的流体流的量中确定至少在二维上指示流体流的方向范围的信息。

$$\rho c \left[\frac{\partial T}{\partial t} + v_i \frac{\partial T}{\partial x_i} \right] - \frac{\partial}{\partial x_i} \left(k \frac{\partial T}{\partial x_i} \right) - q = 0$$