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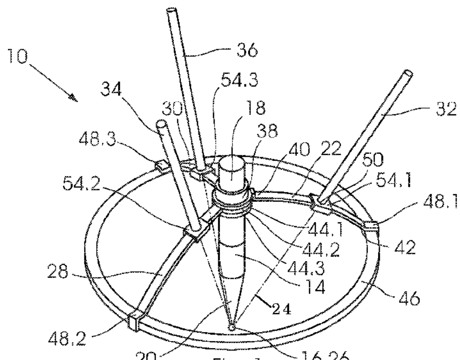

Fig. 1

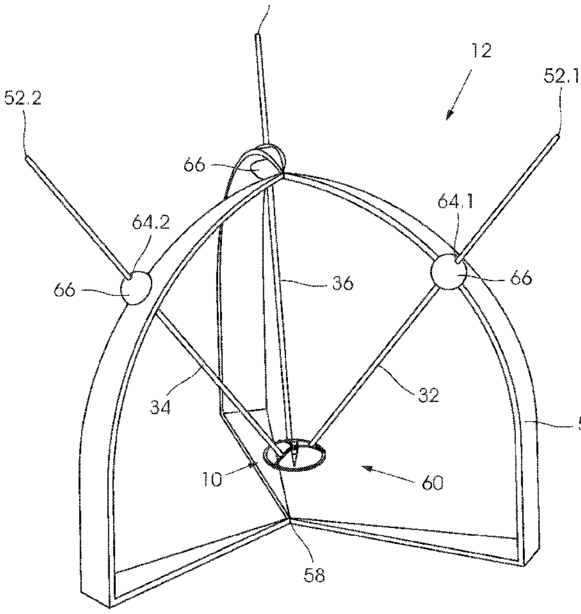

Fig. 7

(57) **Abstract:** This invention relates to a probe assembly (100), a probing configuration (10), a coordinate measuring machine (CMM) (12) including the probing configuration (10) and a method of determining a coordinate of a point on an object using the CMM. The probe assembly (100) is characterized in that it includes a reference body (102) having an outer reference surface (104) in the form of a spherical dome defining a centre point (106). The probe assembly (100) also includes a probe (14) having a tip which defines a probe centre (16), the probe being connected to the reference body and arranged such that the centre point and probe centre coincide. Due to this configuration, a measurement datum for taking of at least one measurement associated with a position of the probe tip is defined by the spherical dome when a reading axis of a measurement instrument is normally aligned to the spherical dome such that the reading axis intersects the probe centre thus facilitating reduction or elimination of Abbe errors.

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PROBING CONFIGURATION

FIELD OF THE INVENTION

This invention relates to a probe assembly and a probing configuration used in a coordinate measuring machine (CMM). In particular, the invention relates to a probe assembly and a probing configuration adapted to eliminate or at least reduce the Abbe error when taking measurements. The invention also relates to a CMM incorporating said probe assembly and/or probing configuration, and methods of determining coordinates on an object using said CMM. The probe assembly may also find application in laser trackers.

BACKGROUND OF INVENTION

According to the International Bureau of Weights and Measures, metrology is concerned with the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology. Errors, and a level of uncertainty are therefore inherent considerations in the field of metrology, and therefore, within the field of metrology, a driving force is the reduction or quantification of such errors or levels of uncertainty.

One type of error frequently encountered in the field of metrology, is the so called “Abbe” error which relates to the magnification of an angular error over a measured distance. An Abbe error occurs where the measured distance is not a straight-line extension of the scale that serves as reference for the measurement, and therefore, the Abbe error occurs whenever an offset is present between the measured distance and the scale. Put differently, when the measured distance extends along a different axis than the scale from which the distance is determined, the accuracy of the measured distance will be determined by the degree of relative rotation, pivoting or displacement which is not purely parallel to the measuring scale. If the movement itself is not purely parallel, the measurement will be inaccurate and will include an Abbe error.

Therefore, a measuring instrument that conforms with the Abbe principle of alignment, is one where the measured distance is a straight-line extension of the measuring scale. One example of a measuring instrument that conforms with the Abbe principle of alignment, is a hand micrometer. Here, a measurement is made on an object that is received between two opposing points on a substantially C-shaped body. The measuring scale extends along an axis connecting the two opposing points. Therefore, the measured distance can be said to be a straight-line extension of the measuring scale.

On the other hand, an example of a measuring instrument that does not conform with the Abbe principle of alignment, is a Vernier scale (also known as a Vernier calliper). Here, the measurement is made between the tips of two callipers which are axially displaceable relative to one another. The measuring scale is located towards the bases of the callipers, and is spaced from the measured distance. Therefore, in cases where the callipers are allowed relative rotational or pivotable movement, albeit very slight, the distance on the measuring scale will differ from the measured distance, and the measurement will include an Abbe error.

Coordinate measuring machines (CMMs) are devices with which a geometry of an object is measured, and are mainly used in the field of dimensional metrology. A CMM comprises a probe which is moved within a three-dimensional space along a Cartesian coordinate system (x, y and z axes). CMM systems making use of different measuring configurations, such as articulated arms, are also known in the art. A tip of the probe is brought into contact with various points of the object, the outer geometry of which is measured, and distinct measurements of these contact points are taken by measuring the position of the probe within the Cartesian coordinate system.

In some cases, the probes are also allowed rotational degrees of freedom, to increase the probe's range of motion, and to enable the measurement of more complex geometries. Since the probe needs to be displaceable at least linearly along the three axes of the Cartesian coordinate system, the probes are typically mounted to at least three displaceable arms. By reading from linear scales, the relative axial displacements of the arms are used to determine the coordinates of the probe at all times. The probe is typically pivotably fixed to front ends of the arms, and extends vertically downward by a predetermined distance from such pivotable connection points, to prevent interference between the arms and the object being measured.

Due to this vertical extension of the probe below the pivotable connection points, Abbe errors occur in most, if not all positions of the probe within the Cartesian system, due to an offset between the measuring scale and the measuring point, resulting in an Abbe offset. Other CMMs exist, such as CT scanners, laser scanners, laser trackers and articulated arms.

To date, some systems incorporating planar mirrors with laser interferometers as linear readers have been proposed in an effort to compensate for the Abbe error in CMMs. However, the mirrors of these systems are not connected to their probes. Alternative forms of CMMs have been proposed which claim a non-Cartesian structure. However, these systems still do not fully eliminate the Abbe error.

It is accordingly an object of the invention to provide a probe assembly, a probing configuration typically used in a CMM, a CMM including said probing configuration, and methods of determining coordinates of points on objects using the CMM, that will, at least partially, address the above disadvantages. It is also an object of the invention to provide a probe assembly, a probing configuration typically used in a CMM, a CMM including said probing configuration, and methods of determining coordinates of points on objects using the CMM, which will be useful alternatives to existing probing configurations and CMMs.

SUMMARY OF INVENTION

In accordance with a first aspect of the invention, there is provided a probe assembly, comprising:

a reference body having an outer reference surface in the form of a spherical dome, defining a centre point; and

a probe having a tip which defines a probe centre, the probe being fixed relative to the reference body and arranged such that the centre point of the spherical dome and the probe centre coincide,

wherein the spherical dome defines a measurement datum for taking of at least one measurement associated with a position of the probe tip when a reading axis of a measurement instrument is normally aligned to the spherical dome such that the reading axis intersects the probe centre and coinciding centre point of the spherical dome, the measurement being taken referenced from the spherical dome of the probe assembly.

The reference surface may be manufactured from a conductive material. Alternatively, the reference surface may be reflective. The reference surface may be formed by a mirror. Alternatively, the reflective reference surface may have a polished outer surface.

In accordance with a second aspect of the invention there is provided a probing configuration for a coordinate measuring machine, comprising:

a probe assembly as described above;

a first curved track section attached to the probe, the first curved track section defining a radius about a centre point such that the probe centre of the probe coincides with the centre point;

a second curved track section attached to the probe, the second curved track section defining a radius about the centre point;

a first arm attached to the first curved track section so as to be displaceable along the first curved track section so that the first arm is pivotably displaceable about the centre point and a longitudinal axis of the first arm continuously intersects the probe centre; and

a second arm attached to the second curved track section so as to be displaceable along the second curved track section so that the second arm is pivotably displaceable about the centre point and a longitudinal axis of the second arm continuously intersects the probe centre.

Further according to the second configuration, the probing configuration may further comprise:

a third curved track section attached to the probe, the third curved track section defining a radius about the centre point; and

a third arm fixed to the third curved track section so as to be displaceable along the third curved track section so that the third arm is pivotably displaceable about the centre point and a longitudinal axis of the third arm continuously intersects the probe centre.

The first, second and third curved track sections may be pivotably displaceable relative to the probe and relative to each other about an axis extending axially along a length of the probe.

The probing configuration may include a socket section which surrounds a main body of the probe.

The first curved track may have a first end and a second end.

The first end of the first curved track may comprise a collar within which the socket section of the main body may be received. The first curved track may be arranged to pivot about the socket section. An outer surface of the socket section may be polished or relatively smooth to reduce friction between the outer surface of the socket section and the collar.

The probe assembly may include a ring-shaped track. The spherical dome may extend between the socket section and the ring-shaped track.

The first curved track section may comprise a slide formation towards the second end thereof. The slide formation may be arranged to slide on the ring shaped track, when the first curved track section is pivotably displaced relative to the probe.

An outer surface of the first curved track section may be polished. The ring-shaped track may be polished.

The second and third curved track sections may be of similar construction to the first curved track section.

The radii of the first, second and third curved track sections may be substantially equal.

The collars of the first, second and third curved track sections may be stacked axially along the socket section.

The first arm may comprise a first end and a second end.

The first end of the first arm may be fixed to a first base member, which connects the first arm to the first curved track section. The first base member may be configured to allow displacement of the first arm along the first curved track section. The first base member may be configured to retain the first arm in a substantially radial direction relative to the first curved track section, at any point along the first curved track section.

The first base member may take the form of a first slide formation. A contact surface of the first slide formation may be curved and may have a radius equal to the radius of the first curved track section.

The contact surface of the first slide formation may be formed by a low-friction contact liner, fixed to an inner surface of the first slide formation.

Alternatively, the first base member may comprise a roller arrangement, arranged to make contact with the first curved track section.

The first arm may be supported towards the second end thereof, by a support structure. The first arm may be axially and pivotably displaceable relative to the support structure.

The first arm may be fixed to the support structure by a first linear bearing within which the first arm may be allowed to be displaced axially. The first linear bearing may be fixed pivotably to the support structure to allow the first arm to be displaced pivotably relative to the support structure.

A first linear reader may be provided for measuring the linear position or displacement of the first arm relative to the support structure. The first linear reader may be one of a linear variable differential transformer (LVDT), a linear scale system, or a laser measuring device.

The first linear reader may measure the position or displacement of the first arm relative to the support structure, by measuring the axial displacement of the first arm within, or relative to, the first linear bearing. The support structure may comprise a support structure spherical reference surface.

The first linear reader may measure a distance between the support structure spherical reference surface and the first curved track.

The second and third arms may be similar to the first arm.

Further according to the second configuration, the probe may comprise a probe assembly according to the first aspect of the invention.

The reference body of the probe assembly may be integrally formed with the main body of the probing configuration. The spherical dome-shaped outer reference surface may extend between the socket section and the ring-shaped track, and may retain the socket section and the ring-shaped track relative to each other.

Each of the arms may be provided with a capacitance sensor arranged towards the spherical dome portion. The capacitance sensor of a particular arm may be used to measure an extent by which an axis along the length of the arm deviates from the centre point.

The first linear reader may measure a distance between the support structure spherical reference surface and the reference surface of the probe assembly.

In accordance with another aspect of the invention there is provided a coordinate measuring machine, including the probe assembly according to the first aspect of the invention. In accordance with a third aspect of the invention there is provided a coordinate measuring machine including the probing configuration as described above and a support structure which includes at least two multi-axial pivots, each configured for supporting a linear bearing for receiving one arm of the probing configuration.

The coordinate measuring machine may comprise a bed for receiving an object in use.

The coordinate measuring machine may further comprise a support structure. A volume may be defined between the bed and the support structure.

The support structure may include a multi-axial pivot, for supporting a linear bearing receiving the first arm. The multi-axial pivot may comprise a spherical dome shaped outer surface, and may serve as a reference surface.

According to a fourth aspect of the invention there is provided a method of determining a coordinate of a point on an object, the method including the steps of:

placing the object on a bed of a coordinate measuring machine as described above;

bringing the probe of the probing configuration into contact with the point on the object;

measuring the axial position and/or displacement of each of the first and second arms of the probing configuration relative to the support structure in relation to a reference point; and

determining a coordinate of the point on the object, based on the measured axial positions and/or displacements of the first and second arms.

The method may further comprise measuring the axial position and/or displacement of a third arm of the coordinate measuring machine, and utilising the measured axial position and/or displacement of the third arm in determining the coordinate of the point on the object.

The coordinate may be a coordinate within a Cartesian coordinate system.

The step of determining the coordinate based on the measured axial positions and/or displacements, may involve the use of triangulation.

The method includes measuring a geometric shape of the object by determining the coordinates of a plurality of points on the object in accordance with the method as described above.

BRIEF DESCRIPTION OF DRAWINGS

The invention will now be described in more detail, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a perspective view of a probing configuration in accordance with the invention, in which details about a spherical dome portion which serves as a reference surface has been omitted, and wherein three arms are located in first positions relative to three curved track sections;

Figure 2 shows a perspective view of the probing configuration of Figure 1, in which the three arms have been displaced along the three curved track sections, to second positions;

Figure 3 shows a perspective view of the probing configuration of Figure 1, with details in broken lines showing the arms in the second positions of Figure 2;

Figure 4 shows a perspective view of the probing configuration of Figure 1, where details in broken lines show the curved track portions pivoted away from their original positions;

Figure 5 shows a side view of the probing configuration of Figure 1, where details of the spherical dome shaped portion are included;

Figure 6 shows a bottom perspective view of the probing configuration of Figure 1;

Figure 7 shows a perspective view of a coordinate measuring machine including a probing configuration of Figure 1, with the probing configuration located in a first location;

Figure 8 shows a perspective view of the coordinate measuring machine of Figure 7, wherein the probing configuration is located in a second location;

Figure 9 shows a perspective view of the coordinate measuring machine of Figure 7, with the detail in broken lines showing the probing configuration in the second location of Figure 8;

Figure 10 shows a perspective view of a probe assembly, in accordance with the invention; and

Figure 11 shows a side view of the probe assembly of Figure 10.

DETAILED DESCRIPTION OF ILLUSTRATED EMBODIMENTS

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted", "connected", "engaged" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings and are thus intended to include direct connections between two members without any other members interposed therebetween and indirect connections between members in which one or more other members are interposed therebetween. Further, "connected" and "engaged" are not restricted to physical or mechanical connections or couplings. Additionally, the words "lower", "upper", "upward", "down" and "downward" designate directions in the drawings to which reference is made. The terminology includes the words specifically mentioned above, derivatives thereof, and words of similar import. It is noted that, as used in this specification and the appended claims, the singular forms "a," "an," and "the," and any singular use of any word, include plural referents unless expressly and unequivocally limited to one referent. As used herein, the term “include” and its grammatical variants are intended to be non-limiting, such that recitation of items in a list is not to the exclusion of other like items that can be substituted or added to the listed items.

Referring to the drawings, in which like numerals indicate like features, a non-limiting example of a probing configuration in accordance with the invention is generally indicated by reference numeral 10. The probing configuration 10 is typically used as part of a coordinate measuring machine (“CMM”), designated generally by reference numeral 12 (see figures 7 to 9).

As shown in the figures, the probing configuration 10 includes a probe assembly, which is illustrated in isolation in figures 10 and 11 and designated by reference numeral 100.

It will be understood that a CMM 12 including a probing configuration 10, but not including a probe assembly 100, may be feasible. On the other hand, a CMM 12 including a probe assembly 100 but not including a probing configuration 10 may also be feasible. These configurations, although not exemplified or discussed in more detail herein, are deemed to form part of the present disclosure. With reference to figures 10 and 11, the probe assembly 100 comprises a reference body 102 with an outer reference surface 104 in the form of a spherical dome, having a centre point 106. The spherical dome defines a first radius 108 which extends from the centre point 106 to the reference surface 104. The probe assembly 100 also includes an elongate probe 14 which is connected to the reference body 102 and extends radially inward, away from the reference body 102. The probe 14 has a distal, ball-shaped tip which defines a point of contact or probe centre 16 at its centre. As shown in figures 10 and 11, the point of contact 16 of the probe tip and the centre point 106 coincide.

Since these points coincide, a distance between the reference surface 104 and the point of contact or probe centre 16 therefore always equals the first radius 108. Therefore, a position or coordinates of the probe centre 16 can be determined by taking measurements referenced from the reference surface 104. Depending on the type of hardware used to take the measurements, the reference surface 104 may be manufactured from a conductive material, such as a metal, which may be polished. Accordingly, or alternatively, the reference surface 104 may be reflective. The reference surface 104 may take the form of a mirror. Accordingly, the reference surface 104 may be configured to reflect incident rays thus rendering the probe assembly 100 useful with a laser tracker. To this end, although this has not been illustrated in figures 10 and 11, the probe assembly 100 may include a handle which is operatively connected to an outer periphery of the reference body 102. A user can therefore grip the handle in order to hold and move the probe assembly 100 around whilst the tip of the probe 14 contacts an object and the laser tracker tracks the probe 14 by measuring rays reflected off the reference surface 104.

The probing configuration 10 comprises the probe 14, which defines the point of contact or probe centre 16. The point of contact or probe centre 16 is defined in the centre of the ball-shaped tip of the probe 14. The probe 14 is of the known kind generally associated with CMMs. The probe 14 comprises a substantially cylindrical main body 18, terminating, towards the ball-shaped tip, in a cone-shaped portion 20.

The probing configuration 10 further comprises a first curved track section 22, which is, as is discussed more clearly below, connected to the probe 14. The first curved track section 22 defines a radius 24 extending from a centre point 26. The arrangement of the probe 14 and the first curved track section 22 is such that the point of contact or probe centre 16 coincides with the centre point 26. As will become more apparent from what follows, the coinciding of the centre point 26 and the probe centre 16 is critical in reducing or even eliminating the Abbe error when using the CMM 12.

The probing configuration 10 furthermore comprises a second curved track section 28 and a third curved track section 30. Both the second and third curved track sections (28, 30) define radii about the centre point 26. It will be understood that, for practical purposes, the radii defined by the first, second and third curved track sections (22, 28, 30) are equal, though, in some cases, these radii may differ. In such cases, suitable calibration of measuring equipment may be required.

The second and third curved track sections (28, 30) are attached to the probe 14 in similar fashion as the first curved track section 22. A first arm 32 is attached to the first curved track section 22, such that the first arm 32 is displaceable relative to the first curved track section 22 along at least a part of the first curved track section 22. The first arm 32 extends and remains normal to the first curved track section, irrespective of the displacement along or the specific position of the first arm 32 relative to the first curved track section 22. It follows that displacement of the arm 32 along the first curved track section 22 defines an angular displacement of the first arm 32, likened with a pivoting of the first arm 32 about the centre point 26. An axis extending axially or longitudinally along the first arm 32, intersects the centre point 26, irrespective of the displacement along or the specific position of the first arm 32 along the first curved track section 22.

The probing configuration 10 furthermore comprises a second arm 34 which is attached to the second curved track section 28 in similar fashion to the way in which the first arm 32 is attached to the first curved track section 22, and a third arm 36 which is attached to the third curved track section 30 in similar fashion to the way in which the first and second arms (32, 34) are attached to the first and second curved track sections (22, 28), respectively. It will be understood that axes about which the first, second and third arms (32, 34, 36) pivot when displaced along the first, second and third curved track sections

(22, 28, 30) respectively, intersect at the centre point 26. That said, these axes are not colinear.

The first, second and third curved track sections (22, 28, 30) are pivotable relative to the probe 14 and relative to each other, about an axis which extends through the centre point 26, and axially or longitudinally along the main body 18 of the probe 14. The axis about which the first, second and third curved track sections (22, 28, 30) are pivotable, is perpendicular to all three of the axes about which the first, second and third arms (32, 34, 36) pivot.

The relative pivoting of the first, second and third curved track sections (22, 28, 30) and the pivoting of the first, second and third arms (32, 34, 36) relative to the first, second and third curved track sections (22, 28, 30) respectively, are required to facilitate three-dimensional translation of the probe 14, as is discussed below. The probing configuration 10 includes a socket section 38, within which the cylindrical main body 18 of the probe 14 is received and held.

The construction and configuration of the first, second and third curved track sections (22, 28, 30) are similar. The features of the first curved track section 22 discussed below, therefore have equivalents which are present in the second and third curved track sections (28, 30). In the figures, similar features which are associated with different ones of the first, second and third curved track sections (22, 28, 30), are indicated by similar reference numerals, but distinguished by different suffixes, denoting the track number to which they relate.

The first curved track section 22 has a first end 40 and a second end 42. A first collar 44.1 is formed at the first end 40 of the first curved track section 22. The socket section 38 of the main body is received within the first collar 44.1, so that the first collar 44.1 is free to pivot about the first socket section 38. The fit between an outer surface of the socket section 38 and an inner surface of the first collar 44.1, is very fine. The outer surface of the socket section 38 and the inner surface of the first collar 44.1 are polished to reduce friction between the surfaces.

The probing configuration 10 also comprises a ring-shaped track 46 with a smooth and polished outer surface. The first curved track section 22 comprises a slide formation 48.1 towards the second end 42. The slide formation is arranged to slide along the ring-shaped track 46 when the first curved track section 22 pivots about the probe 14. An outer surface of the first curved track section 22 is polished to reduce friction when the first arm 32 is displaced along the outer surface. The radii of the first, second and third curved track sections (22, 28, 30) are substantially identical.

As shown in the figures, the collars (44.1, 44.2, 44.3) of the first to third curved track sections (22, 28, 30) are received in stacked formation about the socket section 38. The collars (44.1, 44.2, 44.3) are free to rotate relative to each other. The construction and configuration of the first, second and third arms (32, 34, 36) are also similar. Again, the features of the first arm 32 discussed below, therefore have equivalents which are present in the second and third arms (34, 36). In the figures, similar features which are associated with different ones of the first, second and third arms (32, 34, 36), are again indicated by similar reference numerals, but distinguished by different suffixes denoting the number of the arm to which they relate.

First arm 32 comprises a first end 50 and a second end 52.1 (see Figure 7), and is of a predetermined length. A base member 54.1 is located at the first end 50, which connects the first arm 32 to the first curved track section 22. The base member 54.1 can be displaced along the first curved track section 22 in sliding fashion. The base member 54.1 is configured to retain the first arm 32 in a substantially radial direction, and therefore substantially normal to the first curved track section 22, at any point along the first curved track section 22, and during displacement. The base member 54 takes the form of a slide formation. The slide formation comprises an internal contact surface which runs on an outer surface of the first curved track section 22. The contact surface is manufactured from a material selected to limit friction between the slide formation and the first curved track section 22. The contact surface is concave and matches the radius of the first curved track section 22.

With reference to figures 7 to 9, the CMM 12 comprises a support structure 56 and a bed 58. A volume 60 is defined between the structure 56 and the bed 58, within which the probing configuration 10 may be displaced. The operation of the CMM 12 is discussed below. The first arm 32 is supported relative to the support structure 56, towards the second end 52.1 of the first arm 32. The first arm 32 is received by a linear bearing 64.1 which allows the first arm 32 to be axially displaced relative to the support structure 56. The linear bearing 64.1, in turn is mounted to the support structure 56 via a multi-axial pivot 66, which allows the first arm 32 to pivot relative to the support structure 56. The multi-axial pivot 66 comprises a substantially spherical dome shaped outer surface, which may be used as a reference surface. The multi-axial pivot pivots about a centre point of the substantially spherical dome shaped outer surface.

With reference to figure 5, the reference body 102 of the probe assembly 100 is integrally formed with the main body 18 of the probing configuration 10 and extends between the socket section 38 and the ring-shaped track 46 and retains the socket section 38 and the ring-shaped track 46 relative to each other. As will be discussed more fully below, the reference surface 104 of the substantially spherical dome reference body 102 is also used as a reference surface. A first reader (not shown) is provided for measuring a linear position or displacement of the first arm 32 relative to the support structure 56. The first reader therefore measures axial displacement or an axial position of the first arm 32, relative to the linear bearing 64.1 within which the first arm 32 is received.

It will be understood that various types of linear readers may be used, such as a linear transducer (linear variable differential transformer or “LVDT”), a linear scale system or a laser measuring device. In cases where the linear reader is a laser measuring device, reference surface 104 has a reflective, mirror outer surface finish, to reflect a beam projected by the laser measuring device. In cases where the linear reader is a LVDT sensor, the reference surface 104 is manufactured from a conductive material, such as a metal. Now a capacitance sensor (not shown) may be employed in close proximity with the reference surface 104, to determine or measure small deviations (typically caused by imperfect fit between cooperating components) of the first arm from a purely radial position relative to the centre point 26 of the first curved track section 22. An actuator of the known type (not shown) is provided for axially displacing the first arm 32 relative to the linear bearing 64.1. As stated above, the second arm 34 and the third arm 36 are both also associated with linear bearings 64, multi-axial pivots 66, linear readers, and actuators. It will be understood that the linear actuators of the three arms (32, 34, 36) may be used to displace the probe 14 within the volume 60.

The use of the CMM 12 will now be discussed. As mentioned, the CMM 12 is used to measure or determine one or more coordinates on a surface of an object (not shown). In use, the object is placed and secured on the bed 58 of the CMM 12. The linear actuators of the three arms (32, 34, 36) are now used to displace the probing configuration 10 towards the object, and to bring the ball-shaped tip of the probe 14 into contact with a distinct point on the surface of the object. When the probe 14 makes contact with the object, the specific position or axial displacement of each of the three arms is measured by the three linear readers or encoders. As mentioned above, the various spherical dome shaped reference surfaces may be used to serve as references for taking the measurements and to account for any small amount of deviation.

The measurements of the linear readers or encoders are now used to determine the coordinates of the position within the volume, by means of triangulation, and may be expressed as a coordinate within a Cartesian coordinate system. A reference or zero position may be determined before determining further coordinates. The reference or zero position may be a first position on the object, or may be taken at another position within the volume 60. It will be understood that the base members 54 of the three arms (32, 34, 36) slide along the three curved track sections (22, 28, 30) as the probing configuration 10 is displaced within the volume. The first, second and third curved track sections (22, 28, 30) also pivot relative to each other. In this way, longitudinal extensions of the three arms continue to intersect the probe centre 16. Since the displacement or axial positions of the arms are determined in relation with the linear bearings 64, and the measurements are therefore taken in line with the arms themselves, the Abbe error is eliminated or at least significantly reduced. Due to the elongate, slender main body 18 of the probe 14, the probe assembly 100 and probing configuration 10 are configured to be used to take measurements on an object having one or more cavities due to the fact that the tip of the main body 18 of the probe 14 can extend into the cavity to measure coordinates of points on the object inside the cavity whilst the measurements are referenced off the spherical dome.

Throughout this disclosure, references to coinciding points or alignment of components or axes, will be understood not to exclude the possibility of small or infinitesimal deviations between the points or from the alignment, as can be expected from interacting mechanical componentry. It will be understood that manufacturing tolerances of the various components are very fine and selected to ensure that the deviations as mentioned fall within limits acceptable to the application. Furthermore, provision may be made as mentioned, to account for such deviations, at least to a degree, by using the spherical dome shaped portions or surfaces as reference surfaces.

It will be understood that, in an embodiment not shown, the CMM 12 may instead be adapted for determining two-dimensional coordinates, in which case only two arms, and two curved track sections will be utilised. The two curved track sections may be integrally formed. It will be understood that the radius 24, or the radius of the spherical dome shaped portion may be selected based on the specific application, the size of the CMM 12, or the permissible size of the object in respect of which the coordinates are determined. It will be appreciated that the above description only provides an example embodiment of the invention and that there may be many variations without departing from the spirit and/or the scope of the invention. It is easily understood from the present application that the particular features of the present invention, as generally described and illustrated in the figures, can be arranged and designed according to a wide variety of different configurations. In this way, the description of the present invention and the related figures are not provided to limit the scope of the invention but simply represent selected embodiments. For example, in an alternative embodiment, the base members 54 may comprise a roller arrangement, arranged to make contact with the first curved track section.

It will be understood that no angular measurements of the multi-axial pivoting of the pivots 66 will be required to determine the coordinate. The determination can therefore be done completely my means of the linear readers. The skilled person will understand that the technical characteristics of a given embodiment can in fact be combined with characteristics of another embodiment, unless otherwise expressed or it is evident that these characteristics are incompatible. Also, the technical characteristics described in a given embodiment can be isolated from the other characteristics of this embodiment unless otherwise expressed.

CLAIMS

1. A probe assembly, comprising:

a reference body having an outer reference surface in the form of a spherical dome, defining a centre point; and

a probe having a tip which defines a probe centre, the probe being fixed relative to the reference body and arranged such that the centre point of the spherical dome and the probe centre coincide,

wherein the spherical dome defines a measurement datum for taking of at least one measurement associated with a position of the probe tip when a reading axis of a measurement instrument is normally aligned to the spherical dome such that the reading axis intersects the probe centre and coinciding centre point of the spherical dome, the measurement being taken referenced from the spherical dome of the probe assembly.

2. The probe assembly as claimed in claim 1, wherein the reference surface is manufactured from a conductive material.

3. The probe assembly as claimed in claim 1, wherein the reference surface is reflective, and is formed by a mirror.

4. The probe assembly as claimed in claim 3, wherein the reflective reference surface has a polished outer surface.

5. A probing configuration for a coordinate measuring machine, comprising:

a probe assembly as claimed in any one of the preceding claims;

a first curved track section attached to the probe, the first curved track section defining a radius about the centre point such that the probe centre of the probe coincides with the centre point;

a second curved track section attached to the probe, the second curved track section defining a radius about the centre point;

a first arm attached to the first curved track section so as to be displaceable along the first curved track section so that the first arm is pivotably displaceable about the centre point and a longitudinal axis of the first arm continuously intersects the probe centre; and

a second arm attached to the second curved track section so as to be displaceable along the second curved track section so that the second arm is pivotably displaceable about the centre point and a longitudinal axis of the second arm continuously intersects the probe centre.

6. The probing configuration as claimed in claim 5, further comprising:

a third curved track section attached to the probe, the third curved track section defining a radius about the centre point; and

a third arm fixed to the third curved track section so as to be displaceable along the third curved track section so that the third arm is pivotably displaceable about the centre point and a longitudinal axis of the third arm continuously intersects the probe centre.

7. The probing configuration as claimed in claim 6, wherein the first, second and third curved track sections are pivotably displaceable relative to the probe and relative to each other about an axis extending axially along a length of the probe.

8. The probing configuration as claimed in any one of claims 5 to 7, which includes a socket section which surrounds a main body of the probe.

9. The probing configuration as claimed in claim 8, wherein the first curved track section has a first end and a second end, the first end of the first curved track section comprising a collar within which the socket section is received, the first curved track section being arranged to pivot about the socket section.

10. The probing configuration as claimed in claim 9, wherein the probe assembly includes a ring-shaped track, the spherical dome extending between the socket section and the ring-shaped track.

11. The probing configuration as claimed in claim 10, wherein the first curved track section comprises a slide formation towards its second end, the slide formation being arranged to slide on the ring-shaped track, when the first curved track section is pivotably displaced relative to the probe.

12. The probing configuration as claimed in claim 11, wherein the second and third curved track sections are of similar construction to the first curved track section.

13. The probing configuration as claimed in claim 12, wherein the radii of the first, second and third curved track sections are substantially equal.

14. The probing configuration as claimed in claim 13, wherein collars of the first, second and third curved track sections are stacked axially along the socket section.

15. The probing configuration as claimed in any one of claims 7 to 14, wherein a first end of the first arm is fixed to a first base member, which connects the first arm to the first curved track section, the first base member being configured to allow displacement of the first arm along the first curved track section, wherein the first base member is configured to retain the first arm in a substantially radial direction relative to the first curved track section, at any point along the first curved track section.

16. The probing configuration as claimed in claim 15, wherein the first base member takes the form of a first slide formation, a contact surface of the first slide formation being curved and having a radius equal to the radius of the first curved track section.

17. The probing configuration as claimed in claim 16, wherein a first linear reader is provided for measuring linear displacement of the first arm relative to a support structure and wherein each of the arms are provided with a capacitance sensor arranged towards the spherical dome and used to

measure an extent by which an axis along the length of each arm deviates from the centre point.

18, A coordinate measuring machine including the probing configuration as claimed in any one of claims 5 to 17 and a support structure which includes at least two multi-axial pivots, each configured for supporting a linear bearing for receiving one arm of the probing configuration.

19. A method of determining a coordinate of a point on an object, the method including the steps of:

placing the object on a bed of a coordinate measuring machine as claimed in claim 18;

bringing the probe of the probing configuration into contact with the point on the object;

measuring axial displacement of each of the first and second arms of the probing configuration relative to the support structure in relation to a reference point; and

determining a coordinate of the point on the object, based on the measured axial displacement of the first and second arms.

20. The method as claimed in claim 19, which includes measuring a geometric shape of the object by determining coordinates of a plurality of points on the object in accordance with the method of claim 19.

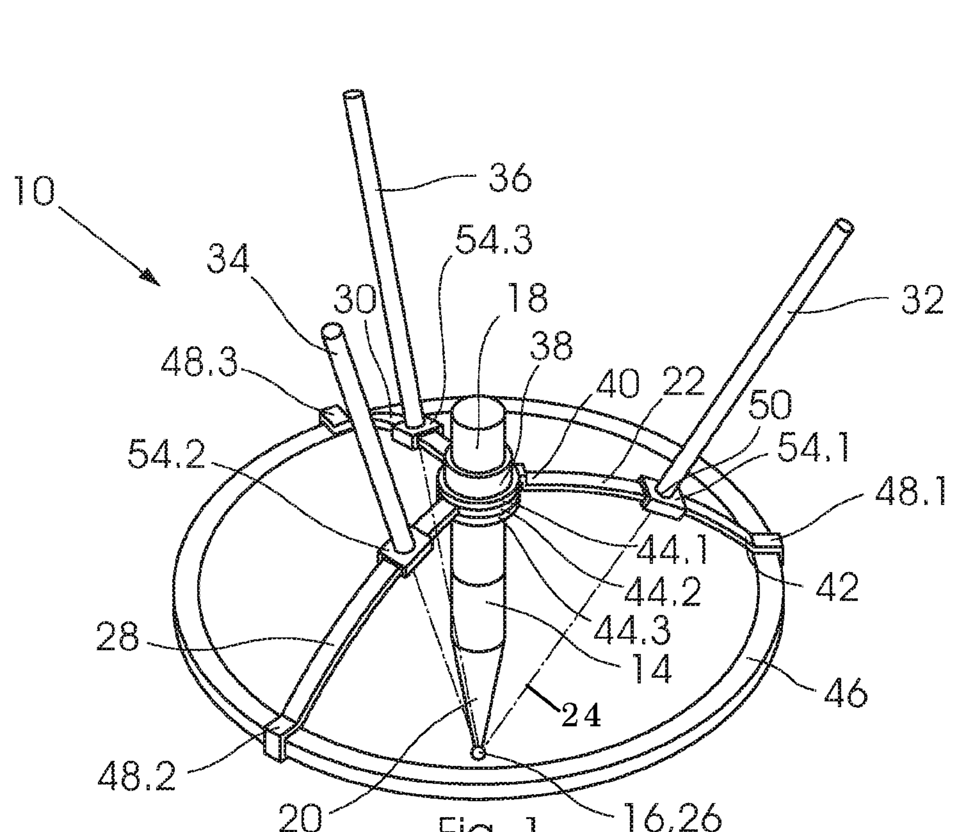
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Fig. 1

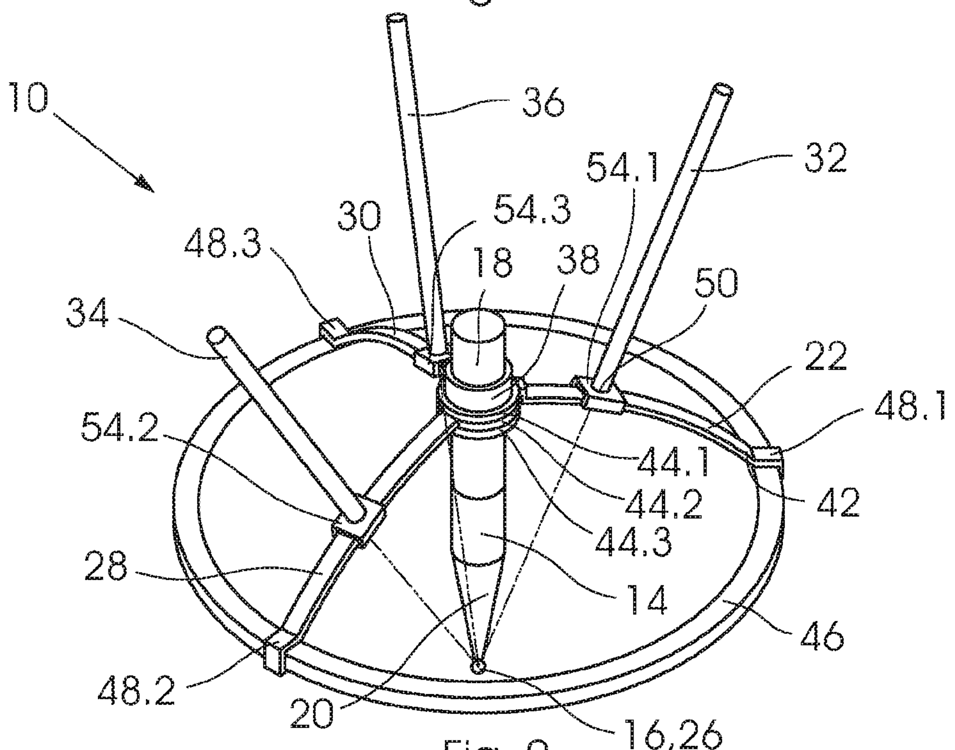
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Fig. 2

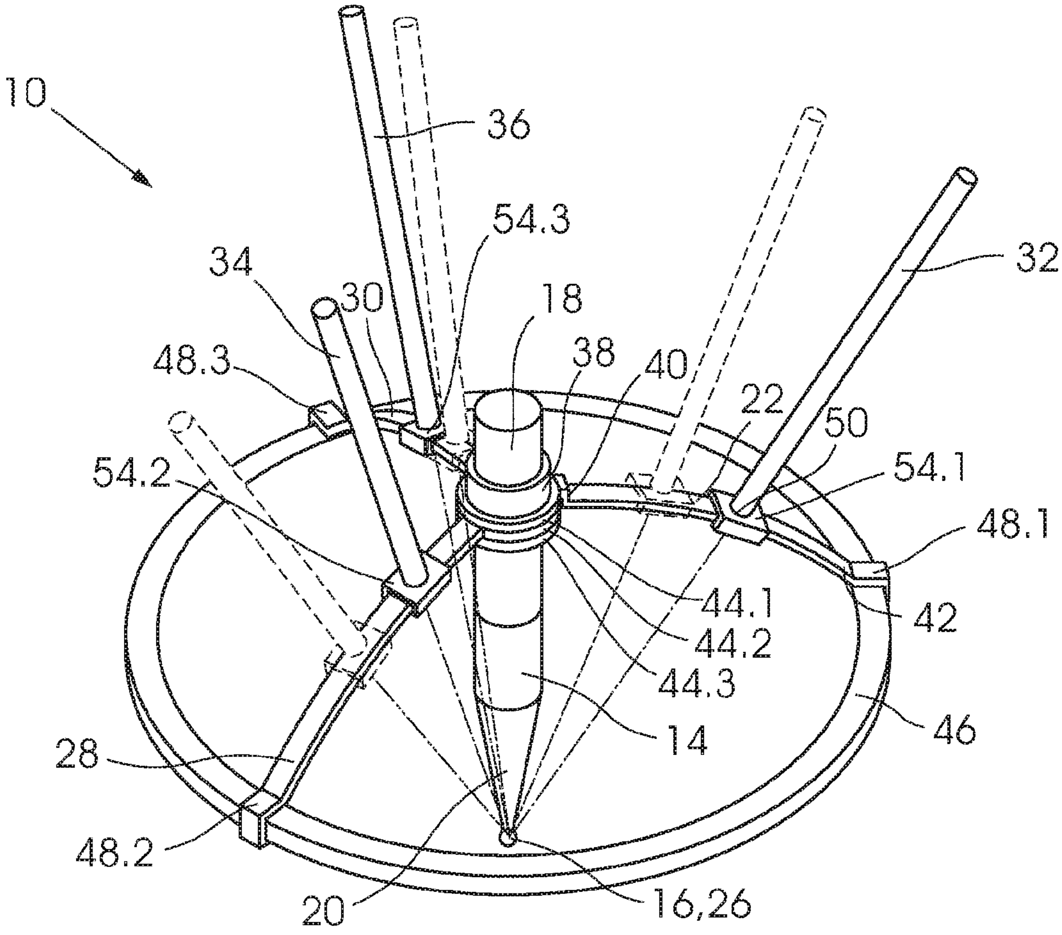
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Fig. 3

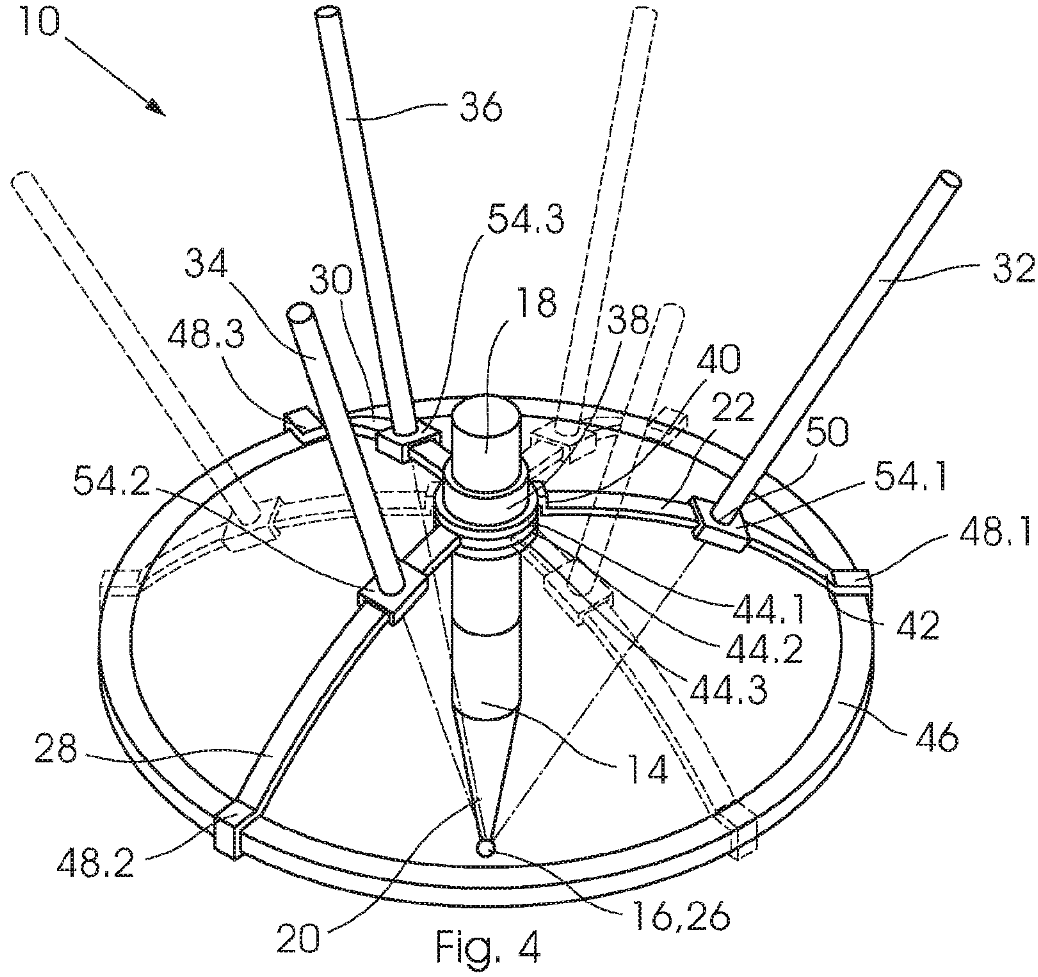
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Fig. 4

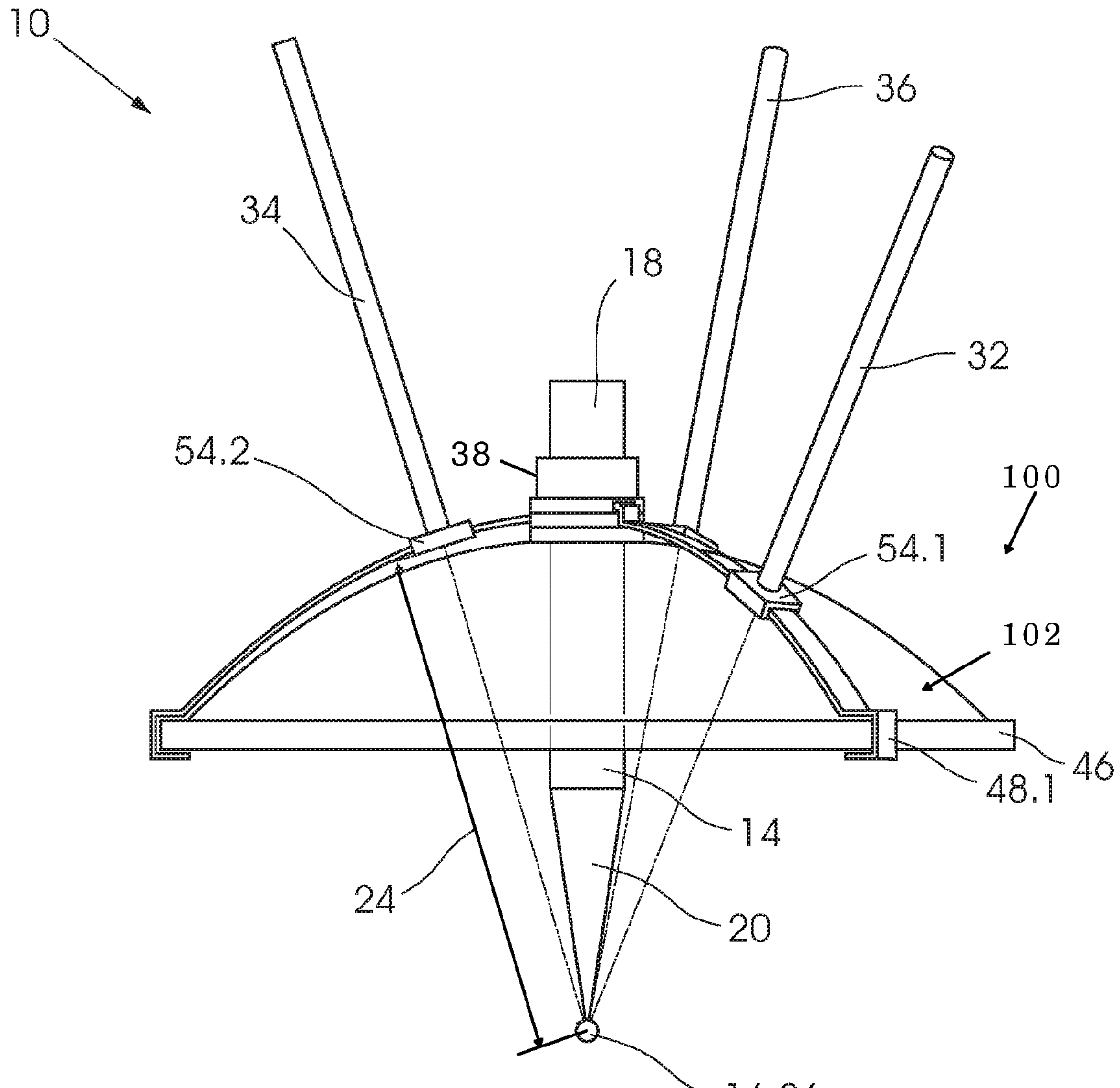

Fig. 5

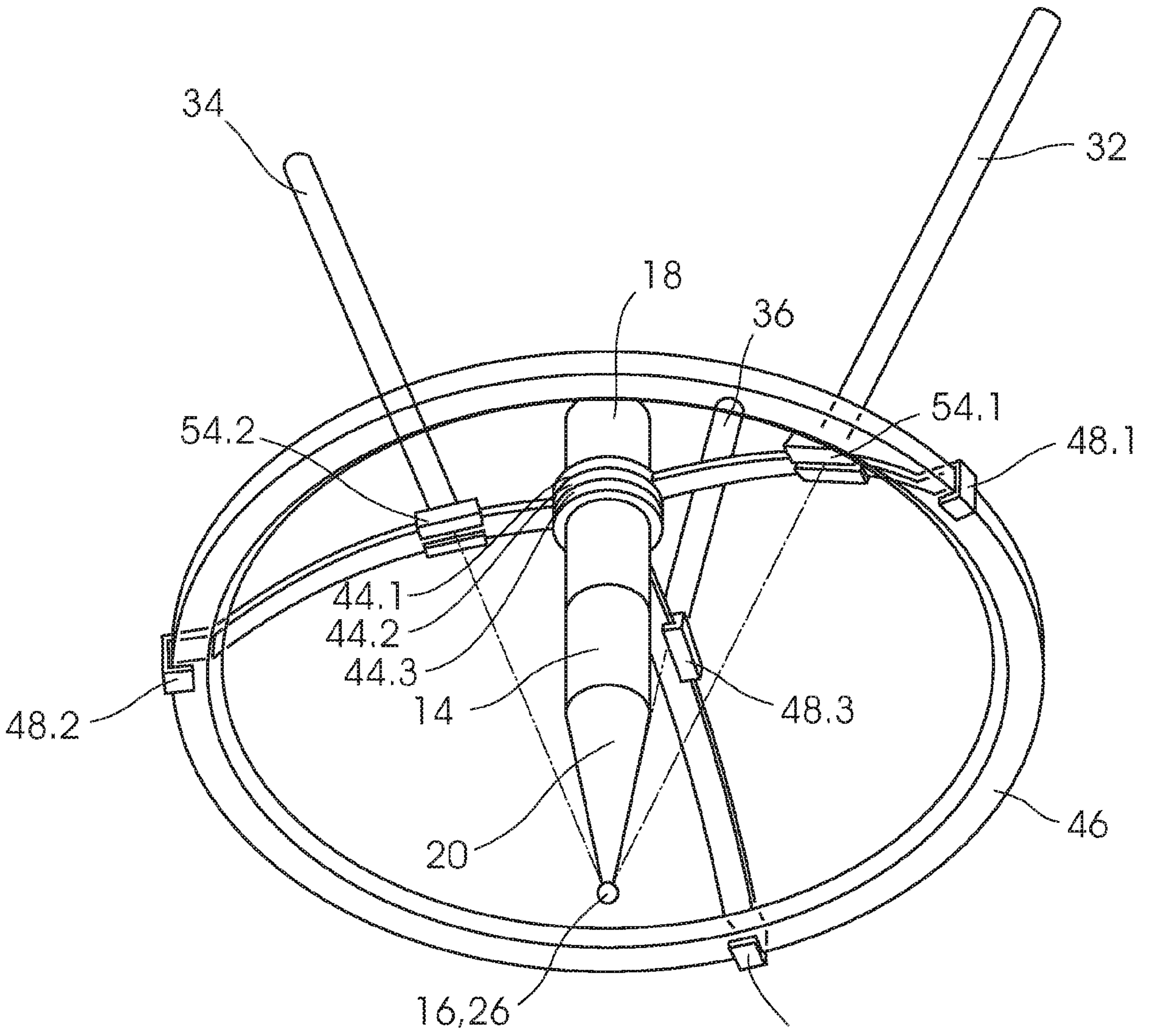

Fig. 6

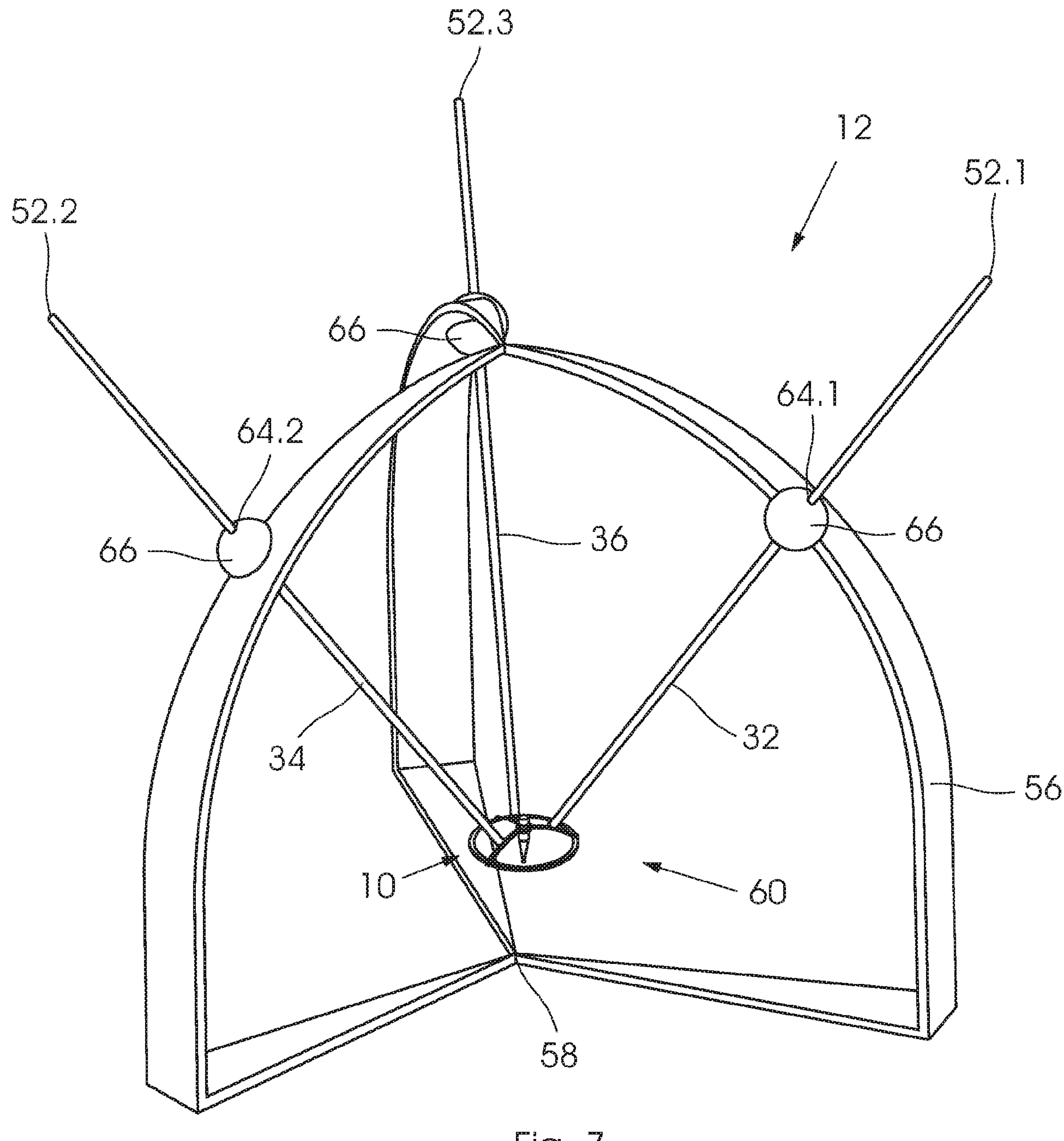

Fig. 7

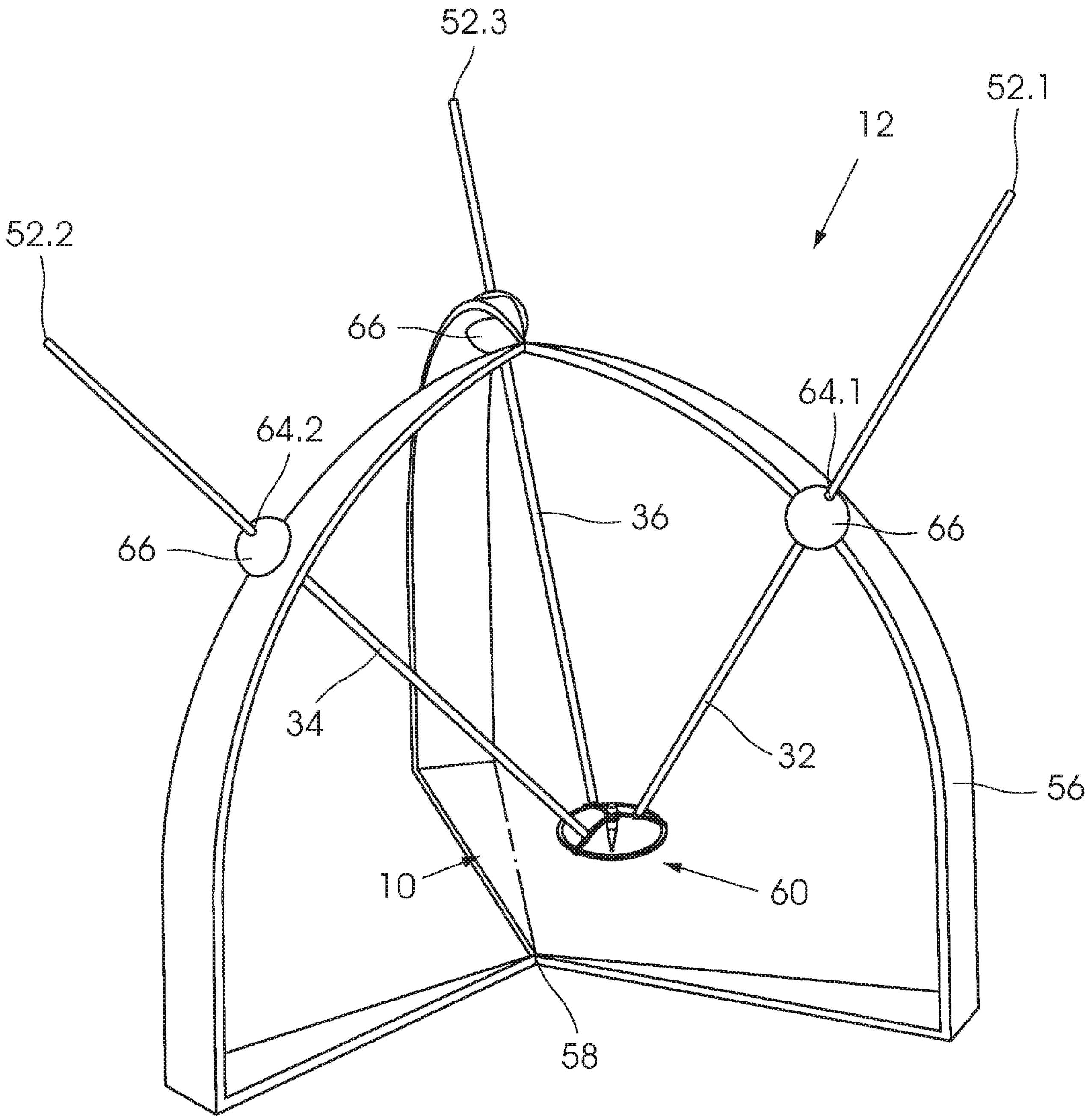

Fig. 8

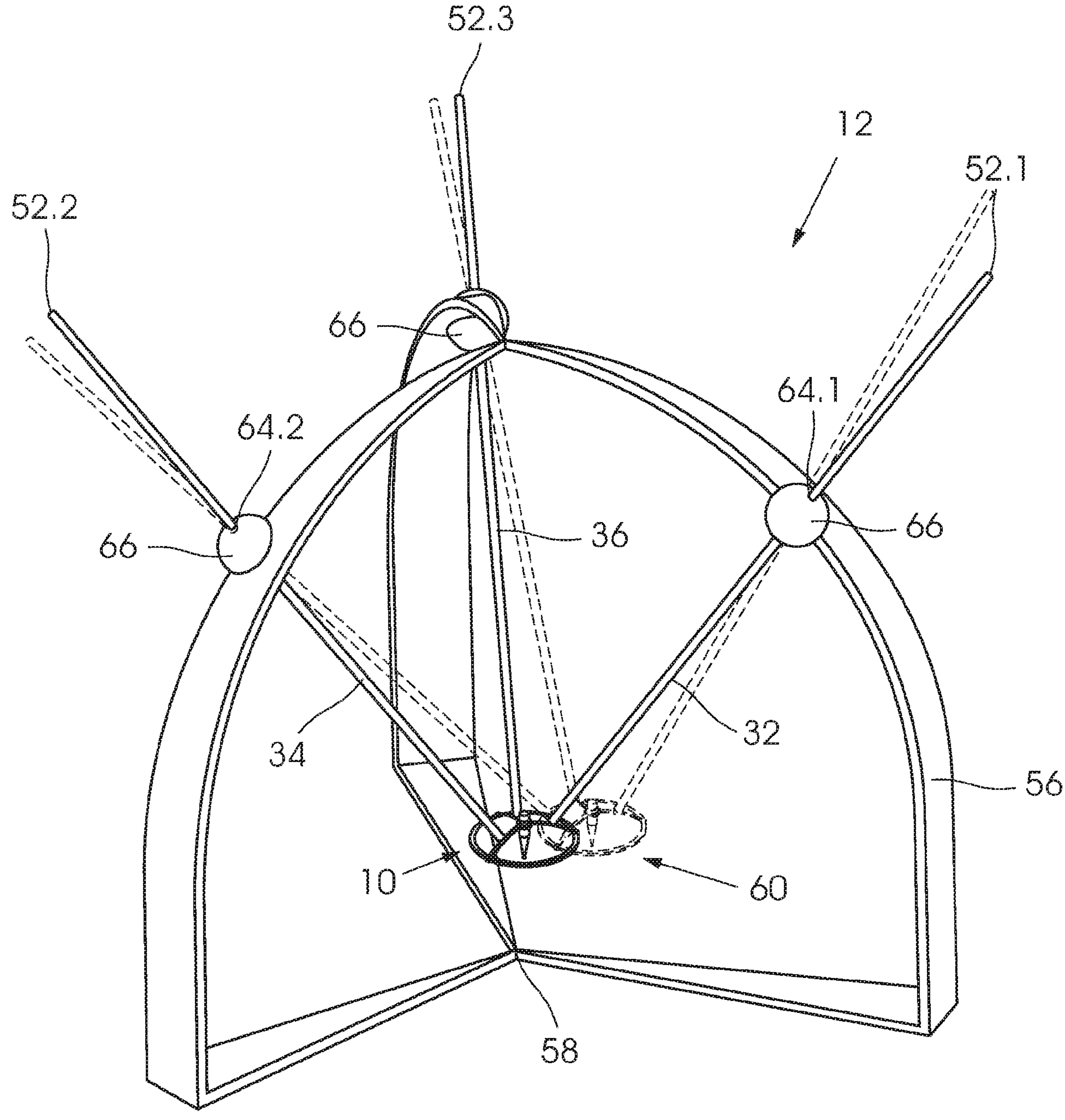

Fig. 9

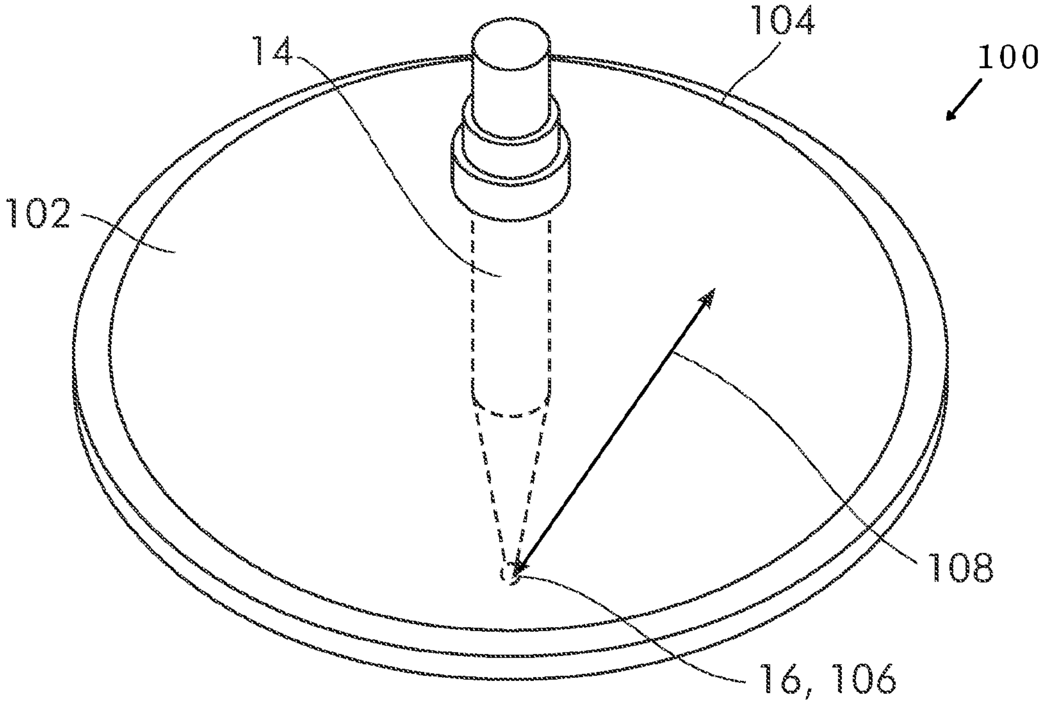

Fig. 10

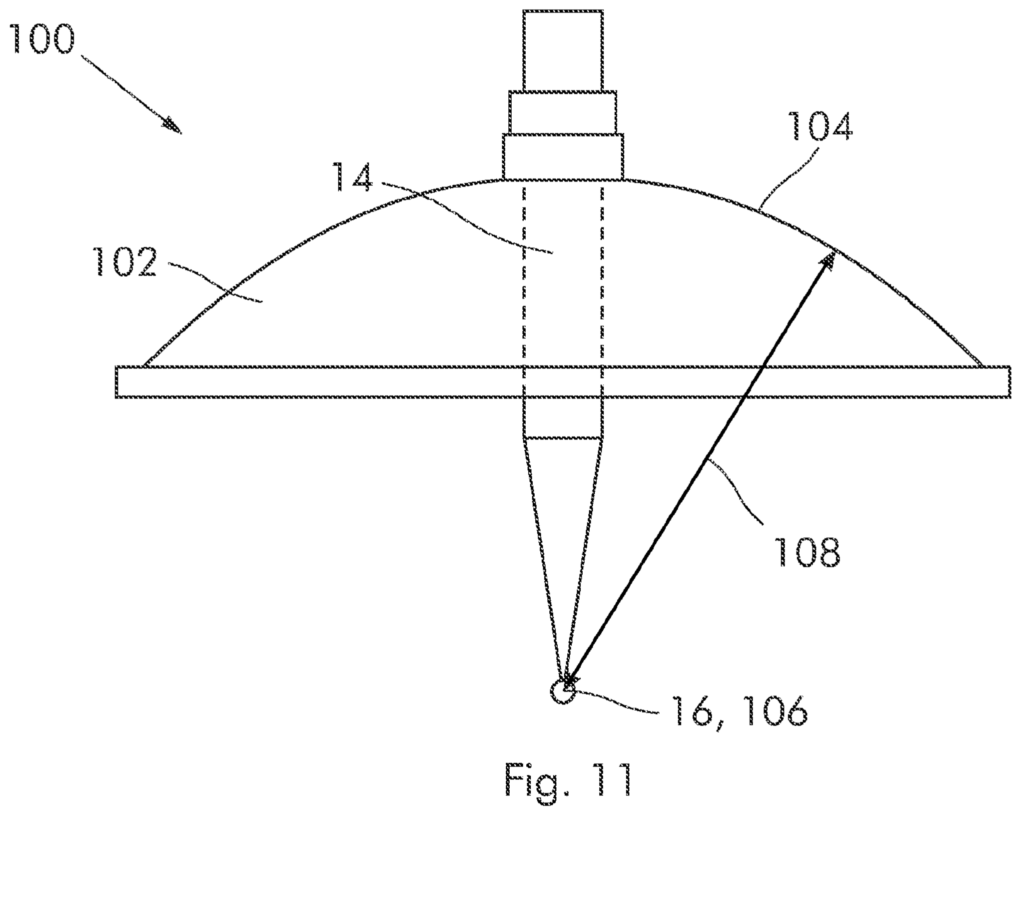

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2021/055852

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B5/00 G01B5/008 G01B21/04 G01B5/012
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01B B23Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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Y	page 95 - page 116	2-4

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 September 2021	10/09/2021

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Poizat, Christophe

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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