DTU Library

Precision coupling

Kain, Martin; Nielsen, Anders; Christensen, Jens; Gani, Michael; Todorovic, Milos; Bjørke, Benjamin; Thompson, Mary

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 June 2020 (25.06.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/127744 A1

(51) International Patent Classification:
G01B 5/00 (2006.01) *G02B 7/00* (2006.01)

(21) International Application Number:
PCT/EP2019/086322

(22) International Filing Date:
19 December 2019 (19.12.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
18213970.9 19 December 2018 (19.12.2018) EP

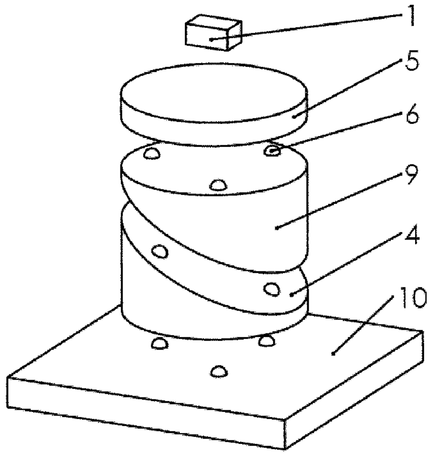
(71) Applicant: DANMARKS TEKNISKE UNIVERSITET [DK/DK]; Anker Engelunds Vej 101 A, 2800 Kgs. Lyngby (DK).

(72) Inventors: KAIN, Martin; Høsterkøbvej 52, 2970 Høsterkøb (DK). NIELSEN, Anders, Møller; Reininghausstrasse 48a/6, 8020 Graz (AT). CHRISTENSEN, Jens, Emil, Meinild; Flintemarken 81, 2950 Vedbæk (DK). GANI, Michael; Skyttemosen 6, 3450 Allerød (DK). TODOROVIC, Milos, Nikolas; Peter Bangs Vej 127, 4. tv., 2000 Frederiksberg (DK). BJØRKE, Benjamin; Niels Juels Gade 29, 1. tv., 8200 Aarhus (DK). THOMPSON, Mary, Kathryn; 7112 Merlin Way, Hamilton, OH 45011 (US).

(74) Agent: PLOUGMANN VINGTOFT A/S; Strandvejen 70, 2900 Hellerup (DK).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,

(54) Title: PRECISION COUPLING



a)

Fig. 3

(57) Abstract: The present invention relates to a precision coupling (3) for precise positioning of a first object (1) relative to a second object (2). It comprises two or more stackable bodies (4,5,9) each having a lower surface and an upper surface. When the bodies are stacked, all other upper and lower surfaces than the bottom body lower surface (4a) and the top body upper surface (5b) mutually form a pair of facing surfaces of adjacent bodies. For each pair of facing surfaces, one or both of the facing surfaces has three or more discrete contact elements (6,7). When the bodies are stacked, the contact elements mate with corresponding contact elements on the other facing surface so that the six relative degrees of freedom between the two adjacent bodies become deterministically constrained. For each of at least one body of the two or more stackable bodies, the upper and lower surfaces of that at least one body are inclined relative to each other.

WO 2020/127744 A1

[Continued on next page]

HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

PRECISION COUPLING

FIELD OF THE INVENTION

The present invention relates to precision couplings, and in particular to precision couplings for precision instruments, where low cost, repeatability, and adjustment in more than one degree of freedom and in more than one plane of motion are desired, as, for example, in applications and processes involving optics, measurement, manufacturing, and assembly.

BACKGROUND OF THE INVENTION

In precision manufacturing and metrology, being able to repeatably and accurately locate and measure specific features is highly desirable. These features can be in the order of microns, meaning that equipment with very accurate fixturing is important.

There are many fields where precise and repeatable positioning and manipulation of one object relative to another is critical, including, but not limited to, optics, dimensional metrology, surface metrology, tomography, microscopy, materials testing, precision manufacturing, micro manufacturing, assembly, repair, and remanufacturing. Many applications require a workpiece to change position along one or more directions of translation or axes of rotation with micron or sub-micron accuracy. In addition, it is often desirable to be able to demount a workpiece and then re-mount it with no loss of positional accuracy. For example, it may be necessary to clean a workpiece during a measurement operation or to inspect a workpiece during a manufacturing operation. It may also be desirable to inspect or repair a workpiece at a first orientation, to change the position or angle of the workpiece, and then to inspect or repair it at a second orientation.

One prior art method is to employ motorized chucks or stages with the required level of precision. These systems can provide near-continuous variation in position or rotation with micron or sub-micron precision. However, user error when operating the stage or when positioning a workpiece relative to the stage can result in a crash that can damage the workpiece, the stage, or other pieces of measurement or manufacturing equipment. These systems are often prone to positional drift over time, especially if closed loop control and calibration are not used. If a workpiece is removed from the mechanized stage, it often cannot be put back without having to recalibrate or otherwise reset the system. Finally, these systems can be prohibitively expensive.

Another prior art solution is the use of kinematic couplings. Kinematic couplings, or exact constraint couplings, have been used to provide simple and affordable micron and sub-micron repeatability in measurement, manufacturing, and assembly contexts. Kinematic couplings are designed so that one body contacts another such that each degree of freedom to be constrained is constrained but that additional constraints for those degrees of freedom are not provided; i.e. the system is not over-constrained. A kinematic coupling system within two bodies that is not over-constrained will provide a deterministical positioning of that one body with respect to the second body. For example, an interface can be fully constrained in six degrees of freedom (three translational degrees of freedom and three rotational degrees of freedom) by creating six points of contact. This can be accomplished by contacting each of three spheres with one of three vee-grooves. A seventh point of contact would over-constrain the system and introduce undesired positional uncertainty. An interface can also be fully constrained by contacting a sphere with a cone to lock the translational degrees of freedom, by contacting a second sphere with a vee-groove to create two points of contact thereby locking two of the rotational degrees of freedom, and contacting a third sphere with a plane to create the third point contact thereby locking the final rotational degree of freedom. Other variations and combinations of kinematic features, for example using hemispheres instead of spheres, using half cylinder pairs instead vee-grooves, etc. are known in the art. The two parts of a kinematic coupling can be held together by friction, gravity, magnets, or other known means. Other variations of kinematic couplings, including low-degree-of-freedom kinematic couplings where fewer than six degrees of freedom are constrained are known in the art. Quasi-kinematic couplings, which relax the requirements for point constrains and allow small areas of contact in exchange for higher load bearing capacity, are also known in the art. Canoe spheres and gothic arches are commonly used as contacting elements for quasi-kinematic couplings. A known benefit of kinematic couplings is that they are de-mountable and re-mountable with no loss of precision. One problem with kinematic couplings is that they are often designed for use in a single position or orientation; the workpiece can be demounted and remounted but the starting and ending position and orientation must be the same.

US 2002/0148392 discloses an example of a device having a tiltable table with which two surfaces can be arranged at controlled mutually tilted orientations for use during analysis or manufacturing of parts. However, if more tiltable positions are required with this device, it is described that two or more of such tables could be placed one on top of the other with their respective rocking axes offset. This means a more complex design and a larger height between the lower and upper surface which is not always possible in a given test set-up.

Hence, an improved precision coupling would be advantageous, and in particular a more efficient and/or reliable precision coupling would be advantageous.

OBJECT OF THE INVENTION

It is an object of the present invention to provide a precision coupling which is easier and faster to handle than prior art couplings.

It is another object of the present invention to provide a precision coupling with which a higher reproducibility between a series of measurements can be ensured without the need for re-adjustments of the parts of the coupling between the measurements.

It is another object of the present invention to provide a precision coupling which enables the user in a flexible way to obtain several discrete inclination angles.

It is an object of some embodiments of the present invention to provide a precision coupling with which it is possible to create a scalable solution for a more versatile use in a broader range of applications.

It is a further object of the present invention to provide an alternative to the prior art.

In particular, it may be seen as an object of the present invention to provide a precision coupling that solves the above-mentioned problems of the prior art.

SUMMARY OF THE INVENTION

The above described object and several other objects are intended to be obtained in a first aspect of the invention by providing a precision coupling for precise positioning of a first object relative to a second object, the precision coupling comprising two or more stackable bodies each having a lower surface and an upper surface, the two or more stackable bodies including:

- a bottom body with a bottom body lower surface which is adapted to be arranged on the second object, and
- a top body with a top body upper surface for supporting or defining the position of the first object,

- wherein, when the bodies are stacked, all other upper and lower surfaces than the bottom body lower surface and the top body upper surface mutually form a pair of facing surfaces of adjacent bodies,

- wherein for each pair of facing surfaces, one or both of the facing surfaces has three or more discrete contact elements which are shaped, sized, and located so that, when the bodies are stacked:
    - these three or more contact elements mate with corresponding contact elements on the other facing surface so that the six relative degrees of freedom between the two adjacent bodies become deterministically constrained, and
    - the facing surfaces of the two adjacent bodies become arranged separated by a finite gap, and

- wherein for each of at least one body of the two or more stackable bodies, the upper and lower surfaces of that at least one body are inclined relative to each other.

The last part of this description of the invention could also be explained as at least one of the bodies being wedge-shaped. By such a design of a precision coupling, it is obtained that a first object can be arranged thereon in a plurality of rotational and tilted orientations relative to the second object by changing the mutual rotational orientations of the bodies in the stack. This will be further explained in relation to the figures. A possible use of a precision coupling according to the present invention will be for precise positioning of an item relative to a mounting surface, such as an item to be analysed e.g. by having a series of dimensional measurements being performed.

The angle of inclination of the upper and lower surfaces of the at least one body should be larger than zero. The angle of inclination to use will depend on the actual application. E.g. when the precision coupling is used for calibration of optical equipment, a small angle of inclination will typically be relevant to ensure sufficient precision. When the precision coupling is used for quality control as part of a manufacturing line, the optimum angle of inclination depends on the components being tested, and for some geometries and points to be measured, a large angle of inclination may be needed.

When the upper and lower surfaces are inclined relative to each other for more than one of the bodies, the angle of inclination may be the same or different for the different bodies.

By “facing surface” is preferably meant a surface on a body that will be facing another surface on another body. The facing surface is not necessarily defined by a plane. A facing surface can in itself represent a contact element.

By “stackable” is preferably meant that the bodies are designed to be arranged at least partly on top of each other. However, the mass centres of the bodies are not necessarily vertically above each other.

In some embodiments of the invention, when the bodies are stacked, there is no physical contact between the facing surfaces of each pair of facing surfaces.

In embodiments of the invention wherein the upper and lower surfaces are non-parallel to each other only for one of the two or more stackable bodies, the top body upper surface cannot be parallel to the bottom body lower surface and thereby to the second object. Such an embodiment can be used for applications where a fixed inclination of the top body upper surface is needed e.g. with respect to a mounting surface.

The bottom body lower surface and the top body upper surface are typically plane. However, in principle they could also have other shapes, such as being curved or recessed to match e.g. a second object in the form of a non-plane mounting surface of a specific test set-up.

By “precise positioning” is preferably meant that the first object can be positioned in a predetermined manner by arranging the stackable bodies in different and well-defined mutual orientations as will be further illustrated in the figures. This positioning is reproducible, which will e.g. be relevant when the precision coupling is used in a quality control procedure. Here a measurement schedule can be designed to ensure that the same points of interest for a given type of measurement can easily be applied to other identical first objects under investigation, such as for quality control with a high reproducibility.

All the contact elements of any facing surface may be arranged equidistant from a centre point on that facing surface. Hereby they can be considered to form a radial array of contact elements arranged along an imaginary circle having its centre at the centre point on the facing surface. In an alternative embodiment, several arrays of grooves can be used and fundamentally offer the same type of kinematic coupling.

The contact elements may be selected from hemispherical holes, conical holes, grooves, vee-grooves, gothic arches, cylinders, partial cylinders, spheres, hemispheres, canoe spheres, tori, cones, and flat surfaces. These kinds of contact elements are known on their own from traditional precision couplings, such as kinematic couplings, and a person skilled in the art would know how to select which specific geometries to use for a given purpose. The functionality of a precision coupling according to the invention can be obtained with many different kinematic and quasi-kinematic designs. The true kinematic designs will give the highest precision while the quasi-kinematic design will offer resistance to higher loads. Thus, which design of the precision coupling to use for a given task will e.g. depend on the precision needed and the kind of forces involved.

In some embodiments of the invention, the contact elements of the two surfaces of a pair of facing surfaces are concave contact elements and convex contact elements, respectively. Some possible combinations will be illustrated in the figures. At least some of the convex contact elements may e.g. be radially extending elongate grooves. By "elongate" is hereby preferably meant that they have a larger dimension in a direction extending radially from the centre point than in a direction perpendicular thereto. The coupling between the two facing surfaces should not be over-constrained and the elongated grooves prevent this on the radial axis. An over-constrained design will deteriorate the precision and reproducibility.

In embodiments having concave contact elements, at least some of these may be resiliently mounted. This can e.g. be obtained by spring loading or by using a slightly elastically deformable material. Such a mounting can be used to allow for small variations to compensate for misalignment. This could be useful in tooling and fixturing, moulding, casting and sub-assemblies where such possible compensating is more important than a very high precision.

In some embodiments of the invention, there are three or more discrete contact elements on all of the facing surfaces. The number of discrete contact elements of at least one of the facing surfaces may be 3 to 40, such as 6 to 24. Hereby it is obtained that two adjacent bodies can be arranged in a corresponding number of discrete mutual and well-defined positions, since the number and distribution of the discrete contact elements represent the number of positions and the angles that can be obtained. To facilitate the correct positioning, the non-contacting surfaces of the bodies may be provided with identification marking as will be explained in relation to the figures.

In any of the embodiments as described above, the precision coupling may comprise three or more stackable bodies. Hereby a higher degree of freedom is obtained with respect to the possible positions, including tilt angles, in which the first object can be arranged relative to the second object.

In presently preferred embodiments of the invention, the bodies can be re-arranged between a plurality of discrete mutual orientations determined by the locations of the contact elements. The bodies may e.g. be loosely arranged when they are stacked. By "loosely" is preferably meant that no mutual fastening between the bodies is performed and that the bodies stay in the actual mutual positions due to geometrical constraints between the kinematic elements, so that vertically stacked bodies are held in place by gravitational forces only. Hereby it is easy and fast to change the position, including the tilt, of the item so that e.g. a sequence of measurements can be performed with a minimum handling time. Alternatively, the bodies may be arranged by use of holding means being comprised in the bodies, which holding means apply a holding force to the bodies, such as the holding means being or comprising magnets or springs. Hereby a secure and fast positioning and mutual holding of the bodies can be obtained, including for large inclinations of the surfaces with respect to horizontal.

In some of the embodiments of the invention, wherein the bodies can be re-arranged between a plurality of discrete mutual orientations, this re-arrangement of the bodies can be performed manually. This will be useful for some applications, wherein the re-arrangement is actually done manually, e.g. as part of experiments performed during research or development. However, such embodiments could also include the use of automation, e.g. using robots, to perform the re-arrangements. For both uses (i.e. manually or by robots), it is advantageous that the bodies will be arranged very precisely due to the design of the precision coupling without the need for high precision in the control of the actual movement. Hereby the re-arrangement can typically also be performed at higher speed, if needed.

In any of the embodiments described above, the top body upper surface may comprise mounting means for removably mounting of the first object. Hereby a stable mounting can be ensured, and the risk of misalignments e.g. due to accidental knocks can be avoided. This may be particularly relevant when the top body upper surface is at a large angle of inclination relative to the second object. This is e.g. the case when the precision coupling is used for the mounting of an item relative to a, typically horizontal, mounting surface. The mounting means may e.g. be threaded holes, a clamp, or some kind of gripping means.

In a precision coupling as described in any of the embodiments above, at least one pair of mating surfaces may be held in contact using magnetic forces.

In any of the above-mentioned embodiments, for the upper and lower surfaces of the at least one body having these surfaces inclined relative to each other, the angle of inclination may be between 0.5 and 90 degrees, such as between 1 and 60 degrees, preferably between 1 and 45 degrees.In a second aspect, the present invention relates to a high precision fixture comprising a precision coupling as described above. Such a high precision fixture may comprise further parts. Such further parts may e.g. be a base plate for fastening the precision coupling to a table or a mounting clamp for fastening the first object to the top body upper surface.

In a third aspect, the present invention relates to the use of a high precision fixture according to the second aspect for optical metrology. Other examples of areas where the present invention can find use is within tactile metrology, tooling and fixturing, assembly and alignment.

The first, second and third aspects of the present invention may each be combined with any of the other aspects. These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE FIGURES

Precision couplings according to the invention will now be described in more detail with regard to the accompanying figures. The figures show one way of implementing the present invention and is not to be construed as being limiting to other possible embodiments falling within the scope of the attached claim set.

Figure 1 schematically shows the use of a precision coupling according to the present invention.

Figure 2 schematically shows a precision coupling according to the invention in exploded and cross-sectional view.

Figure 3 shows an exploded three-dimensional view of an embodiment having three bodies. Figures 3.a and 3.b show the embodiment from two different angles.

Figure 4 schematically shows different six different configurations of the precision coupling in figure 3.

Figure 5 shows the use of the precision coupling in figures 3 and 4 as a high precision fixture for use in relation to optical metrology.

Figure 6 schematically shows different arrangements of a bottom body and a top body of a precision coupling according to the present invention.

Figure 7 schematically shows examples of contact elements. Figure 7.a shows concave elements in the form of balls; and figure 7.b shows convex elements in the form of radially extending elongate grooves.

Figure 8 schematically shows examples of other possible contact elements.

Figure 9 schematically shows top views of bodies having 12 and 21 grooves, respectively.

DETAILED DESCRIPTION OF AN EMBODIMENT

Figure 1 schematically shows the overall principle of arranging an item in a predetermined manner relative to a mounting surface by use of a precision coupling 3 according to the present invention. Thus, in this example of use of the precision coupling 3, the first object 1 is an item and the second object 2 is a mounting surface. This embodiment has only two bodies which are referred to as a bottom body 4 and a top body 5, respectively. A precision coupling 3 is shown schematically in figure 2 with the two bodies arranged at a distance from each other. Figure 2.a is a three-dimensional view of the two bodies, and figure 2.b is a cross-sectional view. The two bodies 4,5 each have a lower surface and an upper surface. As shown in figures 1 and 2, the bottom body 4 has a bottom body lower surface 4a that is adapted to be arranged on the mounting surface 2, and the top body 5 has a top body upper surface 5b for supporting the item 1. In general, also for embodiments with more than two bodies, all other upper and lower surfaces than the bottom body lower surface 4a and the top body upper surface 5b mutually form a pair of facing surfaces of adjacent bodies when the bodies are stacked. In the illustrated embodiments, the facing surfaces are plane. In the simple embodiment with only two bodies 4,5, the facing surfaces are the upper surface 4b of the lower body 4 and the lower surface 5a of the upper body 5.

For each pair of facing surfaces, at least one of the facing surfaces has three discrete contact elements 6; in figure 2 they are shown as hemispheres arranged on the lower body 4. In general, these three discrete contact elements 6 are shaped, sized, and located so that, when the bodies 4,5 are stacked, these three contact elements 6 mate with corresponding one or more contact elements on the other facing surface so that the six relative degrees of freedom between the two adjacent bodies become deterministically constrained. In the illustrated embodiment in figure 2, the hemispheres 6 are shown to mate with three discrete grooves 7. An alternative to having discrete grooves would be to have one annular groove (not shown).

When the bodies 4,5 of the precision coupling 3 are stacked, the facing surfaces 4b,5a of two adjacent bodies become arranged substantially parallel to each other and may be separated by a finite gap 8 as seen in figure 1. For the precision coupling to work as will be described in the following, for at least one of the two or more stackable bodies, the upper and lower surfaces are inclined relative to each other. The angle between these surfaces can be referred to as the angle of inclination β; see figure 1. In the embodiments in figure 1 and 2, the bottom body 4 and the top body 5 have the same angle of inclination β.

Figure 3 shows exploded three-dimensional views of an embodiment having three bodies 4,5,9. Figures 3.a and 3.b show the embodiment from two different angles to better illustrate the shapes of the contact elements 6,7. The embodiment in figure 3 further comprises a base plate 10 which can be used to facilitate the correct mounting of the precision coupling to a larger second object (not shown), e.g. by use of screw connections. Alternatively, the upper surface of such a base element could be considered the second object, or it could be left out so that instead the bottom body could be fastened directly to a larger second object, such as an upper surface of a test rig.

Figure 4 shows how each of the bodies 4,5,6 can be rotated to result in well-defined possible spatial arrangements of the first object 1 relative to the second object 2 both with respect to angular orientation around a vertical axis and with respect to tilting relative to a horizontal plane. The outer non-mating surfaces of the bodies may be provided with reference signs (not shown) to ease keeping track of the possible arrangements.

The precision coupling in figures 3 and 4 can e.g. be used as a high precision fixture for use in relation to optical metrology as shown in figure 5. Figure shows how an item being studied with a microscope can be precisely arranged at different inclinations and positions. If a series of measurements are to be made on the same item, the bodies can easily be arranged at the different mutual orientations. The bodies can be marked along the peripheries to ease the keeping track of the different arrangements. If a series of measurements are to be made on a series of items arranged in the same manner relative to the microscope, the top body 5 with an item 1 arranged thereon can be taken out, the item can be replaced with a subsequent one, and the top body 5 can be re-inserted in the same position as before. Hereby it is ensured that the items 1 are arranged in the same manner without any need for re-adjustment of the precision coupling 3.

Figure 6 schematically shows how different orientations of a first object relative to a mounting surface can be obtained by different arrangements of a bottom body and a top body of a precision coupling. The angle of inclination β as shown in figure 1 can have the same value or different values for the bodies of the precision coupling; this is shown in figure 6. The angles shown in figure 6 are examples of possible total angles that can be obtained by different rotational orientations of the two bodies.
All the contact elements 6,7 of any facing surface are typically arranged equidistant from the centre point of that facing surface. Examples of contact elements are shown in figure 7. Figure 7.a schematically shows concave elements in the form of balls; and figure 7.b shows convex elements in the form of radially

extending elongate grooves. As seen from the figure, the number of contact elements is typically not the same for two facing surfaces.

Examples of other possible contact elements are shown schematically in figure 8, wherein each coupling is shown as seen from the front as well in isometric view. The following embodiments are shown in figure 8:

a) Sphere on plane

b) Sphere section on concave surface

c) Sphere on cone

d) Sphere on three planes

e) Sphere on two half cylinders

f) Cylinder on two half spheres

g) Cone on torus

h) Sphere on three sphere sections

i) Sphere on two torus sections

j) Three toothed kinematic planar face coupling

k) Canoe ball in vee-groove

l) Canoe ball on convex vee-grove

m) Canoe ball in Gothic arch

The embodiments in figures 8.c, 8.g, 8.i, and 8.j are quasi-kinematic contact elements.

The number of discrete contact elements of at least one of the facing surface may be 3 to 40, such as 6 to 24. Figure 9 schematically shows top views of bodies having 12 and 21 grooves, respectively.

The bodies of a precision coupling as described above will typically be made by high precision machining, such as CNC milling, or by 3D printing of metal materials, such as stainless steel. However, all materials and manufacturing processes are intended to be covered by the present invention if the precision for a given application can be ensured. Thus, the bodies and the contact elements can also be made from stone, ceramics, polymers and composites.

In all the illustrated embodiments, the bodies have a circular cross section transverse to the axes of rotation. This is mainly for aesthetic and practical purposes, and in principle, other geometries would also be possible within the scope of protection of the invention.

In all the illustrated embodiments, the bodies are shown as being able to rotate relative to one another but without translation. In practice, additional contact elements could be provided to allow a stack or sub-stack of bodies to be moved to another kinematic or quasi-kinematic mount, thus enabling translation of a portion of the stack. For example, the contact elements on the top surface of the bottom body in the stack could consist of two parallel rows of balls. Thus, a mating surface comprised of vee grooves could be moved back and forth to discrete positions along these rows. This is also within the scope of protection of the invention.

Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to the presented examples. The scope of the present invention is set out by the accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous.

CLAIMS

1. Precision coupling (3) for precise positioning of a first object (1) relative to a second object (2), the precision coupling (3) comprising two or more stackable bodies (4,5,9) each having a lower surface and an upper surface, the two or more stackable bodies including:

- a bottom body (4) with a bottom body lower surface (4a) which is adapted to be arranged on the second object (2), and
- a top body (5) with a top body upper surface (5b) for supporting or defining the position of the first object (1),

- wherein, when the bodies are stacked, all other upper and lower surfaces than the bottom body lower surface (4a) and the top body upper surface (5b) mutually form a pair of facing surfaces of adjacent bodies,

- wherein for each pair of facing surfaces, one or both of the facing surfaces has three or more discrete contact elements (6,7) which are shaped, sized, and located so that, when the bodies are stacked:

- these three or more contact elements (6,7) mate with corresponding contact elements (6,7) on the other facing surface so that the six relative degrees of freedom between the two adjacent bodies become deterministically constrained, and
- the facing surfaces of the two adjacent bodies become arranged separated by a finite gap (8), and

- wherein for each of at least one body of the two or more stackable bodies, the upper and lower surfaces of that at least one body are inclined relative to each other.

2. Precision coupling (1) according to claim 1, wherein all the contact elements (6,7) of any facing surface are arranged equidistant from a centre point on that facing surface.

3. Precision coupling (1) according to claim 1 or 2, wherein the contact elements (6,7) are selected from hemispherical holes, conical holes, grooves, vee-grooves,

gothic arches, cylinders, partial cylinders, spheres, hemispheres, canoe spheres, tori, cones, and flat surfaces.

4. Precision coupling (1) according to any of the preceding claims, wherein the contact elements (6,7) of the two surfaces of a pair of facing surfaces are concave contact elements (6) and convex contact elements (7), respectively.

5. Precision coupling (1) according to claim 4, wherein at least some of the convex contact elements are radially extending elongate grooves.

6. Precision coupling (1) according to claim 4 or 5, wherein at least some of the concave contact elements (6) are resiliently mounted.

7. Precision coupling (1) according to any of the preceding claims, wherein there are three or more discrete contact elements (6,7) on all of the facing surfaces, such as wherein the number of discrete contact elements (6,7) of at least one of the facing surfaces is 3 to 40, such as 6 to 24.

8. Precision coupling (1) according to any of the preceding claims, comprising three or more stackable bodies (4,5,9).

9. Precision coupling (1) according to any of the preceding claims, wherein the bodies (4,5,9) can be re-arranged between a plurality of discrete mutual orientations determined by the locations of the contact elements (6,7).

10. Precision coupling (1) according to claim 9, wherein the re-arrangement of the bodies (4,5,9) can be performed manually.

11. Precision coupling (1) according to any of the preceding claims, wherein the top body upper surface (5b) comprises mounting means for removably mounting of the first object (1).

12. Precision coupling (1) according to any of the preceding claims, wherein at least one pair of mating surfaces is held in contact using magnetic forces.

13. Precision coupling (1) according to any of the preceding claims, wherein for the upper and lower surfaces of the at least one body having these surfaces inclined relative to each other, the angle of inclination is between 0.5 and 90 degrees, such as between 1 and 60 degrees, preferably between 1 and 45 degrees.

14. High precision fixture comprising a precision coupling (3) according to any of the preceding claims.

15. Use of a high precision fixture according to claim 14 for optical metrology.

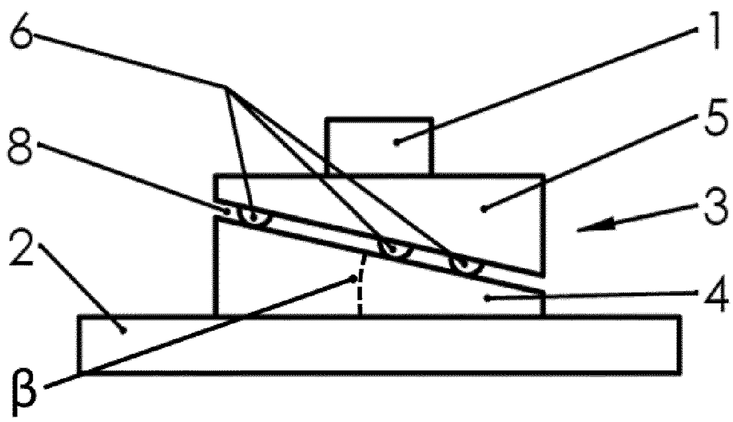


Fig. 1

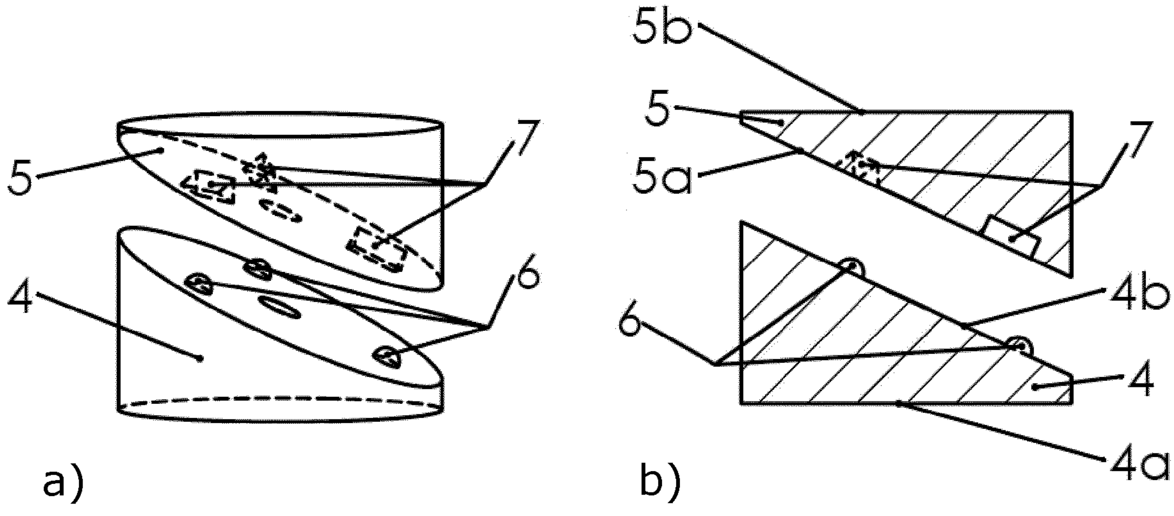


Fig. 2

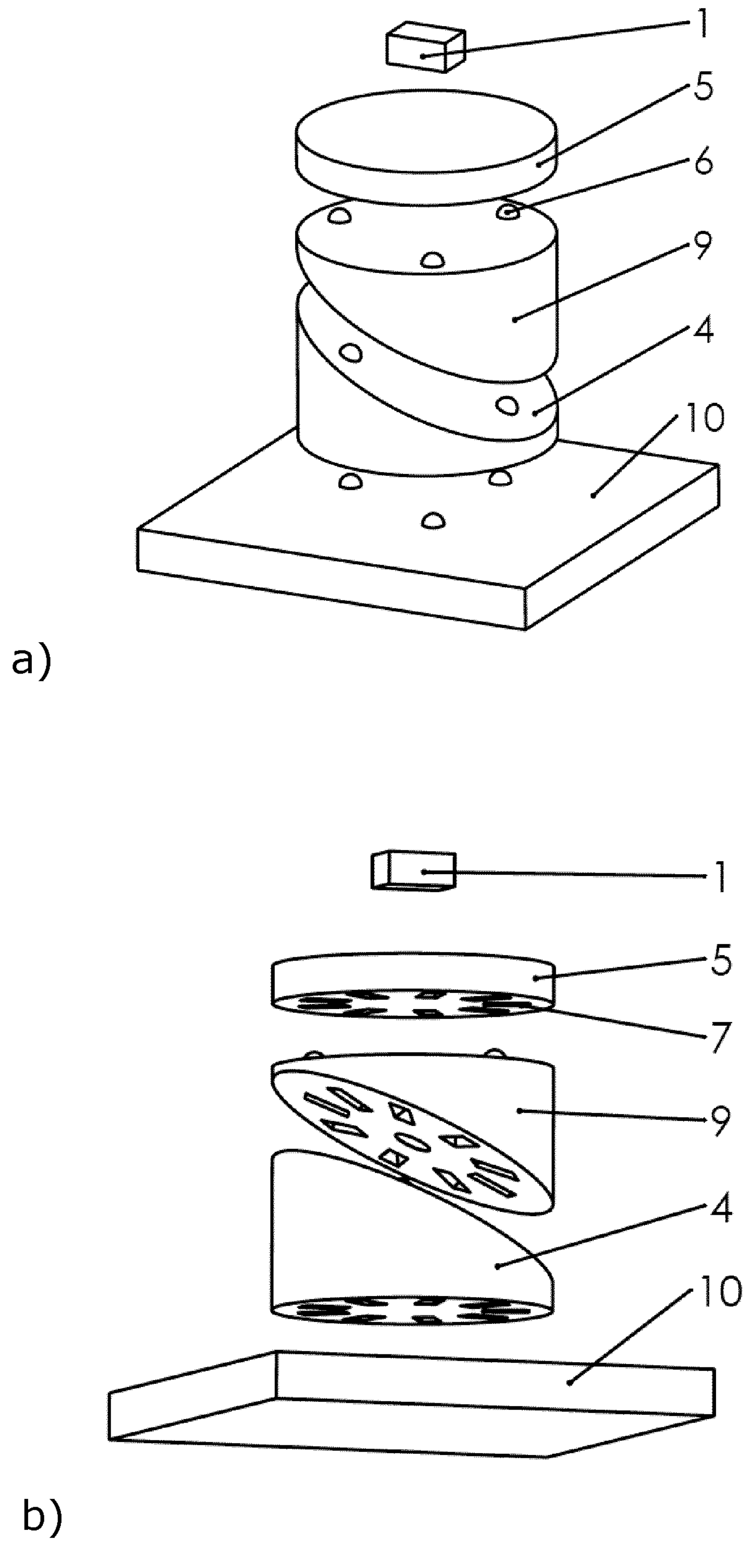


Fig. 3

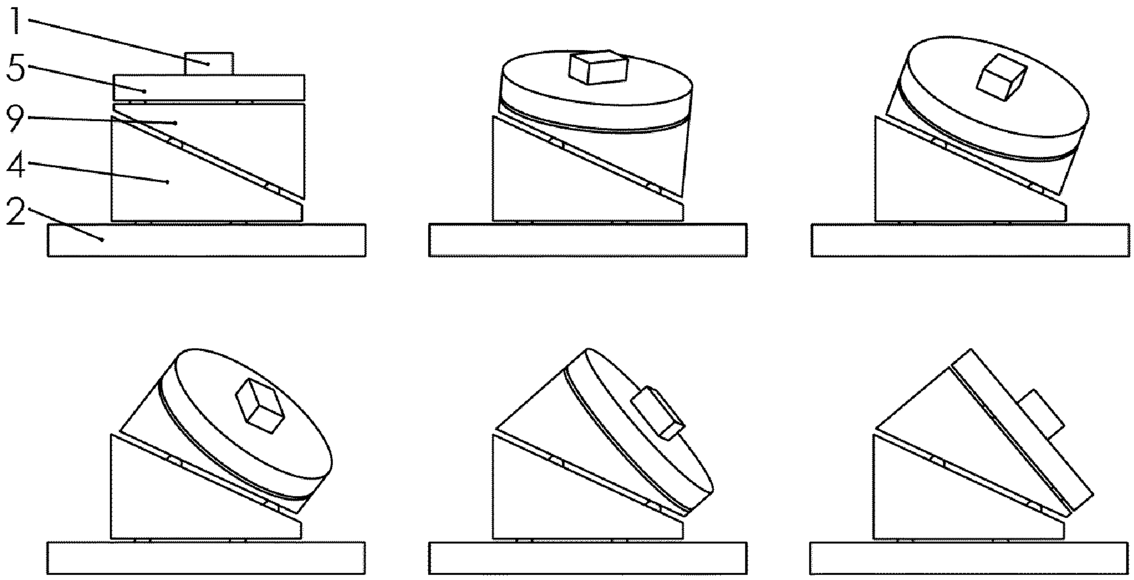


Fig. 4

Fig. 5

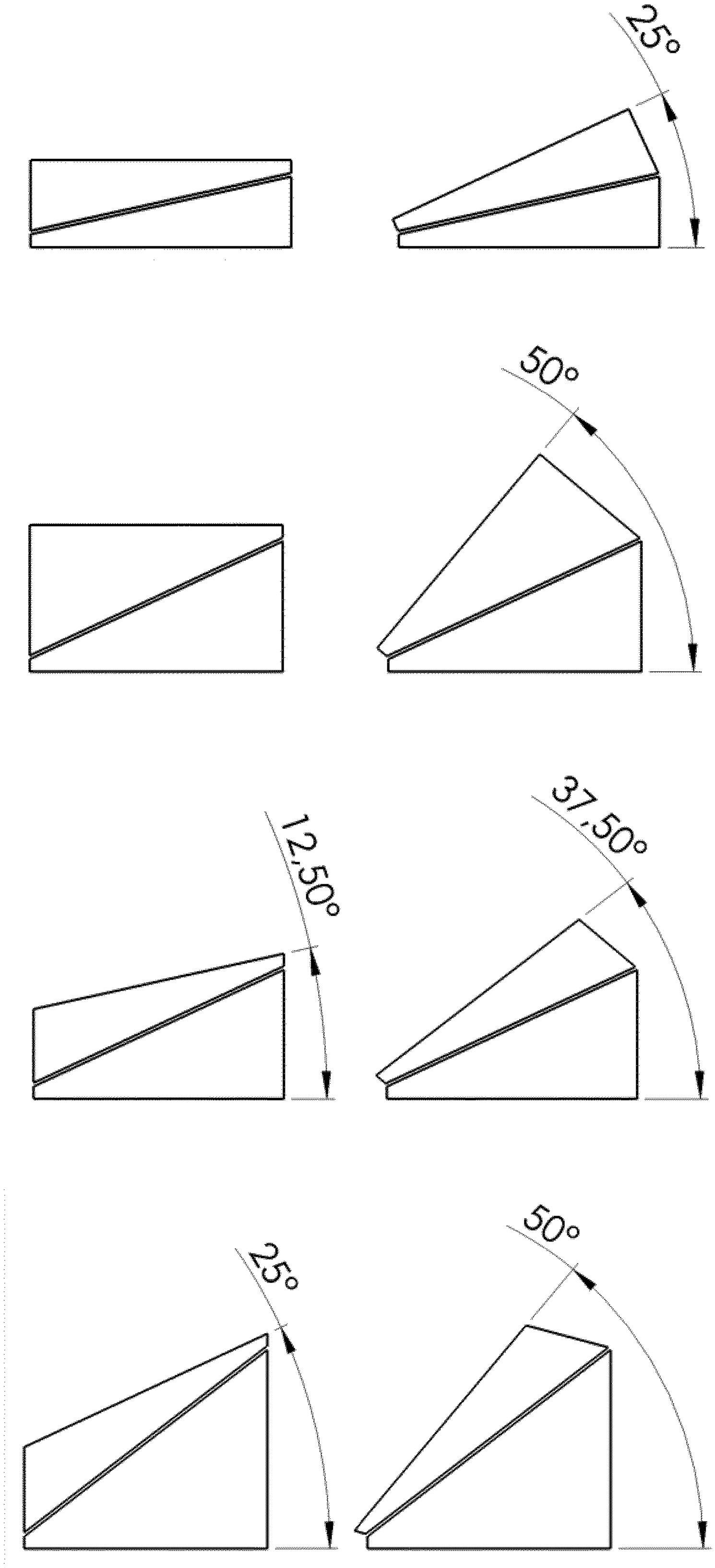
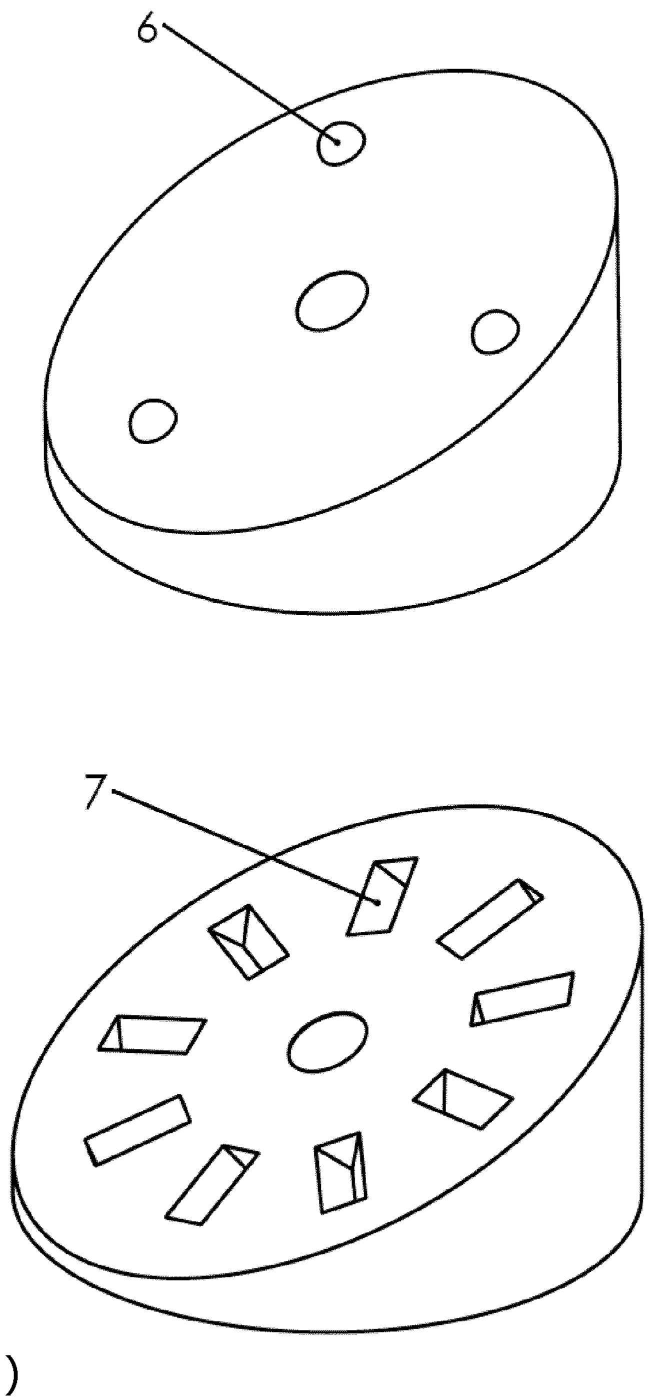


Fig. 6



a)

b)

Fig. 7

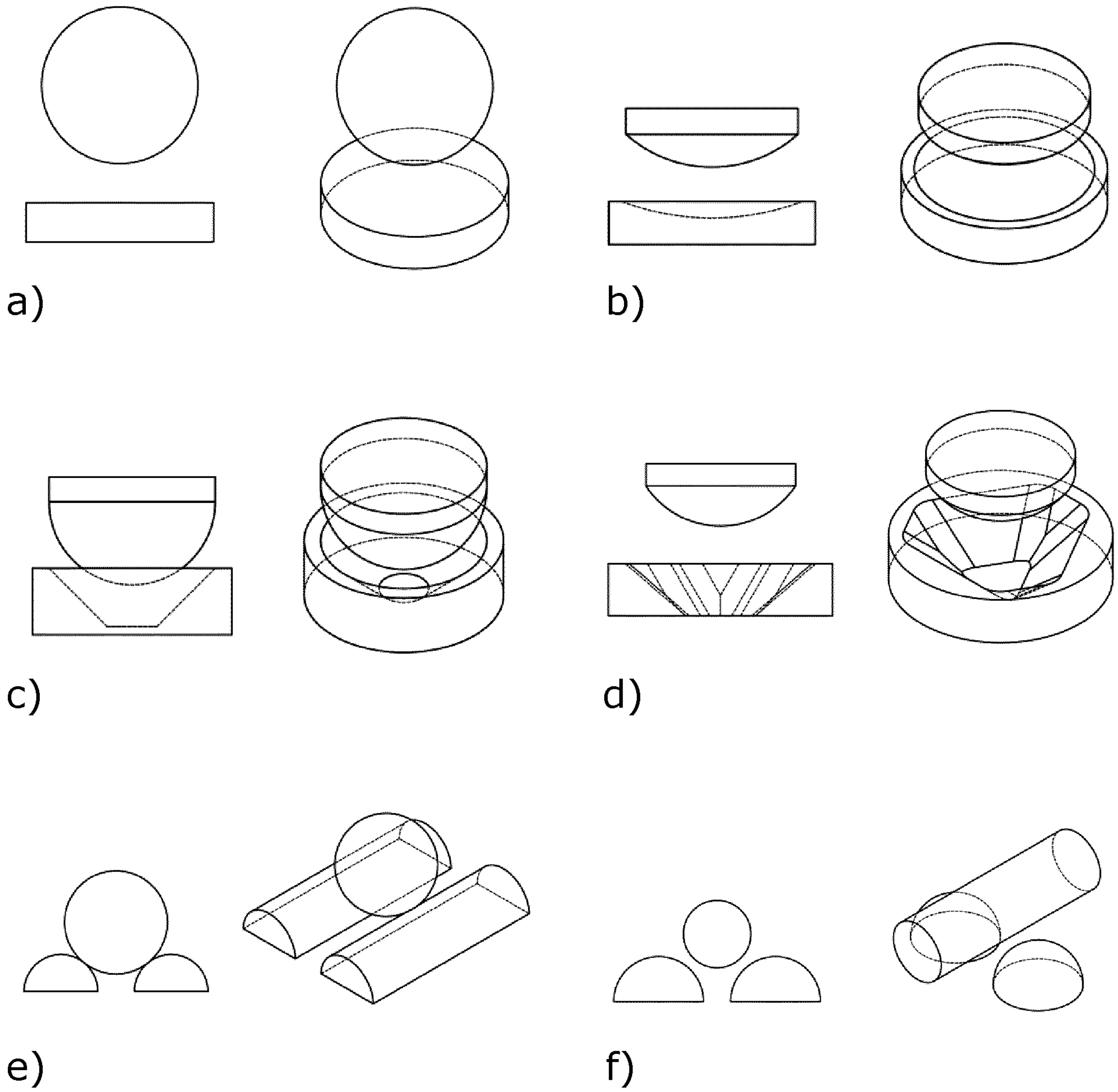
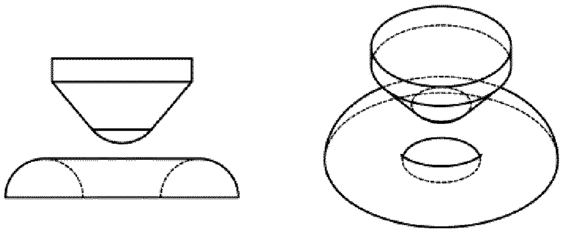
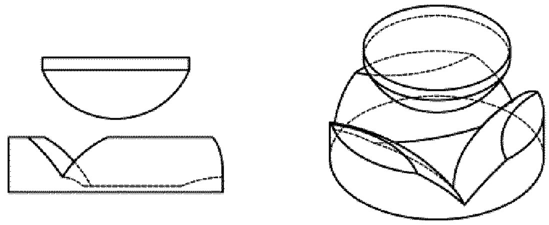


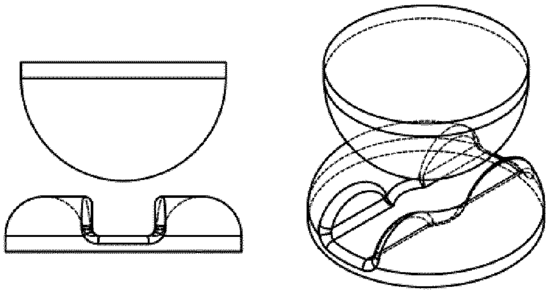
Fig. 8



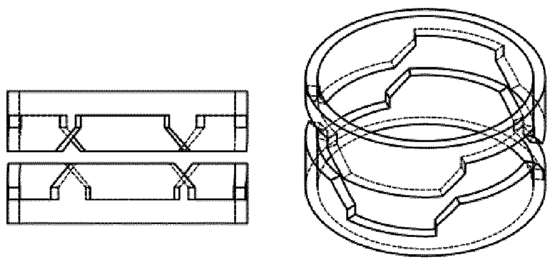
g)



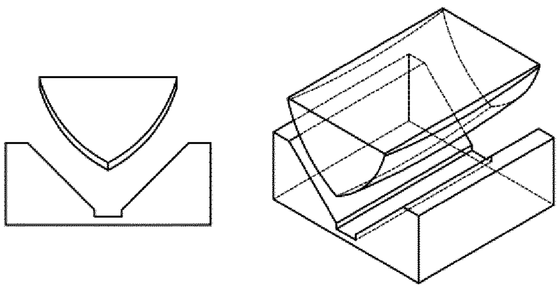
h)



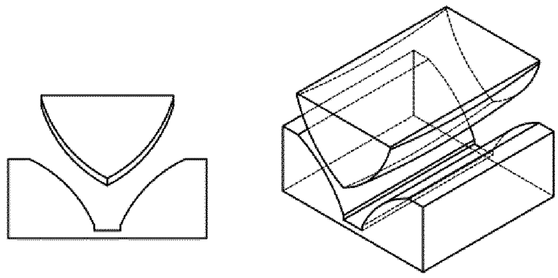
i)



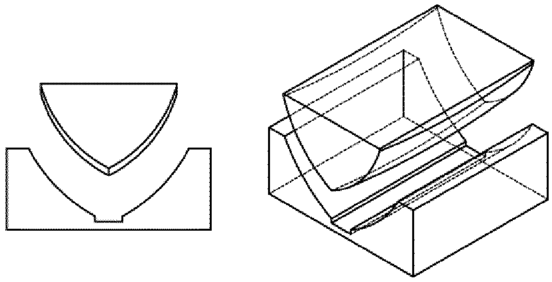
j)



k)

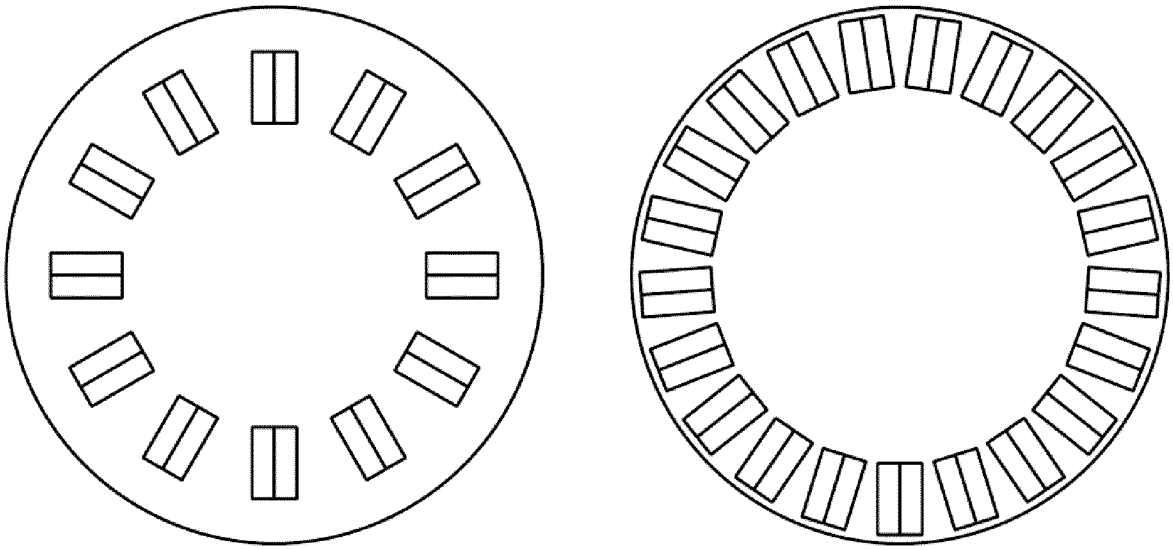


l)



m)

Fig. 8, cont.



a) b)

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/086322

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B5/00 G02B7/00
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 G02B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	GB 2 493 214 A (TAYLOR HOBSON LTD [GB]) 30 January 2013 (2013-01-30) the whole document	1,3-5,7, 9-15 1-15
X Y	US 2002/148392 A1 (WELLS PETER J [GB] ET AL) 17 October 2002 (2002-10-17) paragraph [0005] paragraph [0015] - paragraph [0036]; figures 1-5	1,2,6, 14,15 1-15
Y	US 2010/149550 A1 (DIEFENBACHER ROLF [CH] ET AL) 17 June 2010 (2010-06-17) the whole document	1-15

-/--

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 March 2020	16/03/2020

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	Gomez, Adriana

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/086322

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6 182 582 B1 (BAILEY DAVID ARTHUR [US] ET AL) 6 February 2001 (2001-02-06) abstract column 1, line 6 - column 1, line 10 column 2, line 8 - column 4, line 22; figures 2-6 -----	1-15
A	US 2016/069506 A1 (SHELEF BEN [US] ET AL) 10 March 2016 (2016-03-10) the whole document -----	1-14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/086322

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
GB 2493214	A	30-01-2013	GB 2493214	A	30-01-2013
			WO 2013017834	A1	07-02-2013
US 2002148392	A1	17-10-2002	AT 337515	T	15-09-2006
			DE 60214067	T2	11-01-2007
			EP 1243842	A1	25-09-2002
			JP 4138347	B2	27-08-2008
			JP 2002364799	A	18-12-2002
			US 2002148392	A1	17-10-2002
US 2010149550	A1	17-06-2010	EP 1574817	A1	14-09-2005
			EP 1725833	A2	29-11-2006
			US 2010149550	A1	17-06-2010
			WO 2005088242	A2	22-09-2005
US 6182582	B1	06-02-2001	NONE		
US 2016069506	A1	10-03-2016	EP 2981398	A1	10-02-2016
			US 2016069506	A1	10-03-2016
			WO 2014165828	A1	09-10-2014