



- (51) **International Patent Classification:**
G01N 19/02 (2006.01)
- (21) **International Application Number:**
PCT/IB2016/051297
- (22) **International Filing Date:**
8 March 2016 (08.03.2016)
- (25) **Filing Language:** Italian
- (26) **Publication Language:** English
- (30) **Priority Data:**
MI2015A000348 9 March 2015 (09.03.2015) IT
- (71) **Applicant:** POLITECNICO DI MILANO [IT/IT]; Piazza Leonardo da Vinci 32, 20133 Milano (IT).
- (72) **Inventors:** CHELI, Federico; Piazza Leonardo da Vinci 32, 20133 Milano (IT). BRAGHIN, Francesco; Piazza Leonardo da Vinci 32, 20133 Milano (IT). MILANI, Damiano; Piazza Leonardo da Vinci 32, 20133 Milano (IT). BELLONI, Edoardo; Piazza Leonardo da Vinci 32, 20133 Milano (IT).
- (74) **Agent:** SIMINO, Massimo; C.so di Porta Romana 23, I-20122 Milano - Mi (IT).
- (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, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, 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))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) **Title:** TRIBOMETER AND METHOD OF MEASURING THE SLIDING FRICTION COEFFICIENT

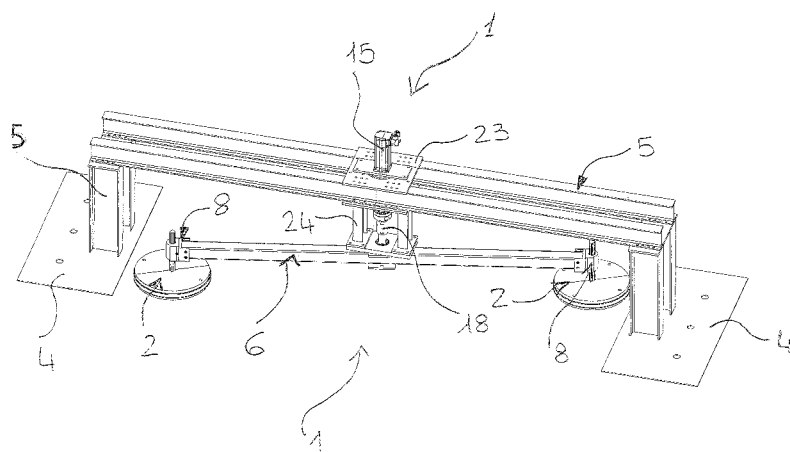


Fig. 1

(57) **Abstract:** A tribometer (1) for measuring the sliding friction of a test piece of a material to be tested on a sliding surface, comprises a ground-supported fixed support structure (5) and a rotating support structure (6), which is supported to rotate about a rotation axis (Y-Y) together with opposite test piece holders (2), said test piece holders (2) being connected in rotatably joined relationship to said rotating support structure (6) at a preset distance (D) from said rotation axis (Y-Y).

"Tribometer and method of measuring the sliding friction coefficient"**DESCRIPTION**

5 The present invention relates to a tribometer as defined in the preamble of claim 1, i.e. an instrument for measuring the sliding friction of a material on a surface. Particularly the invention relates, without limitation, to measurement of friction between a fabric and the ground, e.g. a surface covered with frost or snow, but may be also related to measurement of sliding friction between other
10 types of materials and surfaces, e.g. between a tire tread and asphalt.

For simplicity, reference will be made hereinafter without limitation to measurement of the sliding friction value of a fabric on a surface covered with frost or snow.

With special reference to winter sports equipment, such as skis,
15 snowboards or ice skates, it is highly important to study and check the behavior of soles, blades and the like in contact with a surface covered with snow. This is useful in view of testing and improving their performance, i.e. their sliding performance and/or developing new formulations to be used for soles or ski waxes .

20 With special reference to competition clothing for speed winter sports, it should be noted that the studies conducted heretofore have been aimed at reducing the aerodynamic drag of fabrics, and no attention has been paid to the behavior of these fabrics upon contact with a ground covered with snow, which may occur when an athlete falls. It should be understood in this respect that, in
25 a downhill ski competition, if an athlete falls, then a reduced friction of

competition clothing on snow might cause the athlete to crash at high speed into the protection barriers, even after sliding for a long time on the snow slope. Therefore, competition clothing materials should be appropriately tested even for friction.

5 It shall be further noted that, for winter tires, it is highly important to develop compounds that are able to provide optimized grip on snow, which entails the need to be able to measure friction of the various compounds on ice.

 In view of fulfilling the aforementioned needs by allowing measurement of the sliding friction of a material on a surface, various types of
10 testing/measuring equipment have been developed, none of which is satisfactory from a variety of points of view.

 Thus, for example, JP-2011149870 relates to a device that can create a frozen surface upon which friction tests may be made on various materials. It shall be nevertheless noted that this device was conceived for laboratory use, and
15 cannot be used for field tests, because the device is not designed to be transported. Also, the friction test is carried out by placing the test piece holder with the material to be tested in contact with a rotating cylindrical surface upon which an ice layer has been formed.

 It shall be noted in this respect that the trueness of measurements taken on a
20 frozen or other surface reproduced in a laboratory is undoubtedly penalized as compared with field measurements, i.e. taken on the real surface, be it a snow slope or an asphalt road. A similar problem is found in the apparatuses as disclosed in prior art documents JP-2010249693 and JP-08166339.

 EP-1720620-A1 relates to an apparatus for measuring the friction coefficient of
25 a ski wax, which is applied to the surface of a rotating disk rotated relative to a

frozen surface against which it is pressed into contact. Advantageously, this apparatus has a structure that allows transportation thereof, such that field measurements can be taken, and the problems encountered in the above discussed prior art can be avoided. Nevertheless, it shall be noted, concerning

5 EP-1720620-A1 that the contact force of the rotating plate against the frozen surface is exerted by a spring, whereby the measurement obtained thereby is affected by the force constancy of that particular spring. Furthermore, it shall be noted that the rotation of the table about its axis strongly affects the precision of measurements, due to the large kinematic differences between the

10 various points of the material being tested, as a result of the rotation of the table about its own rotation axis.

A similar high imprecision in friction coefficient measurements is associated with the use of the apparatus of the prior art document US 4051713, in which the disk-shaped test piece holder 24 is rotated about its center. Also, referring

15 to the apparatus of the prior art document US 4051713 it shall be noted that the disk-shaped test piece holder of the apparatus is pressed on the surface to be tested by the weight force of the whole rotating structure, whereby the surface to be tested must be perfectly coplanar to ensure that a uniform pressure is exerted on all the supports.

20 The present invention is based on the problem of conceiving a tribometer having structural and functional characteristics that allow transportation and placement thereof in the field, such that measurements can be taken on a natural surface and not on a sample surface reproduced in a laboratory, while ensuring precision and reliability of measurements and obviating the

25 aforementioned prior art drawbacks.

This problem is solved by an apparatus for measuring the sliding friction of a material on a surface as defined in claim 1.

In a further aspect, the problem is solved by a method of measuring the sliding friction of a material on a surface as defined in claim 21.

5 Further features and advantages of the apparatus for measuring the sliding friction of a material on a surface and the associated measuring method will be apparent from the following description of one preferred exemplary embodiment thereof, which is given by way of illustration and without limitation with reference to the accompanying figures, in which:

10 - Figures 1 and 2 show perspective view of a tribometer of the invention at two different operation times;

- Figure 3 shows a front plane view of the tribometer of the invention;

- Figure 4 shows a top plane view of the tribometer of the invention;

- Figure 5 is a front plane view of a central portion of the tribometer of

15 Figure 3;

- Figure 6 is a perspective view of a test piece holder of the tribometer of the invention;

- Figure 7 is a top plane view of the test piece holder of Figure 6 and

- Figure 8 is an exploded perspective view of the test piece holder of

20 Figure 6.

Referring to the accompanying figures, numeral 1 generally designates a tribometer of the invention, which is an instrument for measuring the sliding friction of a test piece of a material to be tested, not shown, on a sliding surface, also not shown.

25 Reference will be expressly made hereinafter, without limitation, to a fabric as

the material to be tested and to a surface covered with frost or snow as a sliding surface.

The tribometer 2 comprises a framework having support bases 4 which allow it to be placed upon the aforementioned sliding surface. Preferably, the bases 4
5 have holes or other means for securing them to the sliding surface.

The tribometer 1 also comprises a test piece holder 2 having a first side for application of the test piece, or sample, of the material to be tested on the sliding surface. Namely, this side is the underside of the test piece holder 2, i.e. the side of the test piece holder 2 that is designed to face the underlying
10 sliding surface when the tribometer is installed for use, whereby the aforementioned test piece of the material to be tested. applied to such first side of the test piece holder 2 contacts the underlying sliding surface.

According to the preferred embodiment as shown in the figures, the tribometer 1 is shown to have two distinct test piece holders 2, which are
15 placed in such positions as to compensate for the effect of centrifugal forces during use of the tribometer, as better shown hereinafter.

Furthermore, the tribometer 1 comprises:

- means for moving each test piece holder 2 relative to the framework 3, such that, in use, the test piece of the material to be tested, applied to the
20 aforementioned first side of each test piece holder 2, is caused to slide on the sliding surface, and

- means for measuring the resistance to movement of the two test piece holders 2 relative to the framework 3.

Advantageously, the aforementioned framework 3 comprises:

- 25 - a fixed support structure 5 which defines a bridge structure extending

between the opposite support bases 4, the aforementioned bridge structure actually projecting upwards from an underlying ideal support plane 19, which is shown in Figure 3 as a broken line that passes through the support bases 4, and

- 5 - a rotating support structure 6 supported by the fixed support structure 5 to be able to rotate about a rotation axis Y-Y substantially perpendicular to the aforementioned ideal support plane 19.

It shall be noted that the aforementioned ideal support plane 19 is the support plane that passes through the support bases 4 of the fixed support
10 structure 5.

If the sliding surface upon which the test pieces of the material are to be tested is horizontal, then the rotation axis Y-Y will be obviously vertical.

Advantageously, each test piece holder 2 is connected via first constraint means 8 to the rotating support structure 6, namely at a preset
15 distance D from the aforementioned rotation axis Y-Y of the rotating support structure 6, whereby each test piece holder 2 is found to be rotatably joined to the rotating support structure 6, but in an eccentric position relative to the rotation axis Y-Y of the rotating support structure 6.

According to the illustrated embodiment, the afore mentioned rotation
20 axis Y-Y of the rotating support structure 6 is external to, i.e. does not pass through said at least one test piece holder 2.

According to an advantageous aspect, with respect to the aforementioned support bases 4, each test piece holder 2 is supported by said framework 3 so as to be able to move with a displacement component along
25 a direction Y-Y substantially perpendicular to the ideal support plane 19,

between:

- a backward end stop position (see Figure 3a), in which each test piece holder 2 is moved backward to a raised position toward the fixed bridge-like support structure 5 relative to said ideal support plane 19, and

5 - a forward end stop position (see Figure 3b) in which each test piece holder 2 would move beyond the aforementioned ideal support plane 19 relative to the fixed bridge-like support structure 5,

it being understood that each test piece holder 2 tends to move toward the aforementioned forward end stop position (see Figure 3b) due to its weight
10 force, and that when the fixed support structure 5 is placed with its support bases 4 supported by a support plane, such support plane acts as a limit to the forward movement of each test piece holder 2 toward the aforementioned forward end stop position, as shown in Figure 3.

Preferably, the aforementioned first constraint means 8 comprise
15 connection means for connecting each test piece holder 2 to the rotating support structure 6, so as to prevent rotation of the respective test piece holder 2 relative to the rotating support structure 6, and more in detail to prevent rotation of each test piece holder 2 about a rotation axis parallel to the rotation axis Y-Y of the rotating support structure 6.

20 According to a preferred embodiment, not shown, the aforementioned first constraint means also comprise hinge connection means for adjusting the inclination of each test piece holder 2 to the rotating support structure 6, such that the orientation of the test piece holder and the test piece of the material to be tested associated therewith may be adapted to the sliding
25 surface upon which the friction test has to be made.

According to a preferred embodiment, the displacement of the test piece holders 2 between the aforementioned backward end stop position (see Figure 3a) and the aforementioned forward end stop position (see Figure 3b), with the aforementioned displacement component directed in the direction Y-Y substantially perpendicular to the aforementioned ideal support plane 19 is provided by the respective first constraint means 8 that connect each test piece holder 2 to the rotating support structure 6.

Preferably, the aforementioned first constraint means 8 ensure a sliding fit between matching profiles to allow the aforementioned at least one test piece holder 2 to move relative to the rotating support structure 6, with a displacement component directed in the aforementioned direction Y-Y substantially perpendicular to the ideal support plane 19, between the backward end stop position and the forward end stop position. This embodiment is particularly advantageous in that it allows only the test piece holder 2 and not the entire rotating structure 6 to vertically move in the direction y-Y relative to the fixed support structure 5, such that precise friction coefficient measurements can be taken:

- only based on the weight force that pushes the test piece holder toward the forward end stop position and
- such that only the masses of the test piece holder 2 and not those of the entire rotating structure 6 will be vertically rigidly moved in the direction Y-Y, which will provide compensation for any misalignment in the plane of the test surface to be tested, thereby ensuring that the same pressure is exerted on the contact surface to be tested by each particular test piece holder 2.

According to the illustrated embodiment, this can be achieved because the aforementioned first constraint means 8 create a sliding form fit between complementary profiles defined by:

- a linear guide 20 extending parallel to the rotation axis Y-Y and projecting out of the upper side of the respective test piece holder 2, and
- a corresponding sleeve 21 oriented with its axis parallel to the rotation axis Y-Y and rigidly joined to the rotating support structure 6, the aforementioned linear guide 20 being inserted into the sleeve 21 by a sliding fit.

It shall be noted that both the linear guide 20 and the sleeve 21 have a cross section along the axis Y-Y that prevents mutual axial rotation there between. In this example, the linear guide 20 has a three-lobed profile, and engages a corresponding three-lobed seat of the sleeve 21.

As an alternative to the above, it will be understood that the aforementioned displacement between the backward end stop position (see Figure 3a) and the forward end stop position (see Figure 3b) of the test piece holders 20, with a displacement component directed in the direction Y-Y substantially perpendicular to the aforementioned ideal support plane 19 may be obtained in various other manners. For example, the cross sectional profile of the guide rod 20 and the axial opening of the sleeve 21 may be changed to a square, triangular, hexagonal or other shape or a dual case may be considered, in which the guide rod is carried by the rotating support structure 6 and the sleeve is rigidly joined to the test piece holder. Alternatively, structurally or functionally different means may be provided. By way of example only, a rack-and-pinion assembly may be implemented,

or each test piece holder may have two or more cylindrical guides (possibly having a circular section) which are offset from each other and slidingly engage in corresponding through openings of the rotating support structure 6.

As a further alternative, the aforementioned displacement of the test piece holders with a displacement component directed in the direction Y-Y substantially perpendicular to the aforementioned ideal support plane 19 is partially or entirely provided by a displacement of the entire rotating support structure 6 relative to the fixed support structure, which is rigidly joined to the sliding surface.

10 According to the illustrated embodiment:

- the aforementioned rotating support structure 6 comprises a rotating cross member 6 extending parallel to the aforementioned ideal support plane 19, so that in use it is substantially parallel to the sliding surface,

- the rotating cross member 6 is rotatably supported by the fixed support structure 5 about a rotation hub 9 which extends through the center of gravity and

- the test piece holders 2 are connected to said rotating cross member at opposite ends of said rotating cross member 6.

The structure of the tribometer 1 should include counterbalancing means for counterbalancing the centrifugal forces caused by the eccentricity of the test piece holders 2 relative to the rotation axis Y-Y. In the illustrated embodiment these means are not required, as the two test piece holders 2 are symmetrically and oppositely arranged with respect to the rotation axis Y-Y of the rotating support structure 6. Namely, referring to the embodiment with two distinct equal test piece holders 2 symmetrically and oppositely arranged

with respect to the rotation axis, a first test piece holder 2 may be properly said to act as counterbalancing means for the other test piece holder 2 and vice versa.

Referring now to the structure of each individual test piece holder 2, it shall be noted that each test piece holder preferably comprises a housing 10, placed above the aforementioned first side, in which interchangeable masses 11 are housed in rigidly joined relationship, such that the weight force that pushes said at least one test piece holder 2 toward said forced end stop position can be modified.

10 Preferably, each test piece holder 2 comprises a disk-shaped element 12 (preferably a disk having a circular section or less preferably an oval or other shape), whose underside defines the aforementioned first side for application of a test piece of the material to be tested.

15 Preferably, each test piece holder 2 comprises a clamping plate 13 which is coupled to a second side of said disk-shaped element 12, opposite to said first side, by removable fastening means, such as screws. Such clamping plate 13 extends along the peripheral portion of the disc-shaped element 12 to define clamping means, together with such peripheral portion of the disc-shaped element 12, for holding the side portions of the test piece of the material to be tested which is applied to the first side of the disc-shaped element 12.

Preferably, the aforementioned clamping plate 3 has a substantially annular shape, whereby the aforementioned housing 10 is delimited by:

- a bottom defined by a central portion of the disc-shaped element 12;
- 25 - side walls defined by the inner annular perimeter of the clamping

plate 13 and

- an upper side defined by a central portion of a closing lid 14 applied to the top to said clamping plate 13 via removable fastening means, such as screws.

5 Preferably, the aforementioned means for moving the test piece holders 2 relative to the framework 3 comprise an electric motor 15, which is rigidly supported by the fixed support structure 5 and has a rotation shaft rotatably coupled to the rotating support structure 6 at the aforementioned rotation axis Y-Y, with a joint 16 interposed there between to compensate
10 for any misalignment between the rotating parts.

Preferably, the aforementioned means for measuring the resistance to movement of the rotating support structure 6 and the test piece holders 2 relative to the fixed support structure comprise:

- a sensor for determining the rotation speed of said rotating support
15 structure 6, e.g. an encoder or another device for sensing the rotation speed of the electric motor 15, and

- at least one sensor for measuring the resistance to forward rotation of the rotating support structure 6 relative to the fixed support structure 5.

According to the preferred embodiment, the tribometer 1 comprises, as
20 a sensor, a torque meter 18 interposed along the rotation axis Y-Y in the kinematic chain that transfers the drive torque from the drive shaft of the electric motor 15 to the second rotating support structure 6, because the resistant torque measured by the torque meter 18 is correlated to the resistance to forward rotation of the rotating support structure 6.

25 It shall be noted in this respect that, during use of the tribometer 1, as

the material test pieces carried by the test piece holders slide, a resistant torque is induced against forward rotation of the rotating support structure 6, which torque is detected by the torque meter 18 and is then correlated to the sliding movement and thus to the friction coefficient to be measured, as well
5 as to the sliding speed and to the force that presses the test piece of the material to be tested against the reference surface.

According to the illustrated embodiment, the rotation axis Y-Y of the rotating support structure 6 is placed at the center line of the bridge structure defined by the support structure 5, with the elements that compose the
10 aforementioned kinematic chain for transferring the drive torque from the drive shaft to the second rotating support structure 6, i.e, the electric motor 15, a speed reducer, the joint 16, the drive 22 of the rotating support structure 6 and the hub 9, arranged in aligned relationship to one another and to the rotation axis Y-Y (see Figure 5).

15 Concerning the fixed bridge-shaped support structure 5, it shall be noted that that the latter preferably consists of a structure whose uprights and cross members are both I-shaped profiles, providing bending strength, as well as a simple and cost-effective construction. At the rotatably supported mechanical parts, fifth wheels and hubs are provided for support.
20 Particularly, as shown in Figure 5, the fixed support structure 5 forms a central support consisting of two support plates 23, offset from each other in the aforementioned axial direction Y-Y and extending perpendicular to the transverse direction, as well as a plurality of connecting uprights 24, extending between said support plates 23.

25 Instead of or in addition to the above, the aforementioned sensor for

measuring the resistance to forward rotation of the rotating support structure 6 relative to the fixed support structure 5 may comprise one or more strain gauges associated with the rotating support structure 6 to measure strain during rotary operation, the strain of the rotating support structure 6 being
5 correlated to the resistance to forward motion of said rotating structure. It shall be simply noted in this respect that, during use of the tribometer 1, as the material test pieces carried by the test piece holders slide, a strain is induced on said rotating cross member 6 is induced, whose amount is correlated to the sliding movement and hence to the friction coefficient to be
10 measured.

Preferably, the tribometer 1 is also equipped with an accelerometer for measuring the acceleration values of the test pieces 2 in a direction parallel to the rotation axis Y-Y of the rotating support structure 6, as accelerations in this direction are caused by jolts or vibrations of the test piece holders 2 as
15 they slide along the sliding surface and may cause errors in the calculation of the friction coefficients when not duly accounted for.

Referring to the maximum linear dimension of the aforementioned first side of the test piece holders 2, e.g. the diameter of the disk-shaped element, and to the aforementioned preset distance D at which each test piece holder 2
20 is supported by the rotation axis Y-Y of the rotating support structure 6, it was experimentally found that, for highly accurate determination of the friction coefficient, the aforementioned preset distance D should be equal to at least twice, preferably at least three times the aforementioned maximum linear dimension d of each test piece holder 2. The compliance with such
25 ratio can considerably reduce measurement errors associated with the fact

that the test piece holders do not move linearly but along a circumference.

Preferably, the tribometer 1 comprises reversible stop means for locking each test piece holder 2 in the proximity of the aforementioned backward end stop position (see Figure 3a), so that the rotating support structure 6 can be set into rotation together with the test piece holders 2 while such test piece holders and the material test pieces to be tested associated therewith are lifted from the underlying sliding surface. Therefore, the tribometer 1 also allows idle/free operation. Measuring resistance to forward rotation of the rotating support structure 6 in the aforementioned idle/free mode is useful to eliminate environmental parameters, e.g. associated with external friction or weather, from measurements being taken, thereby improving measurement accuracy, as confirmed by the method as described below.

According to the invention, a method of measuring the sliding friction of a material on a sliding surface comprises the steps of:

- arranging a tribometer 1 as described above a sliding surface;
- applying a test piece of the material to be tested to said first side of each test piece holder 2;
- arranging the tribometer 1 so that each test piece holder 2 will be raised from the underlying sliding surface;
- setting said rotating support structure 6 into rotation at a first constant rotation speed in said idle/free configuration;
- measuring the resistance to forward rotation of the rotating support structure 6 in said idle/free configuration, while each test piece holder 2, with the test piece of the material to be tested applied thereto, is raised from

the underlying sliding surface, the resistance to forward motion so measured corresponding to the resistance to idle forward rotation of the tribometer 1;

- moving each test piece holder 2 until it rests on said sliding surface with the interposition of said test piece of the material to be tested applied to the first side of each test piece holder 2 and measuring the resistance to forward rotation under load of said rotating support structure 6 during rotation of the rotating support structure 6 at said first constant rotation speed;

- eliminating the resistance to idle forward rotation of the tribometer 1 from said measured resistance to forward rotation under load of the rotating support structure (6), thereby obtaining a net value of resistance to forward motion, which is only caused by the sliding friction of the test pieces of the material to be tested on the sliding surface and

- based on said net value of resistance to forward motion only caused by sliding friction, calculating the sliding friction coefficient of said test piece of the material to be tested on said sliding surface as a function of the contact area between said test piece of the material to be tested and said sliding surface, as well as of the weight force exerted on each test piece holder 2 to move each test piece holder 2 toward said forward end stop position (see Figure 3b).

If the sliding surface is not horizontal but inclined by a given angle α , this shall be accounted for when calculating the friction coefficient, as the weight force component incident perpendicular to the sliding surface will be accordingly smaller.

As clearly shown in the above description, the tribometer of the present

invention fulfills the above mentioned need and also obviates prior art drawbacks as set out in the introduction of this disclosure. The structure of the tribometer 1 can be transported and used even outside a laboratory, e.g. on a ski slope or on a road, thereby allowing measurements to be taken on real sliding surface and not on laboratory-reconstructed sliding surfaces.

Also, the tribometer and process of the invention can provide very accurate friction coefficient measurements with a totally negligible inaccuracy margin, which can be only associated with the accuracy of sensors and the other measuring instruments that are used for measurement.

Advantageously, the tribometer and process of the invention can provide highly accurate friction coefficient measurements, by considerably reducing measurement errors associated with the fact that the test piece holders do not move linearly but along a circumference.

It shall be noted that the tribometer of the invention and the process as discussed hereinbefore can duly account for external environmental factors, such as wind or external temperature, and eliminate such factors from the measurements being taken, thereby improving the accuracy of the friction coefficient values so determined.

Those skilled in the art will obviously appreciate that a number of changes and variants may be made to the tribometer of the invention as described hereinbefore and the method associated therewith to meet specific needs, without departure from the scope of the invention, as defined in the following claims.

*** * ***

CLAIMS

1. Tribometer (1) for measuring the sliding friction of a test piece of material to be tested on a sliding surface, comprising:

- at least one test piece-holder (2) having a first side on which to apply
5 a test piece of material to be tested;

- a support framework (3) for said at least one test piece-holder (2) which is equipped with support bases (4), wherein, in use, said framework (3) supports said at least one test piece-holder (2) above said sliding surface, so that said test piece of material to be tested applied to said first side of said
10 at least one test piece-holder (2) is in contact with said sliding surface;

- means for moving said at least one test piece-holder (2) with respect to said framework (3), so as to determine, in use, a sliding on said sliding surface of said test piece of material to be tested applied to said first side of said at least one test piece-holder (2) and

15 - means for measuring the resistance to movement of said at least one test piece-holder (2) with respect to said framework (3),

characterised in that:

- said framework (3) comprises a fixed support structure (5), projecting from an underlying ideal support plane (19) passing through said support
20 bases (4), and a rotating support structure (6) supported by said fixed support structure (5) so as to be able to rotate about a rotation axis (Y-Y) substantially perpendicular to said ideal support plane (19),

- first constraint means (8) for connecting said at least one test piece-holder (2) to said rotating support structure (6) at a predetermined distance
25 (D) from said rotation axis (Y-Y) of said rotating support structure (6), so as

to rotate as a unit with said rotating support structure (6), and

- with respect to said support bases (4), said at least one test piece-holder (2) is supported by said framework (3) so as to be movable, with a displacement component along a direction (Y-Y) substantially perpendicular

5 to said ideal support plane (19), between:

- a backward end stop position, in which said at least one test piece-holder (2) is moved backward to a raised position toward said fixed support structure (5) with respect to said ideal support plane (19), and

10 • an advanced end stop position in which said at least one test piece-holder (2) goes in front of said ideal support plane (19) with respect to said fixed support structure (5), said at least one test piece-holder (2) being pushed through the effect of the weight force towards said advanced end stop position.

15 **2.** Tribometer (1) according to claim 1, wherein said first constraint means (8) connect said at least one test piece-holder (2) to said rotating support structure (6) so as to prevent a relative rotation of said at least one test piece-holder (2) with respect to said rotating support structure (6), preferably to prevent a rotation about a rotation axis substantially parallel to
20 the rotation axis (Y-Y) of said rotating support structure (6).

3. Tribometer (1) according to claim 1 or 2, wherein said first constraint means (8) make a sliding coupling between matching profiles to allow said at least one test piece-holder (2) to move, with a displacement component directed along said direction (Y-Y) substantially perpendicular to said ideal
25 support plane (19), between said backward end stop position and said

advanced end stop position.

4. Tribometer (1) according to claim 3, wherein said first constraint means (8) make a sliding coupling between matching profiles to allow said at least one test piece-holder (2) to move with respect to said rotating support structure (6), with a displacement component directed along said direction (Y-Y) substantially perpendicular to said ideal support plane (19), between
5 said backward end stop position and said advanced end stop position.

5. Tribometer (1) according to any one of claims 1 to 4, wherein said first constraint means (8) comprise hinge connection means to allow an
10 adjustment of the inclination of said at least one test piece-holder (2) with respect to said rotating support structure (6).

6. Tribometer (1) according to any one of claims 1 to 5, wherein said at least one test piece-holder (2) comprises at least two or more test piece-holders (2) connected to said rotating support structure (6) through
15 respective first constraint means (8), said test piece-holders (2) being positioned with respect to said rotation axis (Y-Y) so as to counterbalance the centrifugal forces due to the eccentricity of the test piece-holders themselves with respect to said rotation axis (Y-Y) of the rotating support structure (6).

20 7. Tribometer (1) according to claim 6, wherein:

- said rotating support structure (6) comprises a rotating cross-member (6) extending parallel to said ideal support plane (19), so that in use it is substantially parallel to said sliding surface,

- said rotating cross-member (6) being supported in rotation by said
25 fixed support structure (5) about a barycentric rotation hub (9) and

- said test piece-holders (2) are connected to said rotating cross-member at opposite ends of said rotating cross-member (6).

8. Tribometer (1) according to any one of claims 1 to 7, wherein said fixed support structure (5) defines a bridge structure extending between said support bases (4).

9. Tribometer (1) according to any one of claims 1 to 8, wherein said at least one test piece-holder (2) comprises a housing (10), positioned above said first side, in which interchangeable masses (11) are housed in a fixedly connected manner, so as to allow the weight force with which said at least one test piece-holder (2) is forced towards said advanced end stop position to be modified.

10. Tribometer (1) according to any one of claims 1 to 9, wherein said at least one test piece-holder (2) comprises a disc-shaped element (12) the lower side of which defines said first side to which a test piece of material to be tested is to be applied.

11. Tribometer (1) according to claim 10, wherein said at least one test piece-holder (2) comprises a clamping plate (13) coupled through removable fastening means to a second side of said disc-shaped element (12) opposite said first side, said clamping plate (13) extending along a peripheral portion of said disc-shaped element (12) to define, with said peripheral portion of said disc-shaped element (12), clamping means with which the hold portions of a test piece of material to be tested applied to said first side of the disc-shaped element (12).

12. Tribometer (1) according to claim 9 and 11, wherein said clamping plate (13) has a substantially annular shape and said housing (10) is

delimited:

- by a bottom defined by a central portion of said disc-shaped element

(12);

- by side walls defined by the inner annular perimeter of said clamping

5 plate (13) e

- by an upper side defined by a central portion of a closing lid (14)

applied at the top to said clamping plate (13) through removable fastening means.

13. Tribometer (1) according to any one of claims 1 to 12, wherein said
10 means for moving said at least one test piece-holder (2) with respect to said framework (3) comprise an electric motor (15) fixedly supported by said fixed support structure (5) and having a rotation shaft coupled in rotation with said rotating support structure (6) at said rotation axis (Y-Y) with interposition of a joint (16) to compensate for possible misalignments.

15 14. Tribometer (1) according to any one of claims 1 to 13, wherein said means for measuring the resistance to movement of said at least one test piece-holder (2) with respect to said framework (3) comprise:

- a sensor for determining the rotation speed of said rotating support structure (6) and

20 - at least one sensor for measuring the resistance to forward rotation of said rotating support structure (6) with respect to said fixed support structure (5).

15. Tribometer (1) according to claim 13 and 14, wherein said at least one sensor comprises a torque meter (18) arranged along said rotation axis (Y-Y)
25 in the kinematic chain to transmit the drive torque from said drive shaft to

said second rotating support structure (6) the resistant torque measured by said torque meter (18) being correlated to the resistance to forward motion of said rotating support structure (6).

16. Tribometer (1) according to claim 14, wherein said at least one sensor
5 comprises one or more strain gauges associated with said rotating support structure (6) to measure the deformation during actuation in rotation, the deformation of said rotating support structure (6) being correlated to the resistance to forward motion of said rotating structure.

17. Tribometer (1) according to any one of claims 1 to 16, wherein said
10 means for measuring the resistance to forward motion of said at least one test piece-holder (2) also comprise an accelerometer to measure the value of accelerations of said at least one test piece-holder (2) in a direction parallel to said rotation axis (Y-Y) of said rotating support structure (6).

18. Tribometer (1) according to any one of claims 1 to 17, wherein said at
15 least one test piece-holder (2) is connected through said first constraint means (8) to said rotating support structure (6) at a predetermined distance (D) equal to at least double, preferably at least triple, the maximum linear dimension (d) of said at least one first side of said at least one test piece-holder (2).

20 19. Tribometer (1) according to any one of claims 1 to 18, comprising stop means for blocking said at least one test piece-holder (2) close to said backward end stop position, so that said rotating support structure (6) can be set in rotation together with said at least one test piece-holder (2) while said at least one test piece-holder (2) is lifted from an underlying support surface.

25 20. Tribometer (1) according to any one of claims 1 to 19, wherein said

rotating support structure (6) comprises counterbalancing means for counterbalancing the centrifugal forces due to the eccentricity of said at least one test piece-holder (2) with respect to said rotation axis (Y-Y).

21. Method for measuring the sliding friction of a material on a sliding surface, comprising the steps of:

- arranging a tribometer (1) according to any one of claims 1 to 20 above a sliding surface;
- applying a test piece of material to be tested to said first side of said at least one test piece-holder (2);
- arranging said tribometer (1) so that said at least one test piece-holder (2) is raised from said underlying sliding surface;
- setting said rotating support structure (6) in rotation with a first constant rotation speed;
- measuring the resistance to forward rotation of said rotating support structure (6) while said at least one test piece-holder (2) and the test piece of material to be tested applied to it is raised from said underlying sliding surface, said measured resistance to forward motion corresponding to the resistance to idle forward rotation of the tribometer (1);
- bringing said at least one test piece-holder (2) to rest on said sliding surface with interposition of said test piece of material to be tested applied to said first side of said at least one test piece-holder (2) and measuring the resistance to forward rotation under load of said rotating support structure (6) during the rotation at said first constant rotation speed of said rotating support structure;
- from said measured resistance to forward rotation under load of said

rotating support structure (6) working out the resistance to idle forward rotation of the tribometer (1), obtaining a net value of the resistance to forward motion due to just sliding friction of said test piece of material to be tested on said sliding surface and

- 5 - based on said net value of resistance to forward motion due to just sliding friction, calculating the coefficient of sliding friction of said test piece of material to be tested on said sliding surface as a function of the contact area between said test piece of material to be tested and said sliding surface, as well as of the weight force acting on said at least one test piece-
- 10 holder (2) to bring said at least one test piece-holder (2) towards said advanced end stop position.

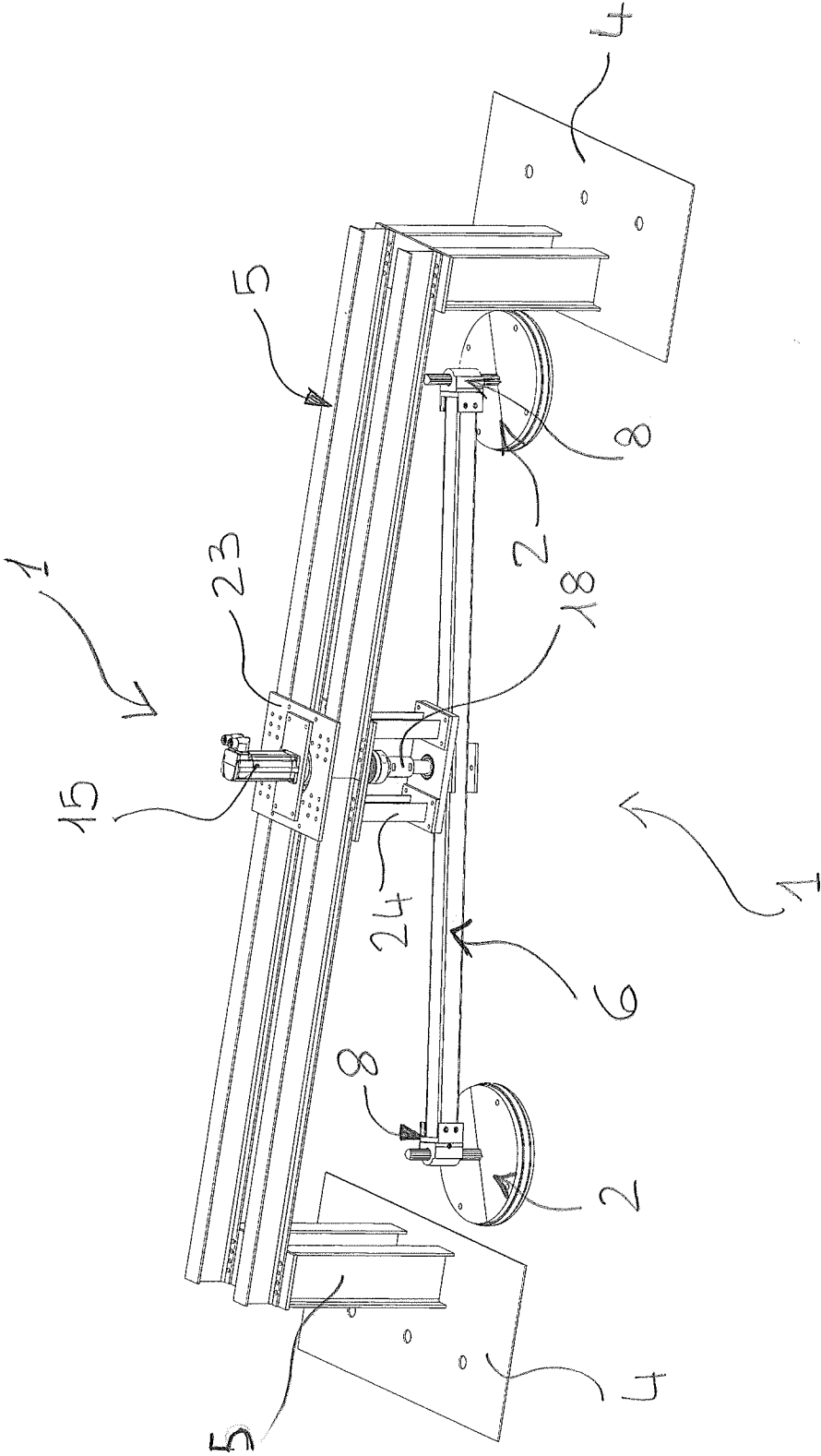


Fig. 1

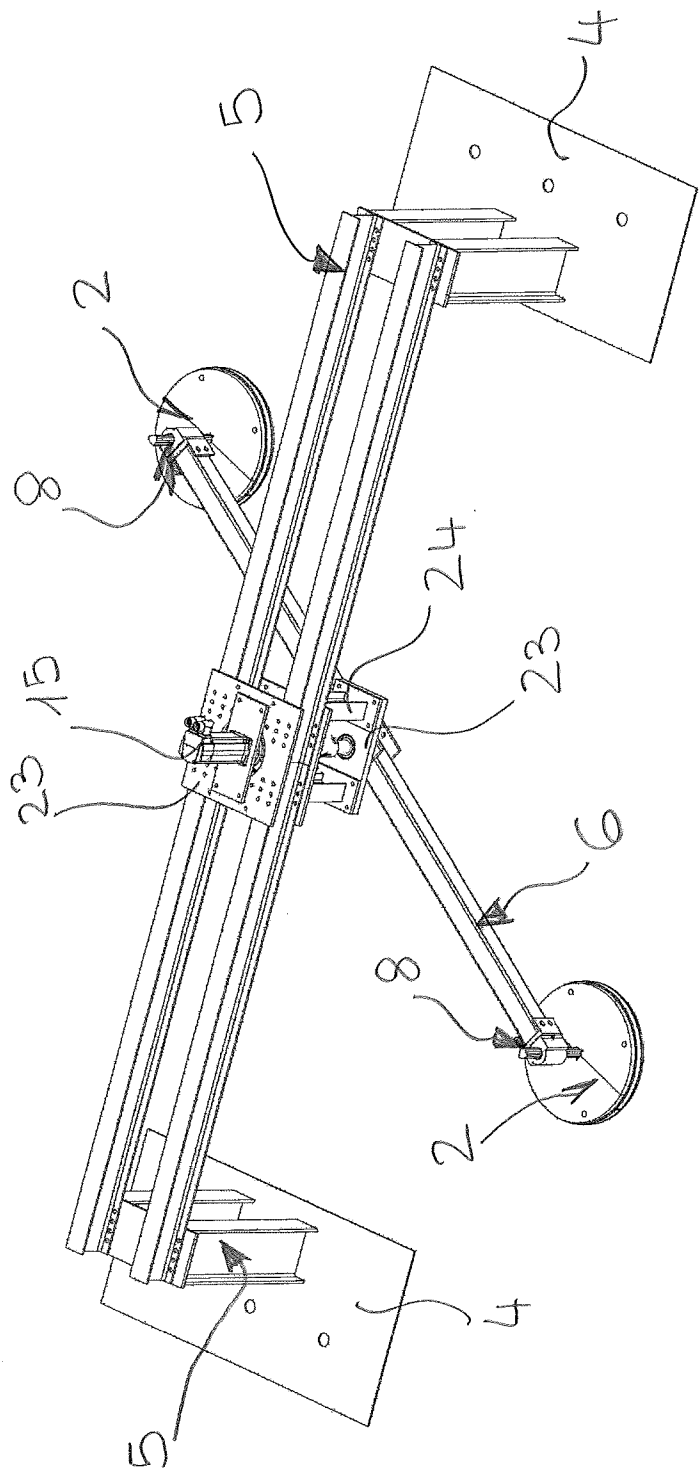


Fig. 2

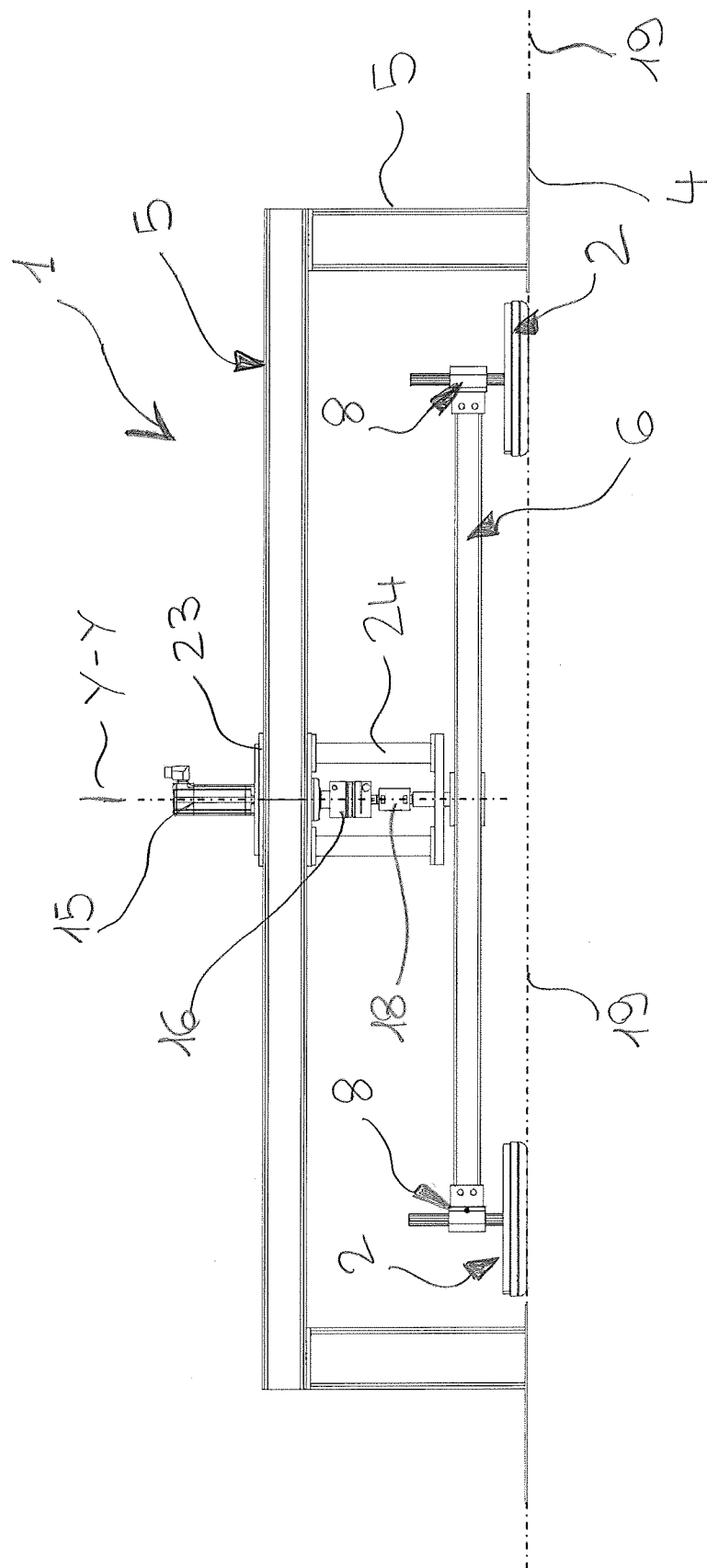


Fig. 3

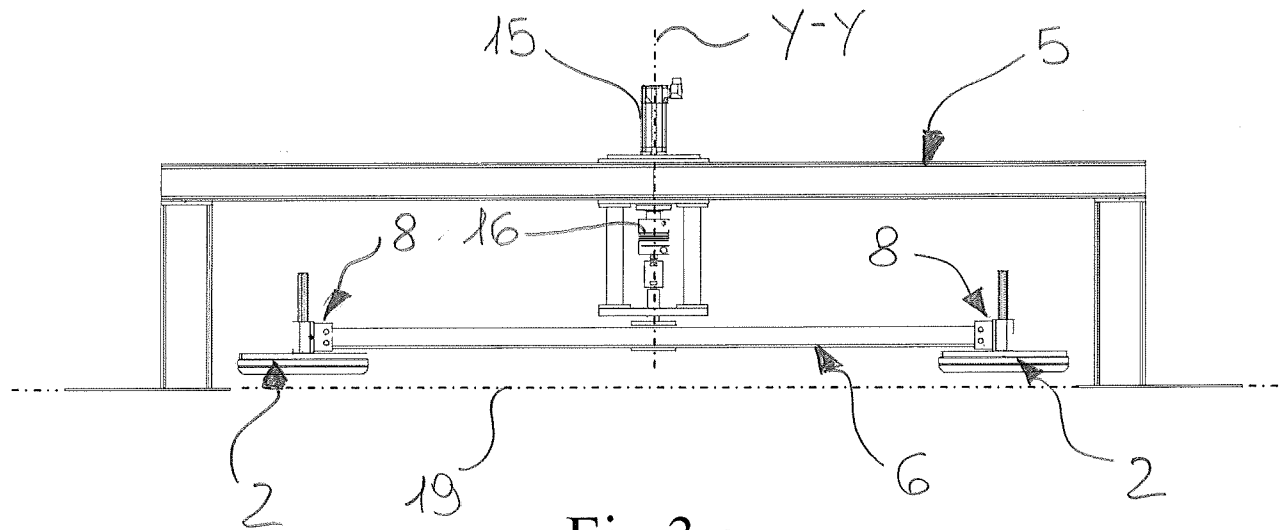


Fig.3 a

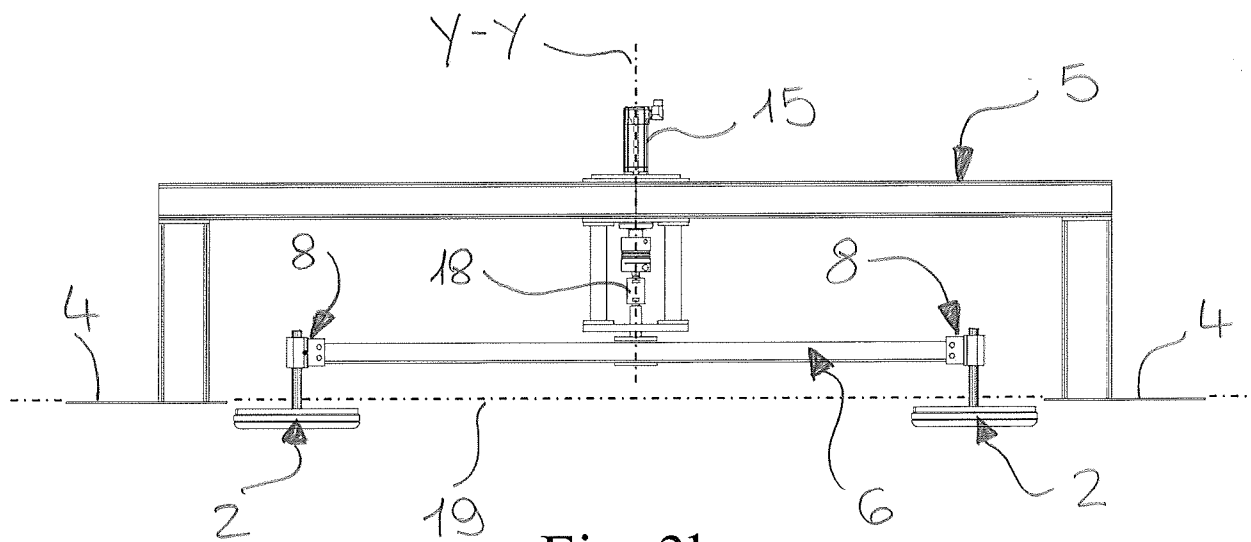


Fig. 3b

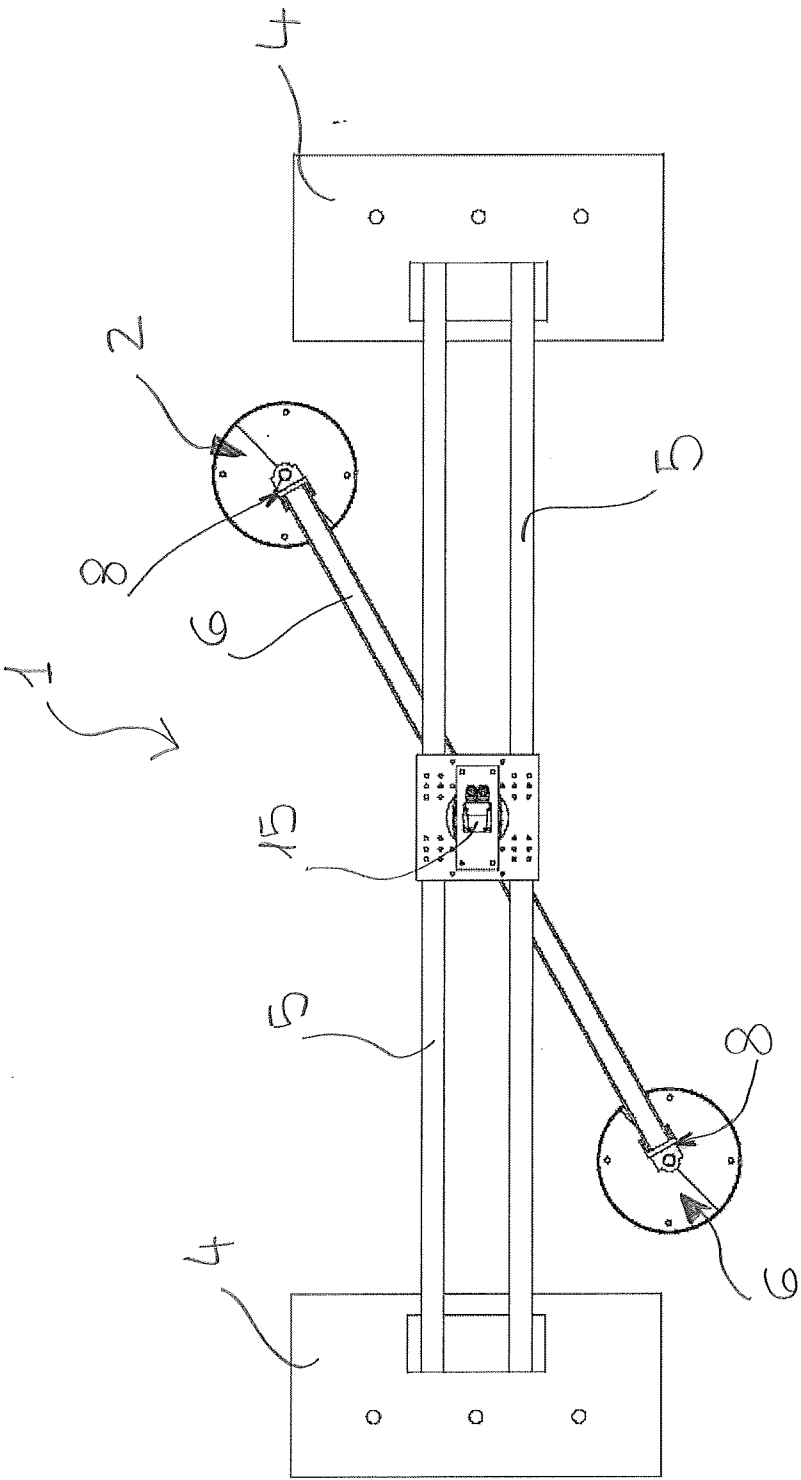


Fig. 4

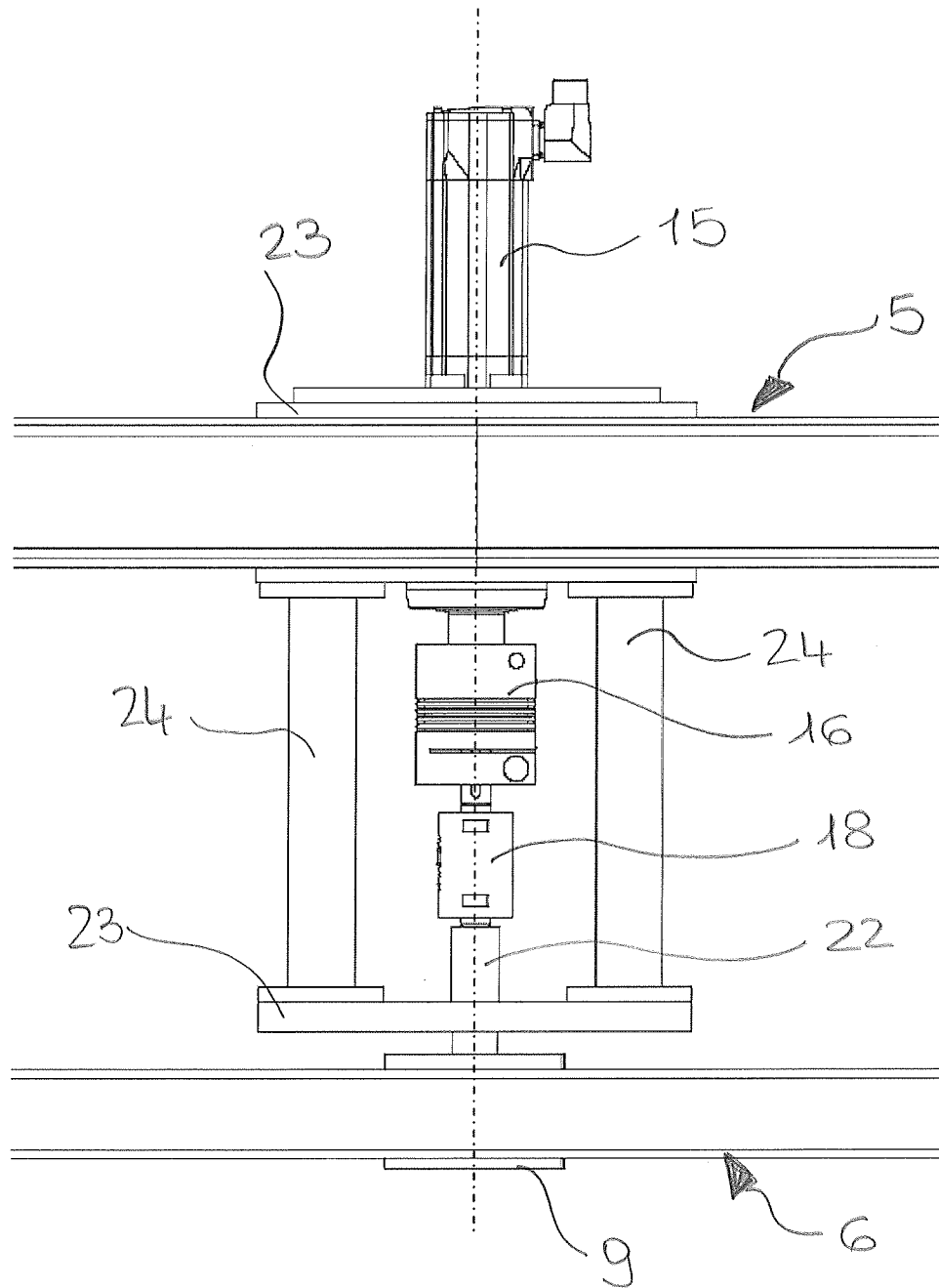


Fig. 5

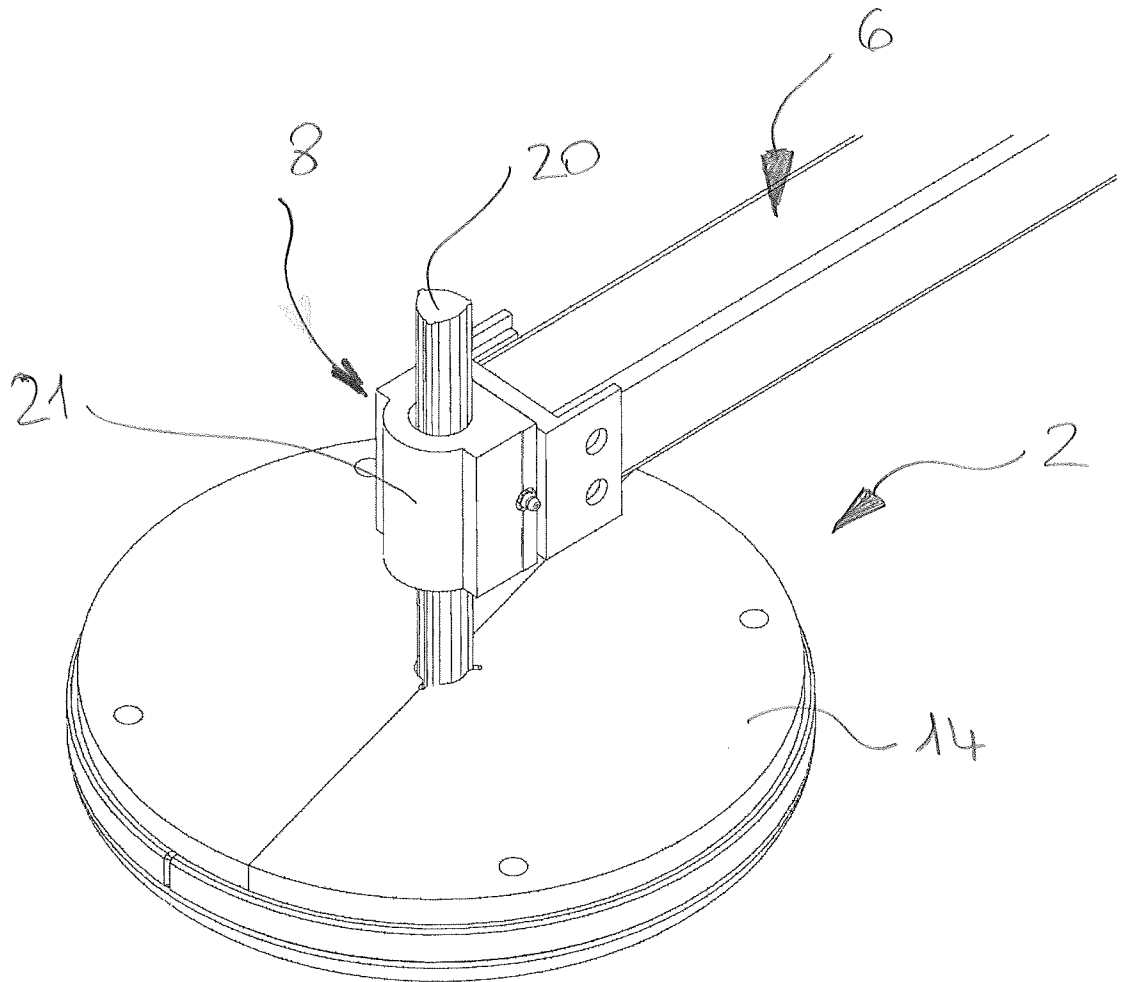


Fig. 6

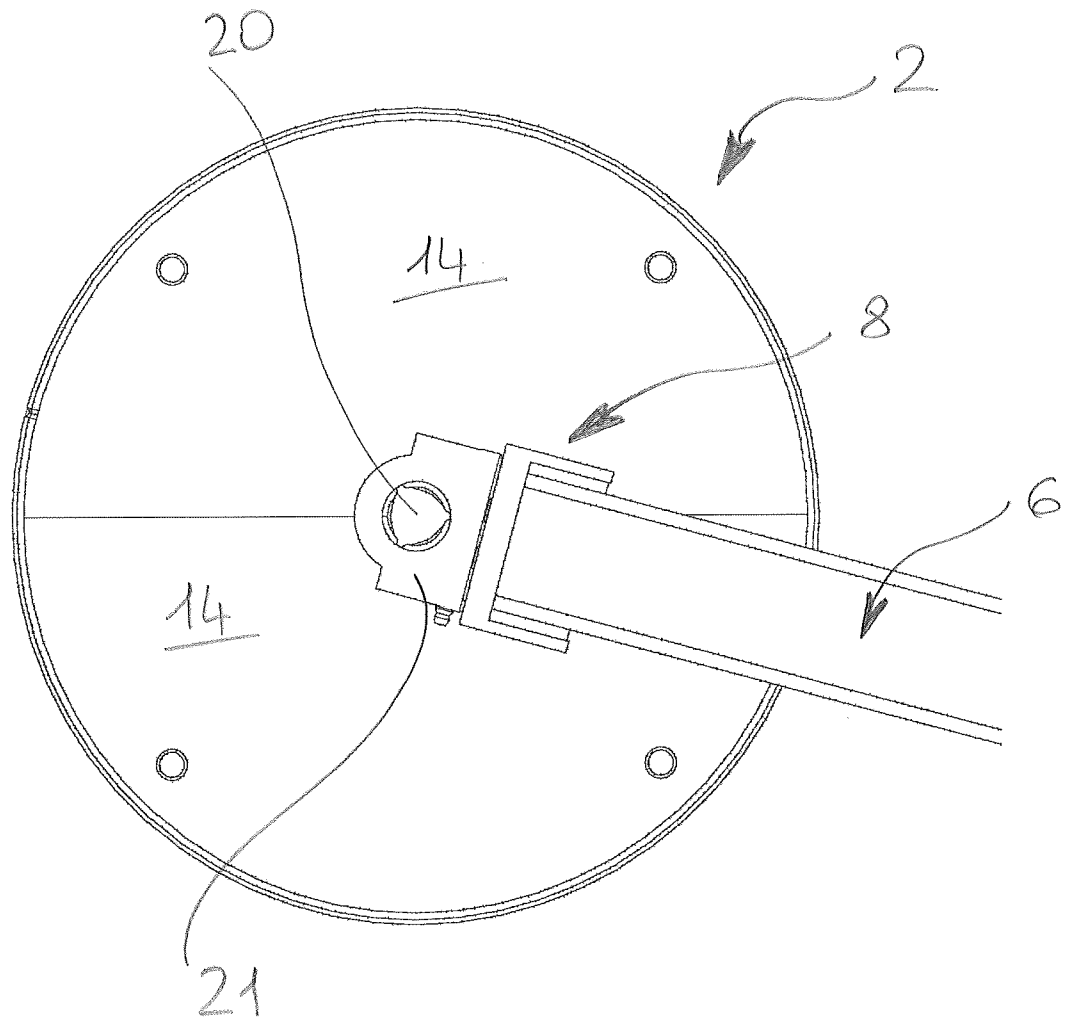


Fig. 7

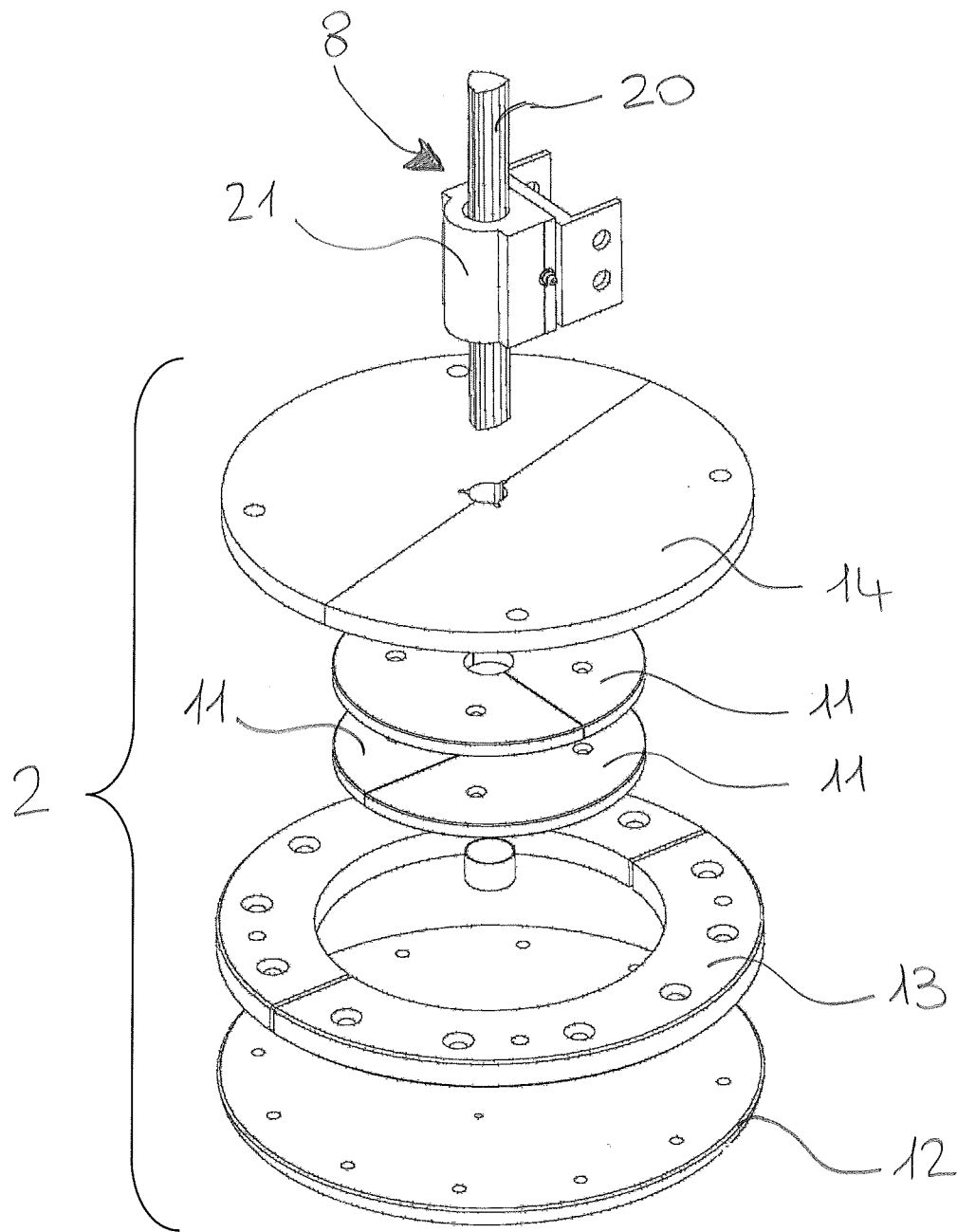


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2016/051297

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N19/02
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)
G01N

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)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 051 713 A (BAO FRANK W ET AL) 4 October 1977 (1977-10-04) the whole document	1-21
A	----- WO 2005/084765 A1 (LACKMAN TOMAS [SE]) 15 September 2005 (2005-09-15) the whole document	1-21
A	----- US 2006/130556 A1 (OLDE WEGHUIS MARINUS H [NL] ET AL) 22 June 2006 (2006-06-22) the whole document	1-21

☐

Further documents are listed in the continuation of Box C.

☒

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

28 June 2016

Date of mailing of the international search report

07/07/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Thomte, Peter

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2016/051297

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4051713	A	04-10-1977	NONE	

WO 2005084765	A1	15-09-2005	EP 1720620 A1	15-11-2006
			NO 327686 B1	14-09-2009
			US 2008163667 A1	10-07-2008
			WO 2005084765 A1	15-09-2005

US 2006130556	A1	22-06-2006	AU 2003266731 A1	23-06-2004
			CN 1717580 A	04-01-2006
			EP 1563276 A1	17-08-2005
			JP 2006506652 A	23-02-2006
			NL 1021957 C2	24-05-2004
			US 2006130556 A1	22-06-2006
			WO 2004051239 A1	17-06-2004
