



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
14.08.2019 Bulletin 2019/33

(51) Int Cl.:
H01R 39/64 (2006.01)

(21) Application number: **19167901.8**

(22) Date of filing: **31.08.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **29.08.2014 NL 2013382**

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
15781446.8 / 3 195 423

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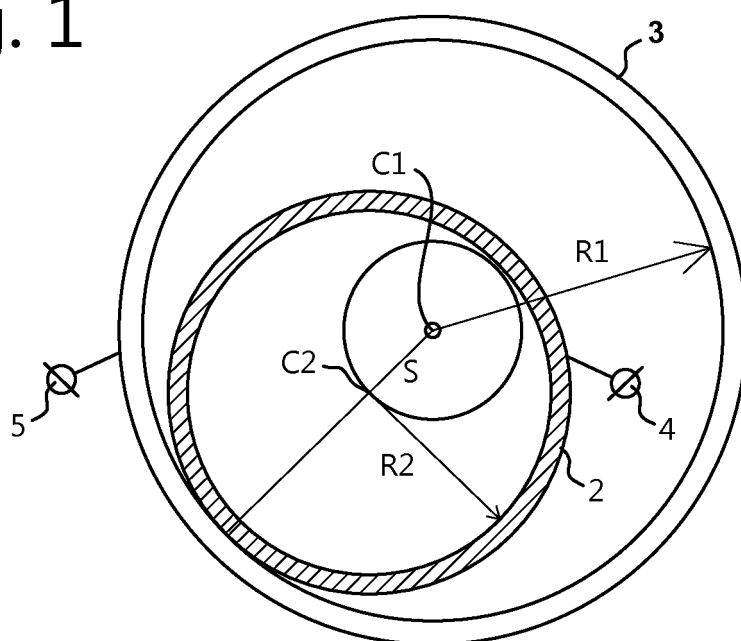
This application was filed on 08-04-2019 as a divisional application to the application mentioned under INID code 62.

(54) **ROTARY ELECTRICAL CONDUCTOR**

(57) The invention relates to Rotary conductor (1,20) comprising a first and second circular bodies (3,22,23) with metal contact surfaces that engage in rolling contact. The metals of the contact surfaces have a predetermined hardness and a corresponding yield pressure, a contact pressure between the contact surfaces being greater or

equal to at least 10%, preferably at least 15% of the yield pressure of the contact surface metal having the lowest hardness. High currents can be transferred between the rolling conductors as well as electrical signals at rates above 1Gb/s.

Fig. 1



Description**Field of the invention**

5 **[0001]** The invention relates to a rotary conductor comprising a first circular body having a first metal circular contact surface, a first electrical terminal attached to the first contact surface, a second circular body having a second metal circular contact surface attached to a second electrical terminal, wherein the first and second metal contact surfaces engage in rolling contact, the metals of the contact surfaces having a predetermined hardness and a corresponding yield pressure.

Background of the invention

10 **[0002]** When electrical current needs to be transferred between parts that show relative rotation, such as machine parts, wind turbines or offshore high voltage swivels, many different solutions are known, some of which allow a limited angle of rotation while others allow unlimited rotational angles.

15 **[0003]** In known slide contacts, such as available from Schleifring or Cavotec, a stack of rings or discs is contacted by one or more sliding contacts or carbon brushes per ring to provide electrical contacts. The slide contacts have several disadvantages such as wear of the contact surfaces. Wear is counteracted by the use of expensive metal alloys and reduced contact pressures between the slide contacts and the rings. Many carbon or composite brushes also contain oil providing lubrication and reducing wear. Typical carbon brushes are used for power transfer, whereas gold or silver brushes are used for transfer of electrical signals.

20 **[0004]** Furthermore, the known slide contacts are sensitive to vibrations, due to the low contact pressures between the sliding contact members and the rings. Too low contact pressures may lead to spark forming. Also, in corrosive environments such as in wind turbines and cranes that are used in maritime environments, the conductivity between the sliding contact members and the rings may decrease due to corrosion. Finally, the known conductors are less suitable for successive smaller rotations or oscillations and changes in the direction of rotation.

25 **[0005]** Another category of current transfer devices is formed by electricity chains connected to machines or robots, which are suitable for limited rotational angles. Despite limited angles of rotation, fatigue loading of the copper conductors by repeated bending may result in a reduced operational life cycle.

30 **[0006]** Other solutions for transferring electric current from a stationary body to a rotating member utilize liquid metal (e.g. mercury), which however is highly toxic and can only be used for transfer of limited power.

35 **[0007]** A rotary conductor is known having coaxial rings, the gap between which is bridged by circular rings that are deformed into a slightly oval shape by the pressures applied. This system is relatively costly due to the expensive gold/silver surface and is subject to fatigue weakening of the deforming rings. Furthermore, the whole conductor needs to be protected against oxidation by preventing oxygen from entering the internals, which would lead to corrosion of the contact surfaces.

40 **[0008]** From US 5,501,604 a rotary conductor according to the pre-amble of claim 1 is known. In this reference a planetary power or signal transmission band-gear system is described in which the flexible metal bands of planet gear assemblies are preloaded against the flexible metal bands of the sun and ring wheels. In so doing, the bands on the planet gear assemblies deform elastically to provide greater area contact, band deformations ranging between 50 μm and 250 μm . The degree of preloading is dependent on the particular application, a device designed for the transmission of power requiring a higher preloading force than that designed for signals only.

45 The power that can be transmitted with the known device is limited in view of the relatively high electrical resistance across the rotating conductors. The lay-out of the known transfer device is relatively complex in view of the combination of the conducting bands with intermeshing gears that drive the rotary motion.

[0009] It is, in view of the above, an object of the present invention to provide a rotary conductor with which high currents can be transferred in a stable and continuous manner between parts that rotate relative to one another. It is a further object of the invention to provide a rotary conductor which is suitable for high speed signal transfer between rotating parts.

50 **[0010]** It is again an object of the present invention to provide a rotary conductor that is of a simple construction and can be easily manufactured, installed and serviced or repaired. It is finally an object of the invention to provide a rotary conductor that has reduced sensitivity to vibrations, corrosion and that can operate reliably when subject to small reciprocating movements.

Summary of the invention

55 **[0011]** Hereto a rotary conductor according to the invention is characterized in that the metals of the contact surfaces having a predetermined hardness and a corresponding yield pressure, a contact pressure between the contact surfaces

being greater or equal to at least 10%, preferably at least 15% of the yield pressure of the contact surface metal having the lowest hardness such that the contact surfaces are smoothed by plastic deformation.

[0012] It was found that by placing the contact surfaces into rolling contact at high contact pressures, a very stable and efficient transfer of electric current can be obtained. It is assumed that due to the high pressures, uneven surface textures in the metal on metal contact surfaces are evened out and the contact surfaces are brought in a closely mating relationship such that a highly conductive current path is established, while wear is prevented by the rolling metal on metal contact. Furthermore, the high pressures ensure that sufficient frictional engagement between the contact surfaces is present to avoid slipping and to ensure a pure rolling motion without requiring the presence of intermeshing teeth.

[0013] During manufacture of the conductor, the contact surfaces are smoothed by any suitable means such as machining, forging, rolling or other methods. However, at microscopic level still significant valleys and peaks remain. To further smoothen the surface of the conductors, the invention teaches to apply prior to and/or during use, the rolling configuration of the conductors at high contact pressures such that the microscopic peaks on the contact surfaces are smoothed by plastic deformation and bright smooth contact surface is obtained.

[0014] By the high rolling contact pressures it was found for copper alloy rings that the Ra value, which is the arithmetic average of the absolute values of profile height variations from the mean line, recorded over the evaluation length, ranged between 1.6 μm and 6.3 μm prior to plastic deformation, while the Ra value after rolling at high contact pressures was found to lie between 0.1 μm and 0.8 μm . The continuous rolling contact at high pressures according to the invention was found to have a fine mechanical "cold forming" effect (plastic deformation), causing a smoothening of the surfaces while also the surface hardness was found to increase (work-hardening) by a factor of 2-2.5 for the investigated copper alloy.

[0015] With the term "yield pressure" as used herein, the pressure is intended at which the deformations in the metal change from being elastic to being plastic. In absence of data for the yield pressure of a particular metal, as an approximation the yield stress can be taken. For instance for a copper alloy of which a yield stress of 120N/mm² is indicated, a contact pressure on this basis is set at least 12 N/mm², preferably at least 18N/mm².

[0016] With the term "rolling contact" as used herein, is meant a movement of one contact surface along the other substantially without any slip between the contact surfaces, one of which rotates around a central axis.

[0017] The "hardness" as defined herein can be measured by the Brinell Hardness (BH), wherein the contact pressure during manufacturing of the conductors by pre-rolling of the contact surfaces, or during use, is about at least 50% of the Brinell Hardness (HB). Hereby plastic deformation of the contact surfaces is achieved. For a copper alloy, the contact pressure on the basis of a Brinell Hardness of between 40 and 45 is set at at least 20-22.5 N/mm².

[0018] The rotary conductor according to the invention may be produced by applying an initial rolling contact of the first and second contact surfaces at an initial relatively high value, the contact pressure during use of the rotary conductor being reduced to 33%- 50% of the initial value. The rotary conductor may comprise a first ring with an internal contact surface, and a second wheel-shaped or ring-shaped conductor of smaller diameter rolling on the internal contact surface. Alternatively, the first rotary conductor may be ring-shaped or wheel -shaped with an external contact surface, one or more second ring- or wheel -shaped conductors rolling along the external contact surface.

[0019] The metals used in the rotary conductor comprise highly conductive metals such as silver, gold, copper and aluminium or an alloy thereof.

[0020] Preferably, the contact pressure between the first and second contact surfaces is at least 20N/mm² for contact surfaces comprising copper and at least about 40 N/mm² for contact surfaces comprising phosphor bronze

[0021] Although it is preferred that a flat metal on metal contact is established, the rotary conductor according to the invention may have first and second contact surfaces that are provided with meshing teeth in order to counteract any slipping movement.

[0022] The first body may comprise a ring-shaped outer body having an inner contact surface with a first centre line and a first radius, the second body comprising a second circular body having an outer contact surface with a second centre line and a second radius, the second center line being at a distance from the first center line, which distance is smaller than the second radius.

[0023] The outer body may be stationary and the second body may be rotatable around the first centre line, the second terminal comprising a universal joint conductor that is with one end connected to the rotatable inner body and with its other end connected to a rotary support that is situated on the first centre line. The transfer of current via the universal joint provides a stable and reliable solution which does not suffer from vibrations, which allows rotation of the bodies at high speed, which accommodates high-frequency signal transfer and/or transmission of high currents without the risk of spark formation at little loss.

[0024] In an embodiment of a rotary conductor according to the invention, the first conductor is ring-shaped, the second conductor being wheel-shaped, the second conductor having a smaller diameter than the first conductor and having at least a 20% higher yield value than the first conductor. The wheels material is harder than the ring material. The wheels are pre-rolled before assembly of the rotary conductor, and the rings are machined before assembly. After assembly, the rings are rolled by a temporarily higher contact pressure that is sufficient to roll the weaker ring material.

[0025] A further embodiment of a rotary conductor according to the invention comprises at least two outer bodies that are supported in a spaced-apart relationship, each connected to a respective terminal, the inner bodies comprising corresponding spaced-apart ring-shaped members rotatably mounted on a rotary support that is rotatable around the first centre line, about an axis situated at a radial distance from the central first center line. The outer bodies form a stack of ring-shaped conductors, one for each phase of current to be transferred. The inner ring-shaped bodies rotate jointly and roll along the inner tracks of the outer bodies to provide parallel current paths. The current is divided evenly over the various rotating conductors. Hereby it is ensured that even if one conductor would lose proper contact, no sparking and consequent material damage will occur as the other conductors can temporarily accommodate the higher current.

[0026] A further rotary conductor has a first body that comprises a ring-shaped angled contact surface with a central axis, the second body comprising at least one radial angled ring-shaped contact surface rotatably mounted around a radial axis, which axis is rotatable around the central axis of the first body. The conical second bodies that rotate about the radial axis provide for stable and even load distribution on the first ring shaped conductors, allowing high contact pressures while not being subject to wear.

[0027] Preferably the first body is provided with opposed and spaced-apart angled contact surfaces that are each contacted by a respective body having a radial angled ring-shaped contact surface rotatably mounted around a radial axis, which axis is rotatable around the central axis of the first body. In this even load distribution the axial pressures exerted on the first body compensate each other so that high contact pressures are possible.

[0028] The second body may comprises a spring element that contacts the at least one radial contact surface for biasing the radial contact surface in the direction of the central axis. The spring biasing elements provide an adjusting force for equalising the contact forces and for removing any play in the radial direction.

[0029] In a preferred embodiment, the rotary conductor comprises conducting oil between the first and second contact surfaces. Surprisingly it was found that the voltage loss between the conductors is strongly reduced by use of oil film between the rotating bodies. In combination with the high pressure, a reduction in resistance of over 20% could be achieved. The oil used may be insulation oil, such as transformer oil. However, the best results were found when using an oil that is a non-conducting penetrating oil that comprises a suspension of conducting lubricating particles, preferably graphite particles.

[0030] The rotary conductor according to the invention is suitable for conducting currents from the first electrical terminal to the second electrical terminal of at least 10 A, preferably at least 25 A, more preferably at least 100 A. For copper electrodes having a contact surface area of about 2mm^2 , currents of up to 60A/mm^2 were measured at a contact pressure of $100\text{-}150\text{ N/mm}^2$ and of up to $4\text{-}5\text{A/mm}^2$ at pressures of $30\text{-}50\text{N/mm}^2$. For copper electrodes, a minimum pressure of 20N/mm^2 is applied. For electrodes comprising phosphor bronze, currents of up to 40A/mm^2 were achieved at pressures of $40\text{-}600\text{N/mm}^2$.

[0031] The rotary conductor according to the invention can be used in wind turbines, offshore installations such as Floating Production Storage and Offloading vessels (FPSO's), or in machine parts. The rotary conductors can also be used for transmitting electrical signals from one contact surface to the other at data rates of up to 1 Gb/s and higher.

Brief description of the drawings

[0032] Some embodiments of a rotary conductor will by way of non-limiting example be described in detail with reference to the accompanying drawings. In the drawings:

Fig.1 shows a schematic representation of a stationary ring-shaped outer conductor and an eccentric rotating inner conductor,

Figs. 2a and 2b-2c show a schematic cross-sectional view through the contact interface of the conductors prior to, and after rolling contact at high contact pressures, respectively,

Fig. 3 shows a detail of a universal joint conductor connecting to the rotating conductor,

Fig. 4 shows a perspective view of a rotary conductor in a stacked configuration, having a universal joint conductor,

Fig. 5 shows a schematic view of an embodiment with spring-biased conical conductors, and

Fig. 6 shows a side view of the embodiment of fig. 4.

Detailed description of the invention

[0033] Fig. 1 shows a rotary conductor 1 for the transfer of current from a rotating terminal 4 to a stationary terminal 5. In figure 1, conductor 3, in the form of a stationary outer ring, has a first centreline C1, and an internal radius R1 and forms a raceway for second conductor 2, being formed by an inner ring or cylinder having a second centreline C2 at a distance s from first centreline C1 and a radius R2, wherein $s = R1 - R2$. The centreline C2 will move along the circular path with radius s about the first center line C1. The pattern of movement of the terminal 4 connected to the circumference of conductor 2 is formed by the combined rotation about the second center line C2 and the rotation of the center line C2

about C1. In this embodiment, R2 preferably is about the size of R1 so that the curvature of inner and outer rings only slightly differ and a large contact surface for current transfer is available.

[0034] For the following metals, the minimum contact pressures apply:

Metal	HB value	Min pressure N/mm ²
Pure Aluminium	15	7.5
Gold	20	10
Silver	25	12.5
Pure Copper	40	20
Electrical Copper	45	22.5
Phosphor Bronze	90	45
Mild Steel	110	55

[0035] Fig. 2a shows a schematic cross-sectional view through the contact surfaces of conductors 2,3 prior to engaging the surfaces at high contact pressures. The Ra values are relatively high and the contact interface is limited.

[0036] Figs. 2b and 2c show the conductors 2,3 in a contacting and in a separated state, respectively after having been in rolling contact at high contact pressures over a time period of a significant number of cycles, such as during several hours, preferably days. The Ra value has decreased and the number of contact surfaces 2' has increased due to smoothening caused by the plastic deformation.

[0037] Fig. 3 shows a perspective view of the rotary conductor 2, that is supported in a bearing 6 that rotates around the first center line C1. The terminal 4 is formed by a universal joint conductor 7 having a first set of perpendicular hinge axes 8,9 and a second set of perpendicular hinge axes 10,11 connecting to a drive axis 12 along the first center line C1. In this way, the combined translational and rotational movement of the inner conductor 2 are transferred to the rotation of the drive axis 12 about first center line C1. Current from the rotating drive axis 12 can hence be transferred via the universal joint conductor 7 and rotary conductor 2 to the stationary conductor 3.

[0038] Fig. 4 shows an embodiment of a stacked rotary conductor 20 comprising a base plate 21 and two spaced-apart stationary conductors 22, 23 supported by axial supporting rods 24,25 that interconnect the base plate 21 with a top plate 26. A support guiding plate 27 is attached to the base plate 21 so that it can rotate via a bearing construction (that is not shown in the drawing) around the center line C1. A stack of rotating conductors 30, 31 is placed onto the support guiding plate 27, the surfaces of which roll along circular contact surfaces 32,33 of the stacked stationary conductors 22,23 that are mounted on the supporting rods 24,25. Support guiding plates 27, 28 are provided that interact with rotating bearing elements 39,40 which are in line with the conductors 30,31, for providing a stable rolling motion of the conductors 30,31 along the circular tracks of the stationary conductors 22,23. The contact surfaces 30,31 may for instance be provided with teeth that mesh with corresponding teeth of the internal gear plate 37.

[0039] At the top end of the stacked rotary conductor 20, a universal joint conductor 41 connects the conductors 30,31 to the drive member 42, that is rotating around the axis C1.

[0040] Fig. 5 shows an embodiment wherein a first conductor comprises a conical member 50 rotatably supported on a radial axis 51. The radial axis 51 rotates around center line L. The conical member 50 contacts with angled contact surfaces 52, 53 corresponding angled contact surfaces of upper rotary electrode 54 and lower stationary electrode 55. A biasing spring member 56 provides an axially compressive force to maintain a predefined contact pressure between the angled surfaces of the conical member 50 and the upper rotary electrode 54 and the lower stationary electrode 55.

[0041] In fig. 6 it can be seen that rotary electrode 62 comprises upper and lower angled contact surfaces 63,64 that are encased between upper and lower conical electrodes 60,61, such that forces on the electrode 62 balance out and effective current transfer at high contact pressures and high rotational speeds can be obtained. The high contact pressure results in a smooth rolled surface 65.

[0042] With the embodiment according to fig. 6, multiple contact points between the upper and lower electrodes 63, 64 and a number of conical electrodes 60,61 can be constructed such that the current transferred between the electrodes 63,64 and the electrodes 60,61 can be strongly increased.

Claims

1. Rotary conductor (1,20) comprising a first circular body (3,22,23) having a first metal circular contact surface, a first center line (C1) and a first electrical terminal (5) attached to the first contact surface, a second circular body (2,30,31)

having a second metal circular contact surface attached to a second electrical terminal (4) and rotatable about a second center line (C2), wherein the second center line (2) is rotatable about the first center line (C1) wherein the first and second metal contact surfaces engage in rolling contact, the metals of the contact surfaces having a predetermined hardness and a corresponding yield pressure, **Characterised in that** the second circular body (2,30,31) is wheel-shaped and that upon rotation of the second center line (C2) about the first center line (C1), a contact pressure between the contact surfaces is greater or equal to at least 10%, preferably at least 15% of the yield pressure of the contact surface metal having the lowest hardness such that the contact surfaces are smoothed by plastic deformation.

2. Rotary conductor according to claim 1 or 2, wherein prior to use and/or or during use, the contact pressure is about at least 50% of the Brinell Hardness (HB) of the contact surfaces.
3. Rotary conductor according to claim 1, wherein at least one of the metal contact surfaces comprises copper, the contact pressure being at least 20N/mm².
4. Rotary conductor according to claim 1 or 2, wherein at least one of the metal contact surfaces comprises phosphor bronze, the contact pressure being at least 40N/mm².
5. Rotary conductor (1,20) according to claim 1 or 2, wherein the contact pressure between the first and second contact surfaces is at least 20N/mm².
6. Rotary conductor (1,20) according to any of the preceding claims, wherein the first body comprises a ring-shaped outer body (3) having an inner contact surface with a first centre line (C1) and a first radius (R1), the second circular body (2) having an outer contact surface with a second centre line (C2) and a second radius (R2), the second center (C2) line being at a distance (S) from the first center line (C1), which distance (S) is smaller than the second radius (R2).
7. Rotary conductor (1,20) according to claim 6, wherein outer body (3) is stationary and the second body (2) is rotatable around the first centre line (C1), the second terminal (4) comprising a universal joint conductor (7) that is with one end connected to the rotatable inner body (2) and with its other end connected to a rotary support (12) that is situated on the first centre line (C1).
8. Rotary conductor (20) according to claim 6 or 7, wherein at least two outer bodies (22,23) are supported in a spaced-apart relationship, each connected to a respective terminal, the inner bodies comprising two spaced-apart cylindrical members (30,31) rotatably mounted on a rotary support (27) that is placed at a radial distance from the first center line (C1) and that is rotatable around the first centre line.
9. Rotary conductor according to any of claims 1-6, wherein the first body (54,55) comprises a ring-shaped angled contact surface, with a central axis (L), the second body (50) comprising at least one radial angled ring-shaped contact surface (52,53) rotatably mounted around a radial axis (51), which axis is rotatable around the central axis (L) of the first body (54,55).
10. Rotary conductor according to any of the preceding claims, the conductor being suitable for leading currents from the first electrical terminal to the second electrical terminal of at least 10 A, preferably at least 25 A, more preferably at least 50 A.
11. Rotary conductor according to any of the preceding claims, the first conductor being ring-shaped, the second conductor being wheel-shaped, the second conductor having a smaller diameter than the first conductor and having at least a 20% higher yield value than the first conductor.
12. Method of transferring electricity between a first and second circular body in a rotary conductor according to any of the preceding claims, wherein after initial rolling contact of the first and second contact surfaces at an initial relatively high value, the contact pressure is reduced to 33%- 50% of the initial value.
13. Method of transferring electricity between a first and a second circular body in a rotary conductor according to any of the preceding claims, wherein data signals are transferred between the first and second bodies.

Fig. 1

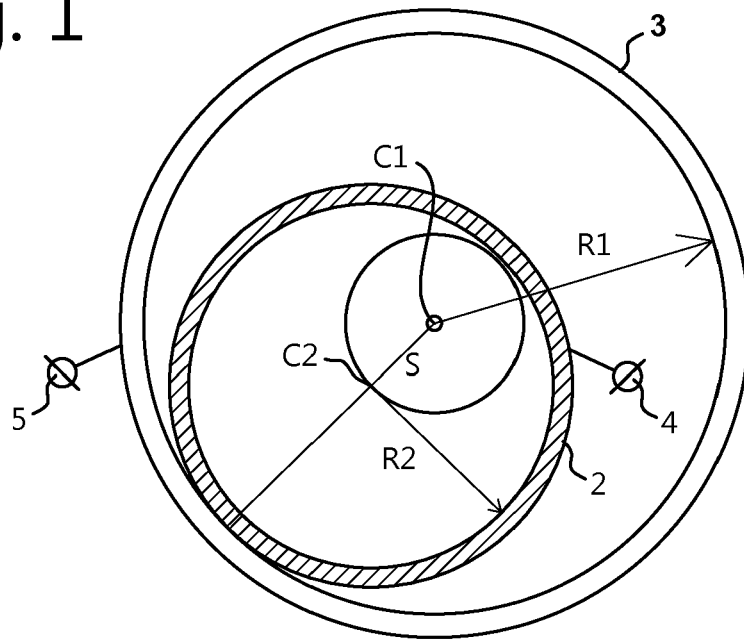


Fig. 3

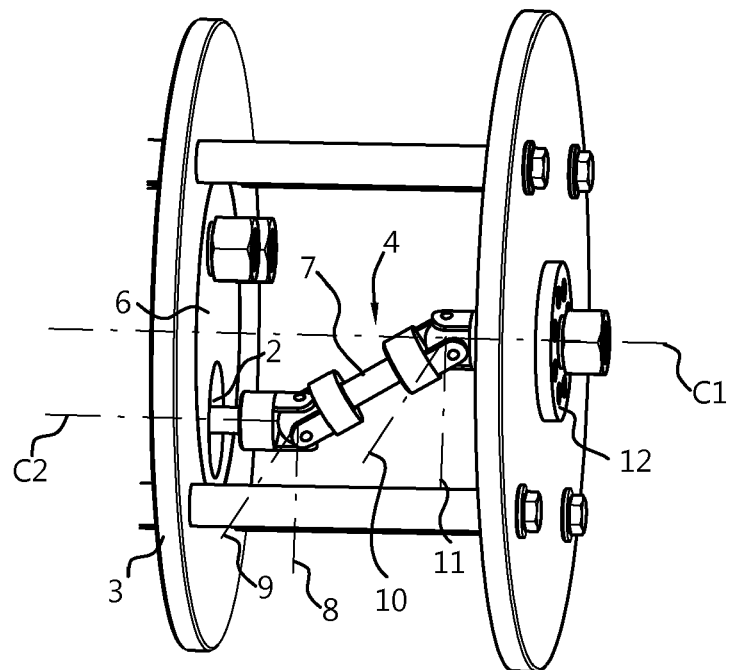


Fig 2a

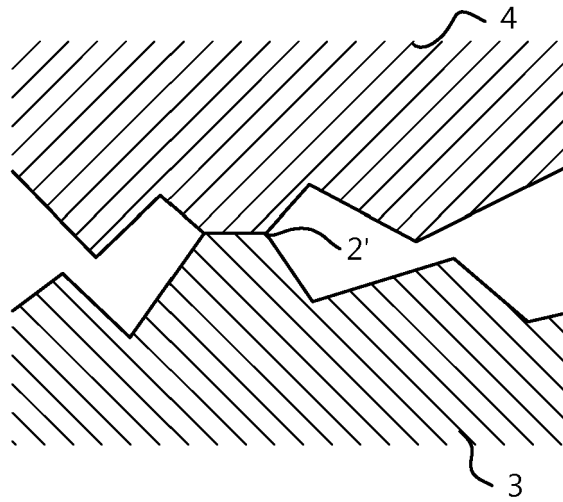


Fig 2b

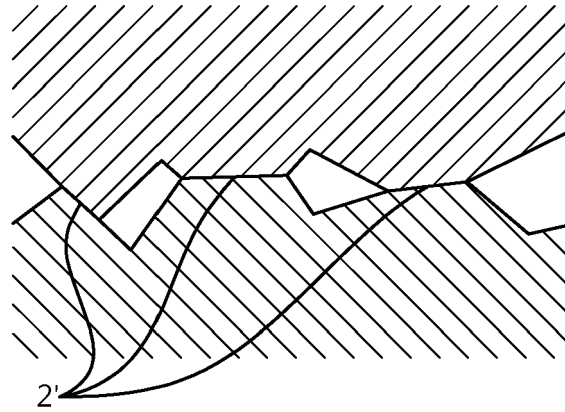


Fig 2c

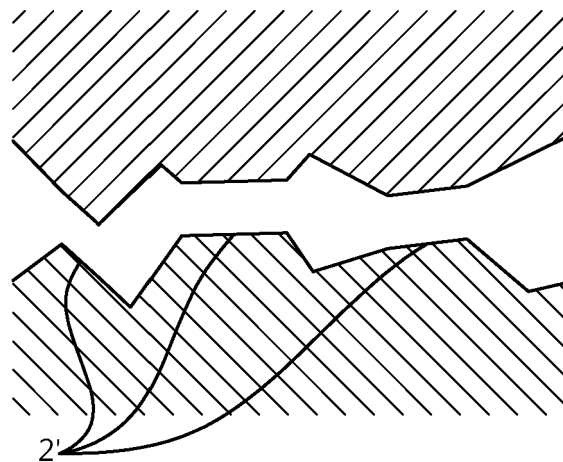


Fig. 4

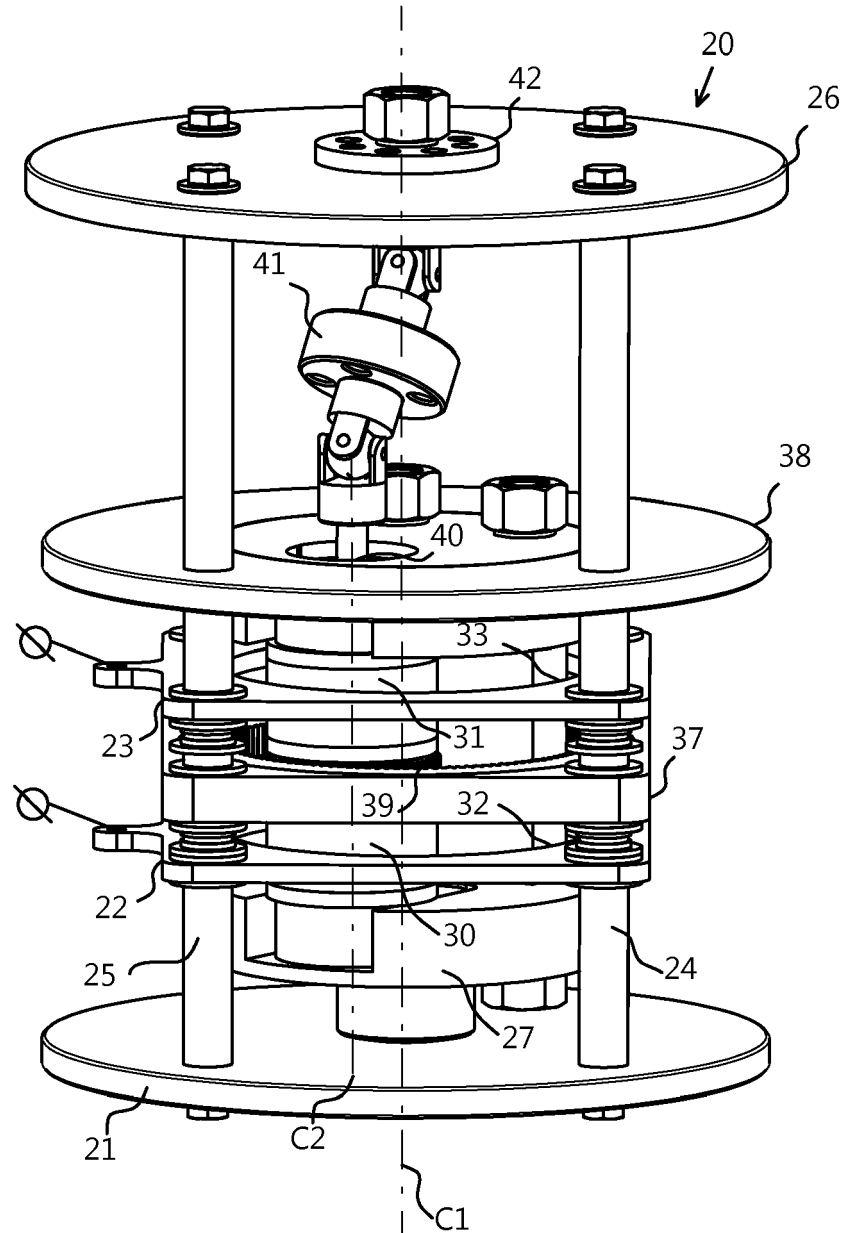


Fig. 5

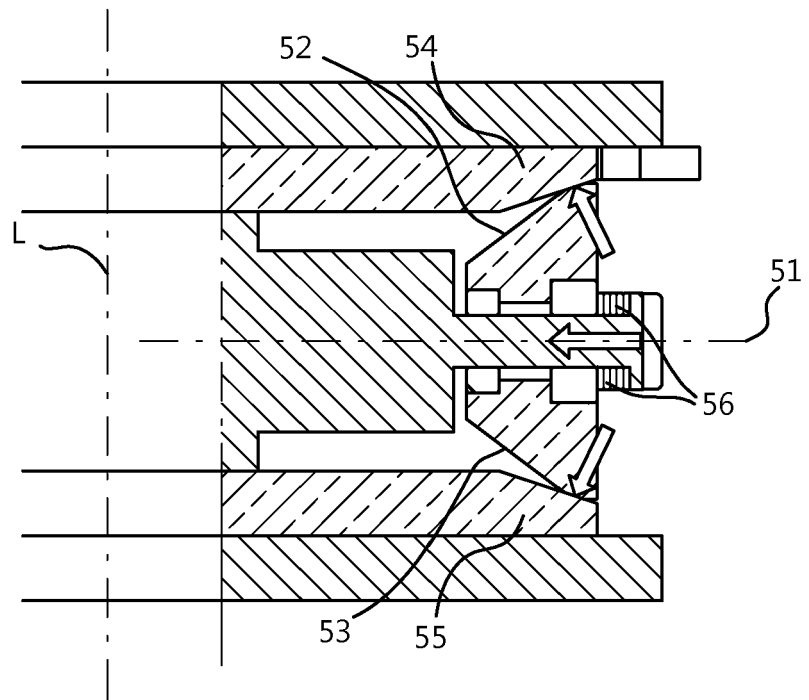
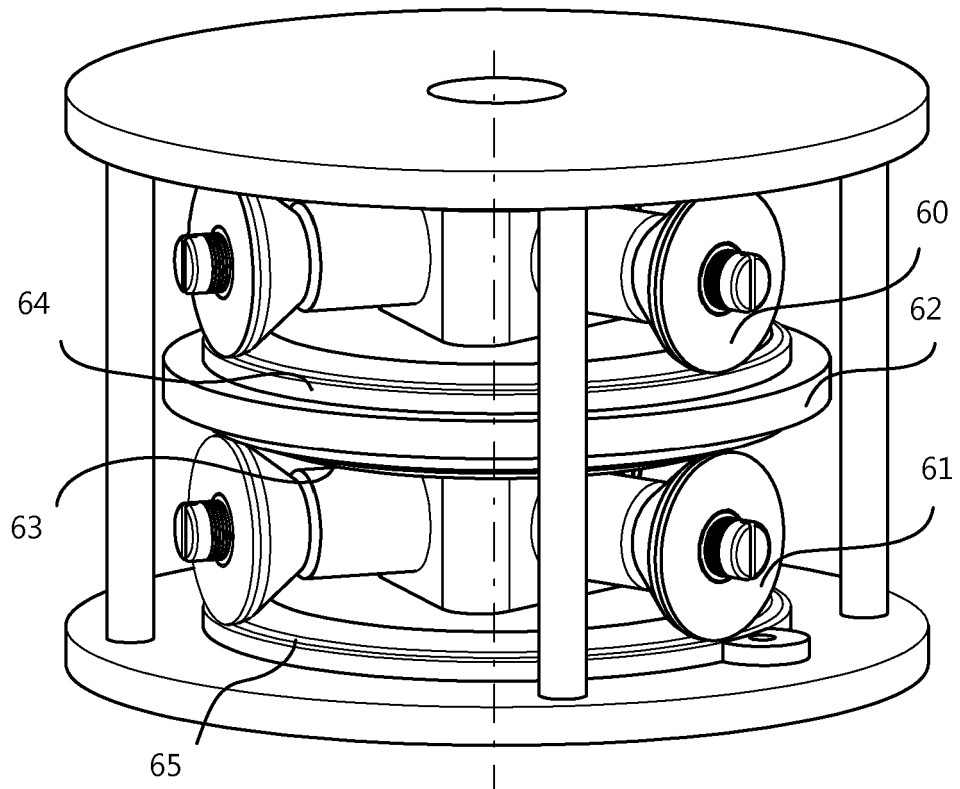


Fig. 6





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 Application Number
 EP 19 16 7901

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Place of search The Hague		Date of completion of the search 24 June 2019	Examiner Criqui, Jean-Jacques
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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