



(51) International Patent Classification:

F16C 11/06 (2006.01) **F16D 3/16** (2006.01)
B25J 17/02 (2006.01) **F16D 3/84** (2006.01)

(21) International Application Number:

PCT/EG20 10/00003 7

(22) International Filing Date:

13 September 2010 (13.09.2010)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

2010071 179 13 July 2010 (13.07.2010) EG

(72) Inventors; and

(71) Applicants : ABOZAIED, AbdAUah Ezzat AbdAllah
[EG/EG]; P.O. Box 108, 5th Settlement (El-Tagamoa El-Khames), Postal code 11835, Helwan ("New Cairo")
(EG). ELSAEID, Ayman, Mahmoud, Mohamed

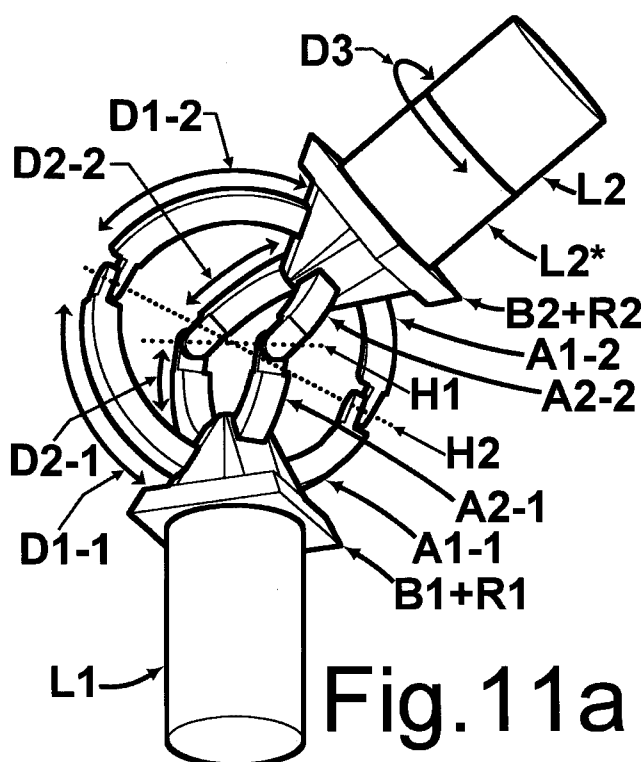
[EG/EG]; 28 st. Mohamed Sakr Kahfagy, first zone, Nasr City, Postal code: 11371, Cairo (EG).

(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, 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, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, 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, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, 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, SE, SI, SK,

[Continued on next page]

(54) Title: JOINT



(57) Abstract: A mechanical joint is disclosed for connecting two mechanical shafts (L1, L2). The joint comprises first and second base members (B1, B2) attached to first and second shaft (L1, L2), a first and a third arc shaped member (A1-1, A2-1), which can slide in the first base member (B1) and a second and a fourth arc shaped member (A1-2, A2-2), which can slide in the second base member (B2). Third and fourth moving members (A2-1, A2-2) are connected to each other by a first hinge (H1). First and second moving members (A1-1, A1-2) are connected to each other by a second hinge (H2). The axes of both hinges (H1, H2) pass through the center point of the joint and are perpendicular to each other. Thus a joint with large deviation without self obstruction or locking is realized.

SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, 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))
- with amended claims (Art. 19(1))

JOINT

Technical Field

The invention is in the field of mechanical mechanisms, specifically mechanisms simulating joints for robotic applications; it is a new mechanism (mechanical configuration) that acts as a 2 degrees of freedom joint suitable for robotic applications. The mechanism can also be used as a constant angular velocity coupling capable of high deviation\inclination angles.

Background Art

In a robotic application, to simulate a ball-joint (with three degrees of freedom) between mechanical parts Links L1 and L2, a mechanism K is installed between them. Since for a revolute joint there are only three rotational degrees of freedom (D1, D2, and D3), no more than three independent actuation inputs should be needed to operate this mechanism. In case more than three inputs are applied, the mechanism is considered redundant and excessively complicated. The common mechanisms currently employed in robotic applications are usually one of two designs:

Mechanism K1 (shown in Fig.1)

- K1 can be broken down to K1a & K1b.
- The 1st degree of freedom D1 is between L1 & K1a.
- The 2nd degree of freedom D2 is between K1a & K1b.
- The 3rd degree of freedom D3 is between K1b & L2.
- The axis of D1 is perpendicular to the axis of D2, and is aligned to the axis of L1.
- The axis of D3 is perpendicular to the axis of D2, and is aligned to the axis of L2.
- All axes of L1, L2, D1, D2, and D3 intersect at a common point C which is also the center of rotation of the ball-joint simulated by this mechanism.

Mechanism K2 (shown in Fig.2) (Also known as Universal Joint, or Hooke's Joint)

- K2 can be broken down to K2a, K2b, & K2c.
- The 1st degree of freedom D1 is between K2a & K2b.
- The 2nd degree of freedom D2 is between K2b & K2c.
- The 3rd degree of freedom D3 is between K2c & L2.
- The axis of D1 is perpendicular to the axis of D2 and L1, and intersects them at C.
- The axis of D3 is perpendicular to the axis of D2, and is aligned to the axis of L2.

- All axes of L1, L2, D1, D2, and D3 intersect at a common point C which is also the center of rotation of the ball-joint simulated by this mechanism.

Note: when saying "the axis of L" where L is a mechanical part, then it is meant the axis lying along L for which the spatial position is of particular interest in the application. For simplicity it is commonly the axis about which the link is geometrically symmetrical in the longitudinal direction (ex: the central axis in a cylindrical link).

Note: when saying "the axis of D" where D is a rotational degree of freedom, then it is meant the axis about which rotation occurs.

Terminology

Coordinates System

In this context the coordinates system used to describe the spatial position of 2nd link L2 relative to the 1st link L1 will be the spherical coordinates system. The standard Cartesian coordinates system may also be used occasionally when needed.

With reference to Fig.3:

- Both coordinate systems will be spatially fixed relative to 1st link L1 with the origins at the center point C which is the center of the ball-joint simulated.
- The Z axis is aligned with the axis of L1, starting from point C and going in the same direction as in the figure.
- Axes X & Y are perpendicular to the axis of L1, starting from point C and going in the same directions as in the figure.
- Θ is the inclination\deviation (or polar angle) it is measured from the zenith direction (Z axis) or the axis of L1 to the axis of L2 as shown in the figure. The range is $[0-180^\circ]$.
- ϕ is the azimuth (or azimuthal angle) and it is the angle measured from the azimuth reference direction (X axis) to the orthogonal projection of the axis of L2 on the reference plane (X-Y plane). The range is $[0-360^\circ]$.

Deviation angle (Θ)

It is an angle measured in the deviation plane between the axes of the two links L1 & L2. It is the angle rotated by link L2 axis from the position where it was aligned with L1 axis (Z axis). The range is $[0-180^\circ]$.

Deviation plane (P)

It is the plane formed by the axes of the two links L1 and L2 when they are not aligned (deviation angle $\neq 0$). This plane contains the axes of the two links. The deviation angle Θ between the two links is measured in this plane.

Notes:

- If the axes of L1 and L2 are aligned (deviation angle = zero), an infinite number of deviation planes can be considered existing or the deviation plane can be considered undefined. In this context it is chosen that an infinite number of deviation planes are considered existing.
- If the axes of L1 and L2 are not aligned, only one deviation plane can be defined.

Mirror plane (M)

A plane passing in center point C and perpendicular to the deviation plane P. it also divides the supplementary angle of the deviation angle ($180 - \Theta$) equally. If the two links L1 and L2 are aligned ($\Theta = 0$) then the mirror plane M is the plane passing through C which is perpendicular to all possible deviation planes.

The two links L1 and L2 are always symmetrical about plane M (hence the name mirror plane).

Twist angle (τ)

It is the angle rotated by a link around its own axis from the position where it is symmetrical to the opposite link about the mirror plane.

Examples on Twist angle for understanding by intuition:

For illustrative purposes, in figures Fig.4a to Fig.4d the 2 links are given a specific cross section along with the joint connecting them, this way any twist that occurs will be noticeable:

- In Fig.4a: Axes of L1 and L2 are aligned ($\Theta = \text{zero}$), and $\tau = \text{Zero}$.
- In Fig.4b: Axes of L1 and L2 are aligned ($\Theta = \text{zero}$), and τ is +Ve.
- In Fig.4c: Axes of L1 and L2 are not aligned, and $\tau = \text{Zero}$.
- In Fig.4d: Axes of L1 and L2 are not aligned, and τ is -Ve.

Note: In all figures, Θ is the deviation angle, and τ is the twist angle.

Locking position

A locking position is a position where the joint is locked and unable to rotate in certain directions. In this position the joint has no complete freedom to rotate in any direction but is constrained to rotate in certain directions (some directions are locked for rotation). This can render some trajectories undoable by the joint or requiring special treatment.

The real reason why a position in the joint workspace becomes a locking position is because at this position the effect of one of the degrees of freedom of the joint becomes permuted. It doesn't contribute to the motion as it did before, but contributes by a totally different way (ex: changing twist instead of changing spatial position). A deeper understanding of the concept can be achieved later when viewing the problems of the prior art.

Locking delay

Locking delay is a side effect for the locking position problem in a joint. The problem that a locking position makes a certain exact trajectory undoable can in certain cases be overcome by introducing a delay for the joint to adjust itself in a new position where it can follow the exact trajectory.

Backward drivability (Motion compliance)

A mechanism is said to be backward drivable (compliant) if it complies with (reacts to) external forces other than the intended actuation inputs. This is sometimes desirable in robotic applications, because even when the mechanism is already actuated it shouldn't be destroyed by overwhelming external force. It is rather better for the mechanism to comply with this external force.

The destruction of the mechanism can be caused by the inability of its physical construction to execute the compliance movement, or by that the material can't handle both opposing forces (actuation inputs and external forces).

A joint having a locking position, means that this joint is not backward drivable at this position, simply because some directions are not allowed for movement (due to its construction). Backward drivability loss can be considered a side effect for the locking position problem.

Self obstruction

Self obstruction is a problem that appears when the physical structure of the joint limits its workspace (work envelope) due to mechanical parts colliding with each other. The joint obstructs itself in certain trajectories. The side effect of self obstruction is discontinuity in the joint workspace.

Notes:

- Self obstruction problem renders some trajectories permanently unallowable.
- Any locking position causes a temporal self obstruction but still the trajectory can be executed with special treatment (ex: introduce time delay). This is why the two problems are considered separate problems.

Dependency of 3rd degree of freedom (Undesired twist)

If the third degree of freedom D3 undergoes obligatory change by only desired changes in D1 and D2, then D3 is not independent but said to be dependent on the first two degrees of freedom.

In any joint two degrees of freedom D1 and D2 are normally used to position the links in a certain spatial posture relative to each other (ex: moving L2 to a certain θ & ϕ relative to LI), and normally a third degree of freedom D3 will be used to control the twist angle τ between the two links. If D3 is dependent on D1 & D2 then an undesired twist will occur when only positioning the links spatially relative to each other.

A joint suffering this dependency can't act as a constant angular velocity flexible coupling.

Note: this dependency is most common in the third degree of freedom responsible for the twist angle τ .

Position-reach redundancy

If a joint can reach the same place in its workspace with several values for the degrees of freedom (ex: D1 & D2) then the joint has a position-reach redundancy. This is not always a problem but may present difficulty in joint programming\control.

Joint programming\control problems

Problems such as locking position, self obstruction, undesired twist, or position-reach redundancy, cause difficulties in programming\controlling the joint (ex: in a robotic application) because intelligence needs to be added for example to:

- Detect locking positions or self obstruction positions and trying to overcome them by either introducing a delay or re-planning trajectory.
- Compensate for the undesired twist.
- Choose among several values for the degrees of freedom to reach the same point.

In order not to include such intelligence the joint can be used to operate in a part of its workspace where none of the problems occur, but this is a limitation of the joint capabilities.

Drawbacks of mechanism KI**1. Locking position and consequent (locking) delay and backward drivability loss**

If the axes of D1 and L2 are aligned, the only allowable axis of rotation is D2. And the effect of D1 is no longer to change the spatial position of L2 relative to LI, but now D1 purely controls the twist angle between LI and L2. This is a locking position; a rotation

about any other arbitrary axis than D2 is not possible, unless the joint first adjusts itself by rotating D1 till the desired rotation can be achieved about the chosen arbitrary axis. This adjustment consumes time which causes a locking delay. The joint is delayed in executing the required trajectory.

In Fig.5a, L2 is required to move from point Z to point X, then to point Y on the path specified. After reaching point X as shown in Fig.5b it is impossible to reach point Y without first rotating D1 with 90° . (If it was required to keep the third degree of freedom D3 independent then it may rotate 90° in the opposite direction of rotation of D1 to maintain a zero twist angle between the links L1 and L2 as shown in Fig.5c). Finally, D2 will rotate until L2 reaches point Y as shown in Fig.5d.

Also a side effect of the locking position is that the joint is not completely backward drivable at this position. This means that in a robotic application if a specific overwhelming force is applied in this position it will actually cause the joint to break instead of just overwhelming the motors.

2. Undesired twist due to dependency of third degree of freedom

When D1 is rotated without rotating D3 then link L2 is twisted relative to L1 as shown in Fig.6a. In the mechanism K1 rotating D1 and D2 was only intended to position L2 in a certain spatial position relative to L1, and D3 was intended to control the twist angle between the two links, but since a twist angle occurred regardless of D3 (third degree of freedom is not independent) then a compensation of this twist is needed if the application requires no change in the twist angle.

The compensation can be done by making D3 rotate in the exact same manner and synchronized speed as D1 but in the opposite direction as shown in Fig.6b, synchronization such as that is troublesome and is an added difficulty.

3. Position-reach redundancy and consequent complications in joint programming

In order to use mechanism K1 with full capabilities D2 should be able to have positive and negative values (where $D2 = 0$ when the two links L1 and L2 are aligned) and D1 should be able to make full rotations. With reference to Fig.7 This results in position-reach redundancy because now each position in space can be reached by two sets of values for the two degrees of freedom D1 and D2 (ex: first solution $[D1=X, D2=Y]$ and second solution $[D1=X+180^\circ, D2=-Y]$).

This results in complications in joint programming/control because when a new position command is given to the joint one of the two solutions will have to be chosen (ex: the solution that will result in faster reach time).

Drawbacks of mechanism K2

1. Undesired twist due to dependency of third degree of freedom

Link L2 is twisted relative to L1 as a result of rotating D1 and D2 simultaneously from their initial positions without rotating D3. This mechanism needs only to rotate D1 and D2 to change the position of L2 in space relative to L1 (as shown in Fig. 8a). D3 is used to rotate L2 about its axis to achieve any desired twist.

In order to compensate for the undesired twist in this mechanism, D3 must rotate in a complex relation and synchronized speed with D1, and D2 as shown in Fig. 8b. Another added difficulty.

Actually the reason why the sense of the twist angle came into consideration in this study is because the universal joint is famous for not conserving a constant angular velocity when being used as a coupling between two shafts. And this happens as a result of the third degree of freedom being dependent on the first two.

2. Self obstruction -for high deviation angles- (discontinuity of work space) and consequent difficulties in joint programming

As shown in Fig. 9a, L2 cannot rotate about the axis of L1 while maintaining a constant deviation angle of 90° or more. This is due to the collision between K2a and K2c (collision zones are pointed out with arrows in the figure).

This discontinuity in the workspace of the joint at high deviation angles causes added difficulty in programming the joint, because if the joint will be used to operate at such deviation angles an algorithm should be added to detect which trajectory will cause self obstruction and either re-plan the trajectory or reject it.

However as shown in Fig. 9b, L1 can rotate easily about the axis of L2, if L2 is fixed. In this case D3 rotates, while D1 and D2 do not. Even so, a twist angle will always exist between L1 and L2 which cannot be completely and permanently eliminated. Also position-reach redundancy will exist.

3. Locking position and consequent (locking) delay and backward drivability loss

As shown in Fig. 10, the universal joint (mechanism K2) has 2 locking positions which cause locking delays to overcome them, also cause backward drivability loss. The positions are when D2 equals to +ve or -ve 90° , (D1 = D2 = zero when L1 & L2 are aligned).

Disclosure of the Invention

The Invention is a unique configuration based on a special mechanical structure and a concept of symmetry. It can be actuated to be used as a joint or can be used passively as a constant angular velocity flexible coupling. Where this configuration is installed between two mechanical links as a joint, the links can move from any point to another on any trajectory without any of the problems found on prior arts such as:

- Dependency of 3rd degree of freedom and consequent undesired twist.
- Locking positions and consequent delays and backward drivability loss.
- Self obstruction and consequent discontinuity of workspace.
- Position-reach redundancy.
- Joint programming\control problems.

The main advantages offered by the Invention are:

- Large deviation angles even obtuse ones (120° for example) with no self obstruction (i.e. any of the links can rotate about the axis of the other while maintaining a constant deviation angle without causing any collisions within the joint). The work space is totally continuous.
- No locking positions and thus no time delays for the links to move from any point to another on any trajectory. Also this means that the mechanism is always backward drivable.
- No undesired twist angle between the links (meaning that if the mechanism is used to simulate a ball and socket joint the 3rd degree of freedom needed will be totally independent). This is the aspect that allows the joint to be used as a flexible constant angular velocity coupling.
- No position-reach redundancy. Each position in the workspace of the joint is reached with a unique set of values for the two degrees of freedom.
- Ease of programming and controlling the joint because of the absence of the previously mentioned problems.
- When used passively as a constant angular velocity flexible coupling, very high deviation angles (more than 90°) can be reached.

Several configurations and designs are proposed, also additional parts for the joint, like a cover to protect it from external factors.

Note: with reference to figure Fig. 11a:

- The joint connects two mechanical links, L1 and L2.

- The degrees of freedom D1 and D2 are responsible for rotating L2 relative to L1 in space without making any twist angle between the two links.
- D3 alone controls the twist angle between L1 and L2.
- L2* is connected to L1 through D1 & D2, the connection between L2* and L2 is through D3.
- The invention has 3 different configurations: Configuration I, Configuration II, & Configuration III.

1- Rotation matrix

- Since it is an important tool for any robotic joint, a rotation matrix between L1 and L2*, will be included.
- The following rotation matrix is the general rotation matrix between any two links rotating with two degrees of freedom relative to each other without any twist between them and thus it is the suitable rotation matrix for the invention.

Notes:

- θ & ϕ (standard spherical coordinates) are used to describe the position of L2* relative to L1.
- Coordinate system 1 is fixed on L1, where its origin is center point C.
- Coordinate system 2* is fixed on L2*, where its origin is center point C.
- In the initial position (θ & ϕ both equal to zero) Coordinate system 1 & Coordinate system 2* are totally coincided.
- $c\phi$ means the cosine value of ϕ and $s\phi$ means the sine value of ϕ , same for θ .
- Matrix T converts points from coordinate system 2* to coordinate system 1:

$$T = \begin{bmatrix} (c\phi)^2 \cdot c\theta + (s\phi)^2 & c\phi \cdot c\theta \cdot s\phi - s\phi \cdot c\phi & c\phi \cdot s\theta \\ c\phi \cdot s\phi \cdot c\theta - s\phi \cdot c\phi & (s\phi)^2 \cdot c\theta + (c\phi)^2 & s\phi \cdot s\theta \\ -s\theta \cdot c\phi & -s\theta \cdot s\phi & c\theta \end{bmatrix} \dots \text{Rotation matrix}$$

2.1.1- Configuration I

As shown in Fig.1la:

- A 1st base part B1 is fixed to the link L1, base B1 may contain the pyramid-shaped component R1, R1 may be replaced with the conical-shaped component O1 (as shown in Fig. 1lb).

- A rotational degree of freedom (D1-1) exists between the first arc A1-1 and base B1 about a spatially fixed axis relative to base B1.
- A rotational degree of freedom (D2-1) exists between the second arc A2-1 and base B1 about a spatially fixed axis relative to base B1, the axis of D2-1 is perpendicular to that of D1-1 and intersects it at a point C, which is the center of the simulated ball-joint.
- The 2nd base part B2 is fixed to the link L2*, base B2 may contain the pyramid-shaped component R2, R2 may be replaced with the conical-shaped component 0 2 (as shown in Fig.1 ib).
- A rotational degree of freedom (D1-2) exists between the first arc A1-2 and base B2 about a spatially fixed axis relative base B2.
- A rotational degree of freedom (D2-2) exists between the second arc A2-2 and base B2 about a spatially fixed axis relative to base B2, the axis of D2-2 is perpendicular to that of D1-2 and intersects it at a point C.
- A rotational degree of freedom (H2) exists between arcs A1-1 and A1-2. The axis of H2 passes through the center point C.
- A rotational degree of freedom (HI) exists between arcs A2-1 and A2-2. The axis of HI passes through the center point C.

Notes:

- The axis of LI as specified is perpendicular to D1-1 and D2-1 and intersects them at the center point C. It is also spatially fixed relative to base B1.
- The axis of L2* as specified is perpendicular to D1-2 and D2-2 and intersects them at the center point C. It is also spatially fixed relative to base B2.
- The vertex of each pyramid-shaped component is at point C.
- The vertex of the conical-shaped components is at point C.
- When referring to HI the following terms will be used interchangeably "degree of freedom HI", "axis HI" or "hinge HI", same for H2

2.1.2- Theory of operation

- The axis of HI and H2 form a plane M. About which, base B1 is symmetric to base B2, A1-1 symmetric to A1-2, A2-1 symmetric to A2-2, and ultimately LI will be symmetric to L2*. This will be referred to later on as the "**mirror rule**".
- As D1-1 rotates, D1-2 also rotates satisfying the mirror rule. This is a motion constraint between D1-1 and D1-2. This forms the degree of freedom D1 which axis is aligned

with the axis of the hinge H1. This motion constraint can be realized by a simple mechanical mechanism.

- As D2-1 rotates, D2-2 also rotates satisfying the mirror rule. This is a motion constraint between D2-1 and D2-2. This forms the degree of freedom D2 which axis is aligned with the axis of the hinge H2. This motion constraint can be realized by a simple mechanical mechanism.
- As a result of this symmetric motion, no twist is possible between B1 and B2, or L1 and L2*.
- D3 is the degree of freedom existing between L2* and L2, and it will be totally independent of D1 and D2, D3 completely controls the angle of twist between L1 and L2.
- Link L2 has three degrees of freedom relative to L1. The two degrees of freedom D1 and D2 which exist between L1 and L2* will be totally responsible of positioning L2 in a certain spatial position relative to L1.
- The angle between the axes of D1 and D2 is variable. The axes H1 & H2 are not necessarily perpendicular to each other all the time.
- The angle between the axes of rotation of the two arc-shaped components on the same pyramid-shaped component (ex: A1-1 and A2-1) is always a right angle.
- If D1-1 is fixed (accordingly D1-2 is fixed), then the axis of D2 (H2) is spatially fixed relative to any of the base parts (B1 & B2), even if D2-1 and D2-2 are rotating. In this case the base parts (B1 & B2) and the links L1 and L2 will be purely rotating about the axis of D2 (H2).
- If D2-1 is fixed (accordingly D2-2 is fixed), then the axis of D1 (H1) is spatially fixed relative to any of the base parts (B1 & B2), even if D1-1 and D1-2 are rotating. In this case the base parts (B1 & B2) and the links L1 and L2 will be purely rotating about the axis of D1 (H1).
- The symmetric configuration of the joint as specified with two symmetric halves and a mirror plane eliminates all the problems found in prior art:
 - No self obstruction and large deviation angles can be achieved because if any of the halves rotate a small angle the other will do the same and the resultant deviation angle is large. Also each half has a completely continuous workspace and so the resultant final workspace is also continuous.
 - No locking positions because at each point in the workspace of the joint the two degrees of freedom D1 and D2 contribute to the movement in the same manner

(no points where the effect of the degree of freedom is permuted to control twist for example rather than spatial positioning)

- No obligatory twist because of sustained symmetry.
- No position-reach redundancy; each point in the workspace has a unique set of values for D1 and D2.
- No problems in joint programming/control because of the absence of the above mentioned problems.

2.2.1- Configuration II

As shown in Fig.11c:

Configuration II is very similar to Configuration I, with few differences:

- Arc-shaped component A2-1 and its degree of freedom (D2-1) don't exist.
- Arc-shaped component A2-2 and its degree of freedom (D2-2) don't exist, and there is no hinge H1.

2.2.2- Theory of operation

It is very similar to the theory of operation of configuration I.

- The hinge H2 is actuated to become the degree of freedom D2.
- Mirror plane (M) contains the axis of D2. About that plane, base B1 is symmetric to base B2, A1-1 symmetric to A1-2, and ultimately L1 will be symmetric to L2*, satisfying the mirror rule.
- As D1-1 rotates, D1-2 also rotates satisfying the mirror rule. This is a motion constraint between D1-1 and D1-2. This forms the degree of freedom D1*, the axis of D1* is perpendicular to the axis of D2, and lies in the mirror plane M. This motion constraint can be realized by a simple mechanical mechanism.
- As a result of this symmetric motion, no twist is possible between the base B1 and base B2, or L1 and L2*.
- The axes of D1* and D2 are always perpendicular to each other, If D1-1 is fixed (accordingly D1-2 is fixed), then the axis of D2 (H2) is spatially fixed relative to any of the base parts (B1 & B2), even if D2 is rotating. In this case base parts (B1 & B2) and the links L1 and L2 will be purely rotating about the axis of D2 (H2)
- If D2 is fixed while D1-1 is rotating (accordingly D1-2 is rotating), then the axis of D1* is not spatially fixed relative to the base parts (B1 & B2). But it will be the instantaneous axis of rotation for the links about each other.

2.3.1- Configuration III

As shown in Fig.1d:

In construction Configuration III is very similar to Configuration I, with few differences:

- Arc-shaped component A2-1 is replaced with Arc-shaped component A3-1, and thus A2-1 is removed and its degree of freedom (D2-1) is removed as well.
- Arc-shaped component A3-1 is connected to a new part called 1st sub-base (B3).
- A rotational degree of freedom (D3-1) exists between arc A3-1 and B3 about a spatially fixed axis relative to B3.
- A rotational degree of freedom exists between B3 and B1 about an axis that passes by center point C, and is perpendicular to both the axes of D1-1 and D3-1. This axis is also aligned with the axis of L1.
- The axis of D3-1 passes by center point C, and it is not necessarily perpendicular to that of D1-1.
- Arc-shaped component A2-2 is replaced with Arc-shaped component A3-2, and thus A2-2 is removed and its degree of freedom (D2-2) is removed as well.
- Arc-shaped component A3-2 is connected to a new part called 2nd sub-base (B4).
- A rotational degree of freedom (D3-2) exists between arc A3-2 and B4 about a spatially fixed axis relative to B4.
- A rotational degree of freedom exists between B4 and B2 about an axis that passes by center point C, and is perpendicular to both the axes of D1-2 and D3-2. This axis is also aligned with the axis of L2.
- The axis of D3-2 passes by center point C, and it is not necessarily perpendicular to that of D1-2.
- There is no hinge H1, since there is no A2-1 and no A2-2.
- A rotational degree of freedom (H3) exists between the arc A3-1 and the arc A3-2. The axis of H3 passes through the center point C.
- The two hinges H2 & H3 are connected with a part (E) that makes their axes perpendicular to one another all time (H2 connects A1-1 & A1-2).

2.3.2- Theory of operation

Configuration III can be considered as another form of configuration II where the axis of H3 is the same as D1*.

- The axis of H1 and H3 form plane M. About that plane, base B1 is symmetric to base B2, A1-1 symmetric to A1-2, A3-1 symmetric to A3-2 and ultimately L1 will be symmetric to L2*, satisfying the mirror rule.
- As D3-1 rotates, D3-2 also rotates satisfying the mirror rule. This is a motion constraint between D3-1 and D3-2. This forms the degree of freedom D1*, the axis of D1* is perpendicular to the axis of D2. This motion constraint can be realized by a simple mechanical mechanism.
- As a result of this symmetric motion, no twist is possible between base B1 and base B2, or L1 and L2*.

3- Symmetry achievement

To satisfy the mirror rule with the symmetry it implies between any arc-shaped component and its pair, such as: A1-1 & A1-2, A2-1 & A2-2, or A3-1 & A3-2, many methods can be used employing strings, gears, hydraulics, links ... etc.

The idea is to create a mechanism that will change when the arc shaped component rotates, and then use this mechanism and the change that happens in it to duplicate\reproduce the motion for the corresponding\peer arc shaped component. Examples include (but not limited to) the following:

- **Achieving symmetry using strings**
 - The strings are connected as shown in Fig. 12a.
 - Considering that base B1 is fixed. If the pulley rotates and displaces the strings for example an angular displacement x , then base B2 will approach base B1 with same displacement x , but hinge H2 will approach base B1 with angular displacement $x/2$ (because the wire is folded on itself). From another point of view this means that both base parts will approach the hinge H2 with same angular displacement $x/2$, hence symmetry is achieved.
 - At hinge H2 the strings go through a hole in a pin and so even if the hinge bends the path of the strings won't be affected.
- **Achieving symmetry using hydraulic fluid**
 - Assume using two hydraulic actuators where for each the inlet flow is always equal to the outlet flow.

- As shown in Fig.12b, if the two hydraulic actuators are to be connected in a similar manner (the inlet of each one is fed with the outlet of the other), then the movement of one will be exactly transferred to the other.
 - This can be used to achieve symmetry in combination with strings as shown in Fig.12c. In this case hydraulic fluid is only used to achieve symmetry but actuation can be done by any other means (for example by a motor).
 - Another idea to achieve not only symmetry but also actuation with hydraulic fluid is presented in Fig. 12d
- **Achieving symmetry using Gears**
(Suitable for Configuration I & Configuration III)
 - As shown in Fig.12e, considering bevel gear G1 which axis is perpendicular to plane M and passes by center point C, when G1 rotates, the two bevel gears G2 and G3 will rotate in opposite directions causing the two arcs A1-1 and A1-2 to rotate opposite to each other and thus the two degrees of freedom D2-1 and D2-2 will change in the same manner (symmetry is achieved), note that the axes of G2 & G3 are aligned with the axis of H2.
 - This mechanism is reversible, meaning that if the motion started by moving D2-1 then the axis H1 will move and so the gear G1 (because it's in a plane fixed relative to axis H1) will roll on G3 rotating about itself, transferring the motion to G2 and causing A1-2 to move, and D2-2 will change in the same manner as D2-1 .
 - This mechanism is repeated for the other set of arcs (A2-1 and A2-2) as shown in Fig.12f, so totally there are two gear mechanisms; one for each set of arcs.
 - For Configuration I the axes H1 and H2 are not always perpendicular. This can be dealt with easily by making the two gear mechanisms rotatable from each other as shown in Fig.12f. As for Configuration III the two axes H3 and H2 are always perpendicular to each other (because of part E) so the two gear mechanisms can be fixed perpendicular to each other.
- **Achieving symmetry using links**
 - As shown in Fig. 12g a pair of links and a pair of sliding sleeves were employed to operate in a manner similar to the famous crank-shaft mechanism. When the arc rotates the links rotate and so the sleeves slide on a guiding rod. This sliding is used to duplicate the motion for the other arc with similar corresponding links.
 - The sliding sleeve has a flexible design that allows bending about the guiding rod, in this case the other pair of arcs can rotate independently (shown in Fig.12g).

4- Means of actuation

After making sure that the symmetry is achieved for each arc-shaped pair, any of the following combinations is suitable for actuating the joint:

- Configuration I: Actuating A1-1 & A2-1, or H1 & H2.
- Configuration II: Actuating A1-1 & H2.
- Configuration III: Actuating A1-1 & A3-1, or H3 & H2.

5- Extra parts:

5.1- Pyramid-shaped components and conical-shaped components (as shown in Fig.lib) for Configuration I:

- If pyramid-shaped component R1 with B1 are fixed on link LI, and Pyramid-shaped component R2 with B2 on link L2*, then the angles rotated by D1-1 & by D2-1 can reach their maximum values simultaneously. This means that any of these two angles can change on all its range independent of the value of the other angle, therefore the pyramid-shaped components increase the workspace of the mechanism to the fullest. That makes angle Θ reach more than 120 degrees on most of the range for angle ϕ . Angle Θ cannot exceed 120 degrees only at four specific values for angle ϕ , these four values are {0, 90, 180, 270} degrees. When both angles rotated by D1-1 & by D2-1 reach their max value which is 60 degrees in the design shown in the figure, angle Θ equals approximately 135.58 degrees.
- However, if conical-shaped component 0 1 is fixed with B1 on link LI, and the conical-shaped component 0 2 with B2 on link L2*, the angles rotated by D1-1 & by D2-1 can't reach their max values simultaneously. Any angle of these two cannot change on all of its range, unless the other one equals zero. This means that the maximum value of angle Θ is always 120°.
- These pyramid-shaped, conical-shaped or whatever shaped components may act as the end limits to the motion of the mechanism when one touches the other. They could be shaped with any profile to get a specifically desired workspace, also it is not a must that the part fixed with B1 on LI is similar to the one fixed with B2 on L2*.

5.2- Cover:

- The mechanism can be completely covered for protection from ambient effects, like dirt or water, or it can be covered to hold lubrication fluids.
- This cover could be made of one elastic piece, as shown in Fig. 13a, where one of the drawings shows a section view.
- A rigid cover could be made of two sets of symmetric rigid shells. Each shell in a set has a corresponding similar peer shell in the opposite set. two designs are available:

First design (shown in Fig.13b)

In this design each shell is formed of a conical surface & a spherical surface. All conical surfaces share their vertex which is center point C, also all spherical surfaces share this same center point (a drawing of a shell and its peer shell is presented in the figure). In extreme positions the conical surfaces (in each half) lean on one another preventing any gaps to occur in the cover (between spherical surfaces), and the spherical surfaces (in each half) work as guides for the adjacent shells to slide on one another, this forms a shield which completely covers the mechanism. In this design the base of the joint should have a spherical surface (fixed to it) to prevent the shells from falling in extreme positions. A simplified conceptual drawing of the cover is presented in the figure. Fig. 13c shows how to assemble this cover parts in order.

Second design (shown in Fig. 13d)

In this design each shell is formed of a conical surface & 2 spherical surfaces. All conical surfaces share their vertex which is center point C, also all spherical surfaces share this same center point (a drawing of a shell is presented in the figure). In extreme positions the conical surfaces (in each half) lean on one another preventing any gaps to occur in the cover (between spherical surfaces), and the spherical surfaces (in each half) work as guides for the adjacent shells to slide on one another, this forms a shield which completely covers the mechanism. As mentioned each shell has an inner spherical surface, and an outer spherical surface. The inner spherical surface of a bigger shell and the inner spherical surface of an adjacent smaller shell prevent the smaller shell from falling inwards. The outer spherical surface of a bigger shell and the outer spherical surface of an adjacent smaller shell prevent the smaller shell from

falling outwards. A simplified conceptual drawing of the cover is presented in the figure. Fig.13e shows how to assemble this cover parts in order.

6- Generally the joint has several designs

Examples include (but not limited to) the following:

- A design with half the structure to save more space (Fig. 14a).
- (Based on configuration II) A power suit design (exoskeleton suit), which allows any material to pass through while the joint is working, with no collusions (Fig. 14b), like a human shoulder to pass through for example.
- A design with telescopic arcs (Fig. 14c).

Different configurations and designs could be mixed and matched with different symmetry means and actuation methods.

Note: the drawings of the invention are purely illustrative and are not necessarily an exact embodiment or a limitation of the invention.

Brief Description of Drawings

Fig.1 (Shows mechanism K1 of the prior art)

L1 and L2 are mechanical links desired to be jointed, K1 is a mechanism of the prior art, K1a and K1b are the parts that form K1, D1 is the degree of freedom between L1 and K1a, as D2 is the degree of freedom between K1a and K1b, and D3 is the degree of freedom between K1b and L2.

Fig.2 (Shows mechanism K2 of the prior art)

L1 and L2 are mechanical links desired to be jointed, K2 is a mechanism of the prior art, K2a, K2b, and K2c are the parts that form K2, D1 is the degree of freedom between K2a and K2b, as D2 is the degree of freedom between K2b and K2c, and D3 is the degree of freedom between K2c and L2.

Fig.3 (Shows some important planes and symbols for the used terminology)

L1 and L2 are mechanical links desired to be jointed, C is the center of the joint, M is the mirror plane, P is the deviation plane, X, Y and Z are conventional Cartesian axes, XY and ZY are Cartesian planes, Θ and ϕ are spherical coordinates of link L2 relative to L1.

Fig.4a (Shows a zero deviation angle and a zero twist angle)

L1 and L2 are mechanical links desired to be jointed, C is the center of the joint.

Fig.4b (Shows a zero deviation angle and a twist angle)

L1 and L2 are mechanical links desired to be jointed, C is the center of the joint, and τ is the twist angle.

Fig.4c (Shows a deviation angle and a zero twist angle)

L1 and L2 are mechanical links desired to be jointed, C is the center of the joint.

Fig.4d (Shows a deviation angle and a twist angle)

L1 and L2 are mechanical links desired to be jointed, C is the center of the joint, and τ is the twist angle.

Fig.5a (Snapshot 1 in a sequence showing the locking delay drawback of mechanism K1)

L1 and L2 are mechanical links, D2 is a degree of freedom of mechanism K1. X, Y, and Z are points in space on a path for motion.

Fig.5b (Snapshot 2 in a sequence showing the locking delay drawback of mechanism K1)

D1 and D3 are degrees of freedom of mechanism K1. X, Y, and Z are points in space on a path for motion.

Fig.5c (Snapshot 3 in a sequence showing the locking delay drawback of mechanism K1)

D2 is a degree of freedom of mechanism K1. X, Y, and Z are points in space on a path for motion.

Fig.5d (Snapshot 4 in a sequence showing the locking delay drawback of mechanism K1)

X, Y, and Z are points in space on a path for motion.

Fig.6a (Shows the undesired twist drawback of mechanism K1 and the role of D1& D2)

L1 and L2 are mechanical links, D1, D2, D3 are the degrees of freedom of mechanism K1, as they are rotational degrees of freedom, the angles traveled by these degrees of freedom are written down, deviation angle Θ and twist angle τ are shown as a result of the angles traveled by D1 & D2.

Fig.6b (The undesired twist drawback of mechanism K1 and the role of D1, D2, & D3)

L1 and L2 are mechanical links, D1, D2, D3 are the degrees of freedom of mechanism K1, as they are rotational degrees of freedom, the angles traveled by these degrees of freedom are written down, deviation angle Θ and twist angle τ are shown as a result of the angles traveled by D1, D2 & D3.

Fig.7 (Shows the position reach redundancy problem in mechanism K1)

Θ and ϕ are spherical angles defining a specific point to reach in the joint workspace, D1 & D2 are the degrees of freedom, the different sets of values for D1 & D2 that make the joint reach the same point are shown.

Fig.8a (Shows the undesired twist drawback of mechanism K2 and the role of D1& D2)

L1 and L2 are mechanical links, D1, D2, D3 are the degrees of freedom of mechanism K2, as they are rotational degrees of freedom, the angles traveled by these degrees of freedom are written down, deviation angle Θ and twist angle τ are shown as a result of the angles traveled by D1 & D2.

Fig.8b (The undesired twist drawback of mechanism K2 and the role of D1, D2, & D3)

L1 and L2 are mechanical links, D1, D2, D3 are the degrees of freedom of mechanism K2, as they are rotational degrees of freedom, the angles traveled by these degrees of freedom are written down, deviation angle Θ and twist angle τ are shown as a result of the angles traveled by D1, D2 & D3.

Fig.9a (Shows the self obstruction drawback of mechanism K2)

L1 and L2 are mechanical links, K2a and K2c are parts of mechanism K2, D1 & D2 are degrees of freedom of K2, the arrows point out the collision zones.

Fig.9b (Shows the self obstruction drawback of mechanism K2)

L1 and L2 are mechanical links, K2a and K2c are parts of mechanism K2, D1, D2, and D3 are the degrees of freedom of K2, and τ is the twist angle.

Fig.10 (Shows the locking position drawback of mechanism K2)

D1 and D2 are the degrees of freedom of mechanism K2, the crossed-over path is an unallowable path in this position.

Fig.11a (Shows Configuration I of the invention)

L1 and L2 are mechanical links desired to be jointed, L2* is a transient link between L1 and L2, Configuration I consists of: Base B1 & B2, pyramid-shaped components R1 & R2, Arc-shaped components A1-1, A2-1, A1-2, & A2-2, where the degrees of freedom in Configuration I are D1-1, D2-1, D1-2, D2-2, & D3 and the two hinges H1 & H2.

Fig.11b (Shows alternate components for Configuration I)

B1 & B2 are the base parts, R1 & R2 are the pyramid-shaped components, and their alternatives are conical-shaped components O1 & O2, A1-1, A2-1, A1-2, & A2-2 are the Arc-shaped components, the figure also shows the reason behind the names pyramid-shaped & conical-shaped, and the difference when using either of them.

Fig.1lc (Shows Configuration II of the invention)

LI and L2 are mechanical links desired to be jointed, L2* is a transient link between LI and L2, Configuration II consists of: Base B1 & B2, pyramid-shaped components R1 & R2, Arc-shaped components A1-1 & A1-2, where the degrees of freedom in Configuration II are D1-1, D1-2, & D3 and the hinge H2.

Fig.1ld (Shows Configuration III of the invention)

LI and L2 are mechanical links desired to be jointed, Configuration III consists of: Base B1 & B2, sub-bases B3 & B4, Arc-shaped components AM, A3-1, A1-2, & A3-2, and the cross part E, where the degrees of freedom in Configuration III are D1-1, D3-1, D1-2, D3-2, and the two hinges H1 & H3/D1*.

Fig.12a (Shows an actuation method using strings for the arc parts, that also applies the mirror rule)

Base B1 & B2 and arc-shaped parts A1-1 and A1-2 are actuated using strings as shown in the figure, the pulley is used to drive the strings. A zoom in view shows that at hinges like H2 the string passes through a hole and thus its path won't be affected even if the hinge bends.

Fig.12b (Shows how to gain symmetry using two hydraulic actuators)

The inlet of each hydraulic actuator is fed with the outlet of the other.

Fig.12c (Shows a method for applying the mirror rule using hydraulic actuators in combination with strings)

Base B1 & B2 are shown, as well as the arc-shaped parts A1-1 and A1-2, strings are used alongside the hydraulic actuators to achieve the symmetry, strings are fixed on pins on hinge H2.

Fig. 12d (Shows a hydraulic actuation method for the arc parts, to apply the mirror rule)

Using only hydraulic fluids, and a valve with 4 different states, to rotate clockwise, counterclockwise, brake lock, or be passive.

Fig.12e (Shows a method to apply the mirror rule and achieve symmetry using gears)

G1, G2 & G3 are bevel gears. G2 and G3 are fixed to arcs A1-2 and A1-1 respectively and the axis of hinge H2 is aligned to their axes after assembly. The axis of gear G1 is perpendicular to the plane containing H1 & H2.

Fig.12f (Shows a method to apply the mirror rule and achieve symmetry using gears)

The figure shows the way to assemble 2 sets of gears to apply the mirror rule, it also shows a position where the axes of hinges H1 and H2 are not perpendicular.

Fig.12g (Shows a method to apply the mirror rule and achieve symmetry using links and sliding sleeves)

With a zoom in view shows that the sleeve can accommodate the hinge bending.

Fig.13a (Shows a cover to protect the joint made of elastic material like rubber)

Fig.13b (Shows a first design for a rigid cover for the joint)

Fig.13c (Shows assembly for the first design of the rigid cover)

Fig.13d (Shows a second design for a rigid cover for the joint)

Fig.13e (Shows assembly for the second design of the rigid cover)

Fig.14a (Shows a design with half the structure to save more space)

Fig.14b (Shows a design that allows material through the joint for power suit/exoskeleton applications)

Fig.14c (Shows a design with telescopic arcs)

Fig.15 (Shows several applications for the invention)

Industrial Applicability

This Mechanism could be used in any robotic or mechanical field, like industrial robotic arms (very suited for robotic wrists at the end effector side), manually operated or CNC machines, rotating a surveillance camera, the joints of limbed or moving robots weather bipedal humanoid robots or others, also in military applications like rotating and aiming a tank cannon or an airplane machinegun, it can be used in medical applications as well like artificial limbs, or power suits (exoskeletons).

The mechanism can be also used passively as a flexible constant angular velocity coupling with large deviation angles. This has a wide range of applications in automotive industries, and machines in general.

Concisely this invention is a new mechanical configuration(s); it is not exclusive for a specific application, so it is not possible to enumerate all its possible uses.

Fig.15 shows some visualization for different applications.

23
CLAIMS

What is claimed is:

1. A mechanical joint rotatable in three dimensions using two degrees of rotational freedom to be used for connecting two mechanical links\shafts; a first link\shaft and a second link\shaft, and cause them to rotate about a center point of rotation relative to each other, said joint configuration comprising:
 - (a) a first base member to be attached to said first link\shaft
 - (b) a first moving member connected to said first base member and rotates relative to it about a first axis of rotation, said first axis passes through said center point of rotation
 - (c) a second base member to be attached to said second link\shaft
 - (d) a second moving member connected to said second base member and rotates relative to it about a second axis of rotation, said second axis passes through said center point of rotation
 - (e) a third moving member connected to said first base member and rotates relative to it about a third axis of rotation, said third axis passes through said center point of rotation, and is perpendicular to said first axis
 - (f) a fourth moving member connected to said second base member and rotates relative to it about a fourth axis of rotation, said fourth axis passes through said center point of rotation, and is perpendicular to said second axis
 - (g) said third moving member is hinged to said fourth moving member with a first hinge, the axis of said first hinge passes through said center point and is perpendicular to said third axis, and is perpendicular to said fourth axis
 - (h) said first moving member is hinged to said second moving member with a second hinge, the axis of said second hinge passes through said center point and is perpendicular to said first axis, and is perpendicular to said second axis
 - (i) means for keeping the rotation angle of said first moving member to said first base member equal to the rotation angle of said second moving member to said second base member while preserving symmetry between the spatial position of said first moving member relative to said first base member and the spatial position of said second moving member relative to said second base member, thus the first degree of freedom of said joint configuration is realized

- (j) means for keeping the rotation angle of said third moving member to said first base member equal to the rotation angle of said fourth moving member to said second base member while preserving symmetry between the spatial position of said third moving member relative to said first base member and the spatial position of said fourth moving member relative to said second base member, thus the second degree of freedom of said joint configuration is realized

- (k) means for actuating said joint configuration

whereby said joint configuration allows rotation on any trajectory with a large range of deviation angles even obtuse ones, with no locking positions and subsequent delays in trajectory execution, with no self obstruction and subsequent discontinuity of workspace, with no twist between said connected links\shafts, with no loss of compliance and backward drivability, with no position reach redundancy, and thus said joint is easy to program and control.

2. The invention of Claim 1 wherein an additional function of said joint is that it works as a flexible constant angular velocity coupling with large deviation angles even obtuse ones.
3. The invention of Claim 1 wherein the second degree of freedom of said joint is alternatively realized by removing said third moving member and said fourth moving member along with said first hinge that connects them and further including a direct actuator on said second hinge for example a motor.
4. The invention of Claim 1 wherein the second degree of freedom of said joint is alternatively realized by removing said third moving member and said fourth moving member along with said first hinge that connects them, and further including:
 - (a) a third base member connected to said first base member and rotates relative to it about a fifth axis of rotation, said fifth axis passes through said center point of rotation, and is perpendicular to said first axis
 - (b) a fourth base member connected to said second base member and rotates relative to it about a sixth axis of rotation, said sixth axis passes through said center point of rotation, and is perpendicular to said second axis

- (c) a fifth moving member connected to said third base member and rotates relative to it about a seventh axis of rotation, said seventh axis passes through said center point of rotation, and is perpendicular to said fifth axis
 - (d) a sixth moving member connected to said fourth base member and rotates relative to it about a eighth axis of rotation, said eighth axis passes through said center point of rotation, and is perpendicular to said sixth axis
 - (e) said fifth moving member is hinged to said sixth moving member with a third hinge, the axis of said third hinge passes through said center point and is perpendicular to said seventh axis, and is perpendicular to said eighth axis
 - (f) a connecting member which connects said third hinge to said second hinge, where said connecting member keeps the axis of said third hinge perpendicular to the axis of said second hinge
 - (g) means for keeping the rotation angle of said fifth moving member to said third base member equal to the rotation angle of said sixth moving member to said fourth base member while preserving symmetry between the spatial position of said fifth moving member relative to said third base member and the spatial position of said sixth moving member relative to said fourth base member, thus the second degree of freedom of said joint configuration is realized
 - (h) means for actuating said joint configuration.
5. The invention of Claim 1 wherein said first base member and second base member are equipped with pyramid like shaped members.
6. The invention of Claim 1 wherein said first base member and second base member are equipped with cone like shaped members.
7. The invention of Claims 1, 2, & 3 wherein said first, second, third, fourth, fifth, and sixth moving members are arc like shaped.
8. A cover for protecting any joint configuration that connects two links\shafts, where said joint configuration has a center point, said cover comprising:
- (a) two symmetric sets of shells, a first set and a second set
 - (b) each set of shells has a port for one of the said two connected links\shafts
 - (c) each shell in said first set has a similar corresponding peer shell in said second set

- (d) each said shell is formed of a predetermined portion of a conical surface and a predetermined portion of a spherical surface, all said conical surfaces share their apex which is also said center point, also all said spherical surfaces are concentric at said center point
- (e) said shells in each said set are different in size and ordered from bigger to smaller in a predetermined assembly, each bigger shell overlaps a portion of the next smaller shell in said assembly
- (f) at extreme positions for said protected joint configuration said conical surfaces in each said set lean on one another preventing any gaps to occur in said cover
- (g) said spherical surfaces in each said set work as guides for said shells to slide on one another, said spherical surfaces work as a shield which completely covers and protects said joint configuration
- (h) a most inner shell in each said set is fixed to its corresponding link\shaft, at extreme positions said most inner shell prevents other shells from falling
- (i) a most outer shell in each set is fixed to its corresponding link\shaft
- (j) said cover has enough space inside it to accommodate said joint configuration, and has two ports for said links to interconnect through said joint

whereby with predetermined dimensions and design for each said shell, said cover can be used to protect any joint configuration having large range of deviation angles even obtuse ones and allowing rotation on any trajectory, said cover never obstructs said joint configuration, and with no gaps occurring in said cover, said joint configuration is never subjected to external effects.

9. A cover for protecting any joint configuration that connects two links\shafts, where said joint configuration has a center point, said cover comprising:
- (a) two symmetric sets of shells, a first set and a second set
 - (b) each set of shells has a port for one of the said two connected links\shafts
 - (c) each shell in said first set has a similar corresponding peer shell in said second set
 - (d) each said shell is formed of a predetermined portion of a conical surface and two predetermined portions of spherical surfaces, all said conical surfaces share their apex which is also said center point, also all said spherical surfaces are concentric at said center point

- (e) said shells in each said set are different in size and ordered from bigger to smaller in a predetermined assembly, each bigger shell overlaps a portion of the next smaller shell in said assembly
 - (f) at extreme positions for said protected joint configuration said conical surfaces in each said set lean on one another preventing any gaps to occur in said cover
 - (g) said spherical surfaces in each said set work as guides for said shells to slide on one another, said spherical surfaces work as a shield which completely covers and protects said joint configuration
 - (h) each said shell have an inner spherical surface, and an outer spherical surface
 - (i) said inner spherical surface of a bigger shell and said inner spherical surface of an adjacent smaller shell, prevent that smaller shell from falling inwards
 - (j) said outer spherical surface of a bigger shell and said outer spherical surface of an adjacent smaller shell, prevents that smaller shell from falling outwards
 - (k) a most outer shell in each set is fixed to its corresponding link\shaft, said most outer shell has only one spherical surface
 - (l) said cover has enough space inside it to accommodate said joint configuration, and has two ports for said links to interconnect through said joint
- whereby with predetermined dimensions and design for each said shell, said cover can be used to protect any joint configuration having large range of deviation angles even obtuse ones and allowing rotation on any trajectory, said cover never obstructs said joint configuration, and with no gaps occurring in said cover, said joint configuration is never subjected to external effects.

AMENDED CLAIMS
received by the International Bureau on 15 November 2011 (15.11.2011)

What is claimed is:

1. A mechanical joint rotatable in three dimensions using two degrees of rotational freedom to be used for connecting two mechanical links/shafts; a first linkVshaft and a second MnkXshaft, and cause them to rotate about a center point of rotation relative to each other, said joint configuration comprising:
 - (a) a first base member to be attached to said first linkVshaft
 - (b) a first moving member connected to said first base member and rotates relative to it about a first axis of rotation, said first axis passes through said center point of rotation
 - (c) a second base member to be attached to said second linkVshaft
 - (d) a second moving member connected to said second base member and rotates relative to it about a second axis of rotation, said second axis passes through said center point of rotation
 - (e) a third moving member connected to said first base member and rotates relative to it about a third axis of rotation, said third axis passes through said center point of rotation, and is perpendicular to said first axis
 - (f) a fourth moving member connected to said second base member and rotates relative to it about a fourth axis of rotation, said fourth axis passes through said center point of rotation, and is perpendicular to said second axis
 - (g) said third moving member is hinged to said fourth moving member with a first hinge, the axis of said first hinge passes through said center point and is perpendicular to said third axis, and is perpendicular to said fourth axis
 - (h) said first moving member is hinged to said second moving member with a second hinge, the axis of said second hinge passes through said center point and is perpendicular to said first axis, and is perpendicular to said second axis
 - (i) means for keeping the rotation angle of said first moving member to said first base member equal to the rotation angle of said second moving member to said second base member while preserving symmetry between the spatial position of said first moving member relative to said first base member and the spatial position of said second moving member relative to said second base member, thus the first degree of freedom of said joint configuration is realized

- (j) means for keeping the rotation angle of said third moving member to said first base member equal to the rotation angle of said fourth moving member to said second base member while preserving symmetry between the spatial position of said third moving member relative to said first base member and the spatial position of said fourth moving member relative to said second base member, thus the second degree of freedom of said joint configuration is realized

- (k) means for actuating said joint configuration

whereby said joint configuration allows rotation on any trajectory with a large range of deviation angles even obtuse ones, with no locking positions and subsequent delays in trajectory execution, with no self obstruction and subsequent discontinuity of workspace, with no twist between said connected links\shafts, with no loss of compliance and backward drivability, with no position reach redundancy, and thus said joint is easy to program and control.

2. A mechanical joint of Claim 1 wherein an additional function of said joint is that it works as a flexible constant angular velocity coupling with large deviation angles even obtuse ones.
3. A mechanical joint of Claim 1 or Claim 2 wherein said first base member and second base member are equipped with pyramid like shaped members.
4. A mechanical joint of Claim 1 or Claim 2 wherein said first base member and second base member are equipped with cone like shaped members.
5. A mechanical joint of Claims 1 or Claim 2 wherein said first, second, third, and fourth moving members are arc like shaped.
6. A cover for protecting any joint configuration that connects two links\shafts, where said joint configuration has a center point, said cover comprising:
 - (a) two symmetric sets of shells, a first set and a second set
 - (b) each set of shells has a port for one of the said two connected links\shafts
 - (c) each shell in said first set has a similar corresponding peer shell in said second set

- (d) each said shell is formed of a predetermined portion of a conical surface and a predetermined portion of a spherical surface, all said conical surfaces share their apex which is also said center point, also all said spherical surfaces are concentric at said center point
- (e) said shells in each said set are different in size and ordered from bigger to smaller in a predetermined assembly, each bigger shell overlaps a portion of the next smaller shell in said assembly
- (f) at extreme positions for said protected joint configuration said conical surfaces in each said set lean on one another preventing any gaps to occur in said cover
- (g) said spherical surfaces in each said set work as guides for said shells to slide on one another, said spherical surfaces work as a shield which completely covers and protects said joint configuration
- (h) a most inner shell in each said set is fixed to its corresponding link\shaft, at extreme positions said most inner shell prevents other shells from falling
- (i) a most outer shell in each set is fixed to its corresponding link\shaft
- (j) said cover has enough space inside it to accommodate said joint configuration, and has two ports for said links to interconnect through said joint

whereby with predetermined dimensions and design for each said shell, said cover can be used to protect any joint configuration having large range of deviation angles even obtuse ones and allowing rotation on any trajectory, said cover never obstructs said joint configuration, and with no gaps occurring in said cover, said joint configuration is never subjected to external effects.

7. A cover for protecting any joint configuration that connects two links\shafts, where said joint configuration has a center point, said cover comprising:
- (a) two symmetric sets of shells, a first set and a second set
 - (b) each set of shells has a port for one of the said two connected links\shafts
 - (c) each shell in said first set has a similar corresponding peer shell in said second set
 - (d) each said shell is formed of a predetermined portion of a conical surface and two predetermined portions of spherical surfaces, all said conical surfaces share their apex which is also said center point, also all said spherical surfaces are concentric at said center point

- (e) said shells in each said set are different in size and ordered from bigger to smaller in a predetermined assembly, each bigger shell overlaps a portion of the next smaller shell in said assembly
- (f) at extreme positions for said protected joint configuration said conical surfaces in each said set lean on one another preventing any gaps to occur in said cover
- (g) said spherical surfaces in each said set work as guides for said shells to slide on one another, said spherical surfaces work as a shield which completely covers and protects said joint configuration
- (h) each said shell have an inner spherical surface, and an outer spherical surface
- (i) said inner spherical surface of a bigger shell and said inner spherical surface of an adjacent smaller shell, prevent that smaller shell from falling inwards
- (j) said outer spherical surface of a bigger shell and said outer spherical surface of an adjacent smaller shell, prevents that smaller shell from falling outwards
- (k) a most outer shell in each set is fixed to its corresponding link/shaft, said most outer shell has only one spherical surface
- (l) said cover has enough space inside it to accommodate said joint configuration, and has two ports for said links to interconnect through said joint

whereby with predetermined dimensions and design for each said shell, said cover can be used to protect any joint configuration having large range of deviation angles even obtuse ones and allowing rotation on any trajectory, said cover never obstructs said joint configuration, and with no gaps occurring in said cover, said joint configuration is never subjected to external effects.

1/20
DRAWINGS

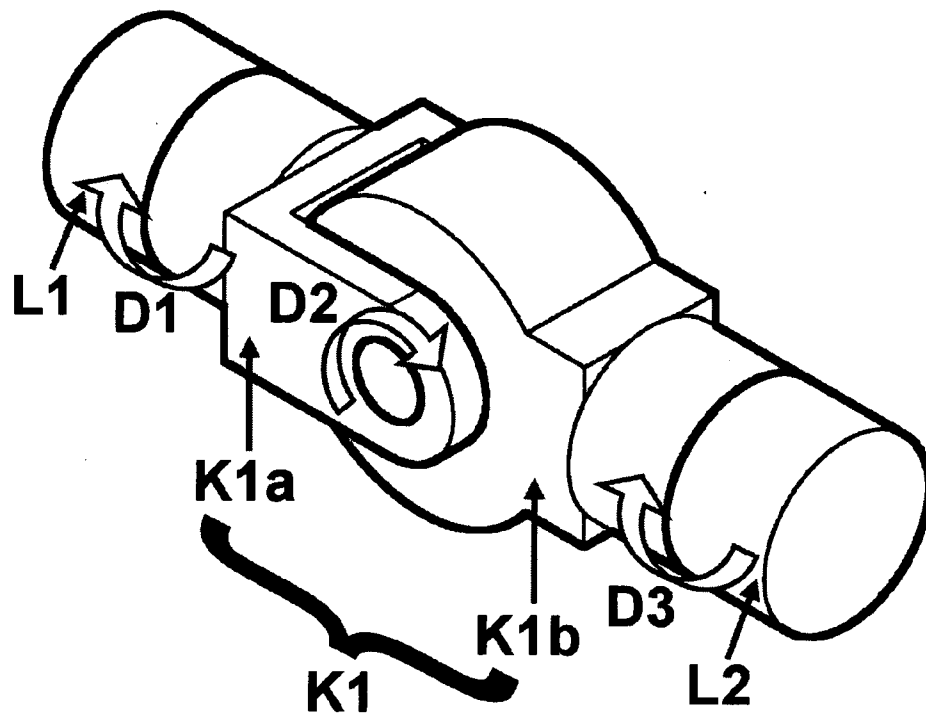


Fig.1

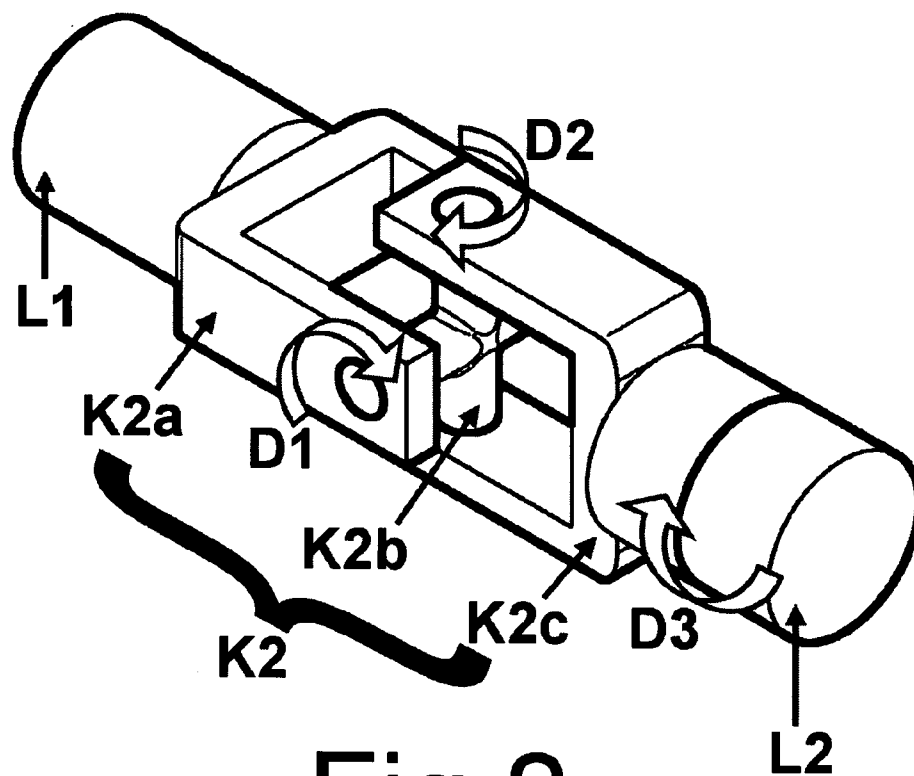


Fig.2

2/20

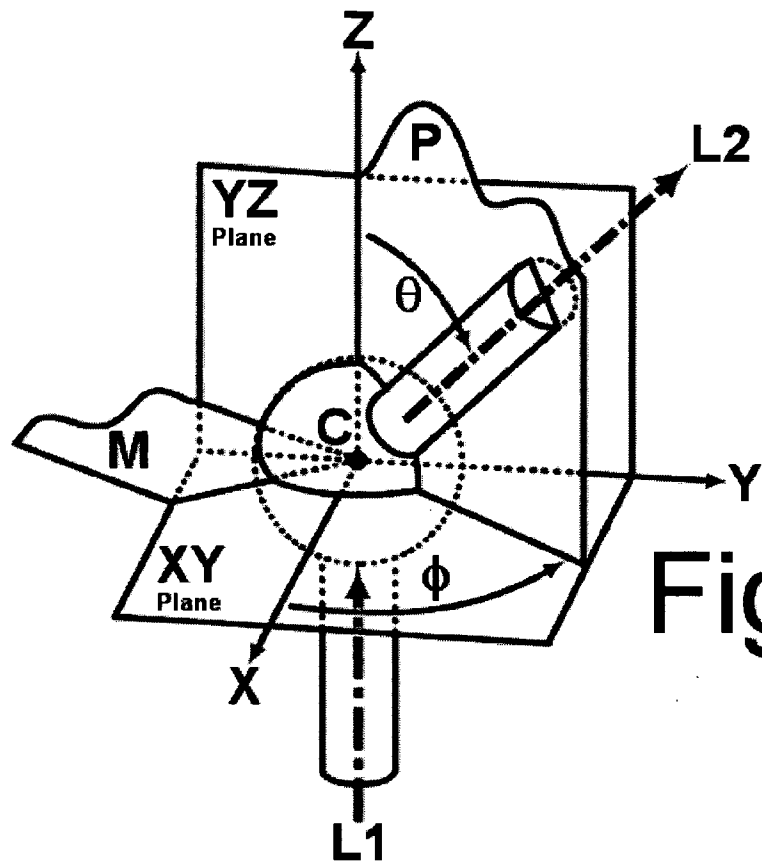


Fig.3

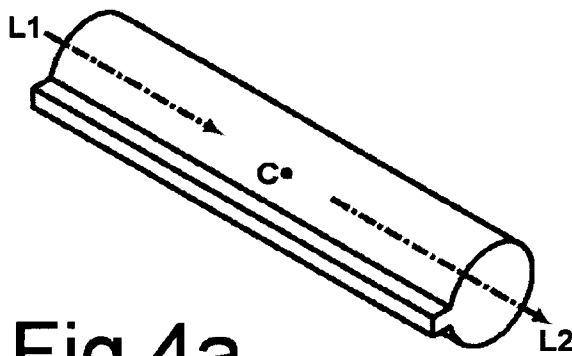


Fig.4a

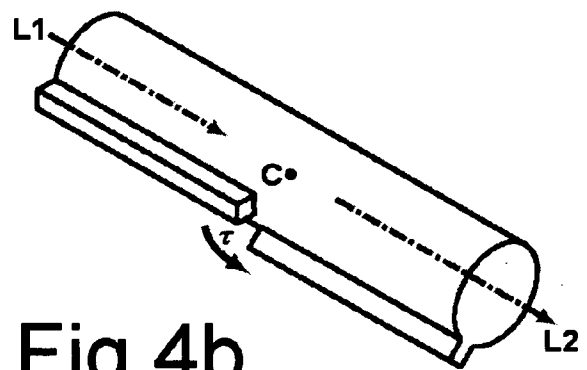


Fig.4b

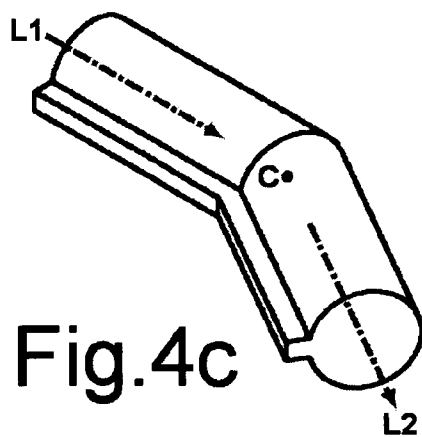


Fig.4c

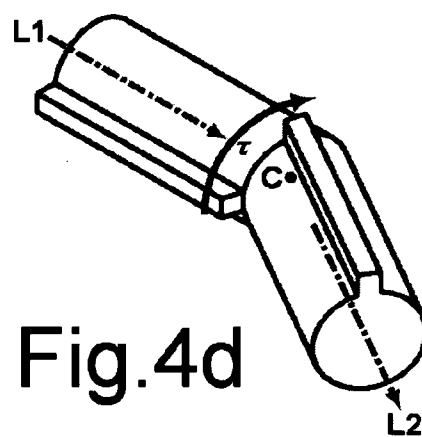
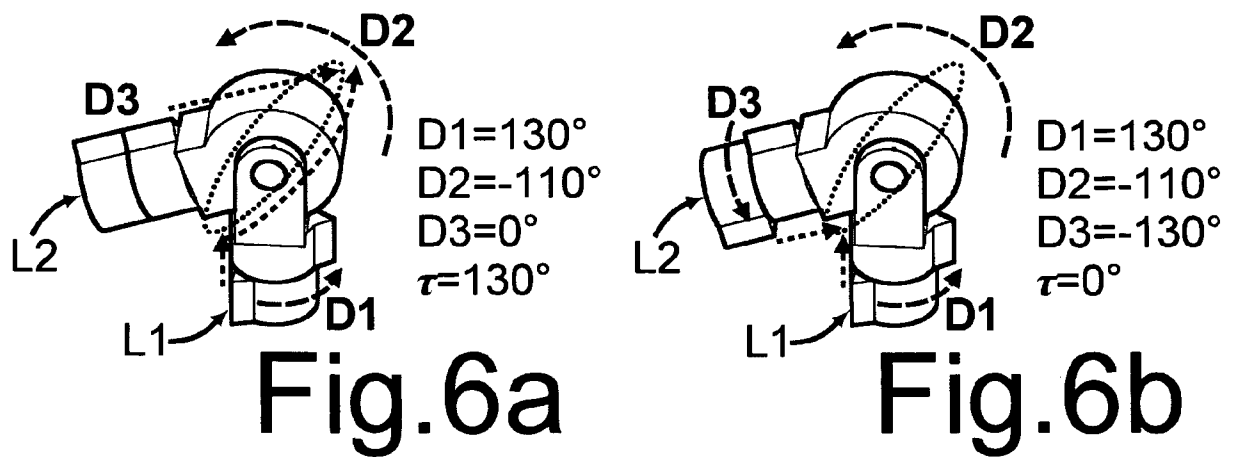
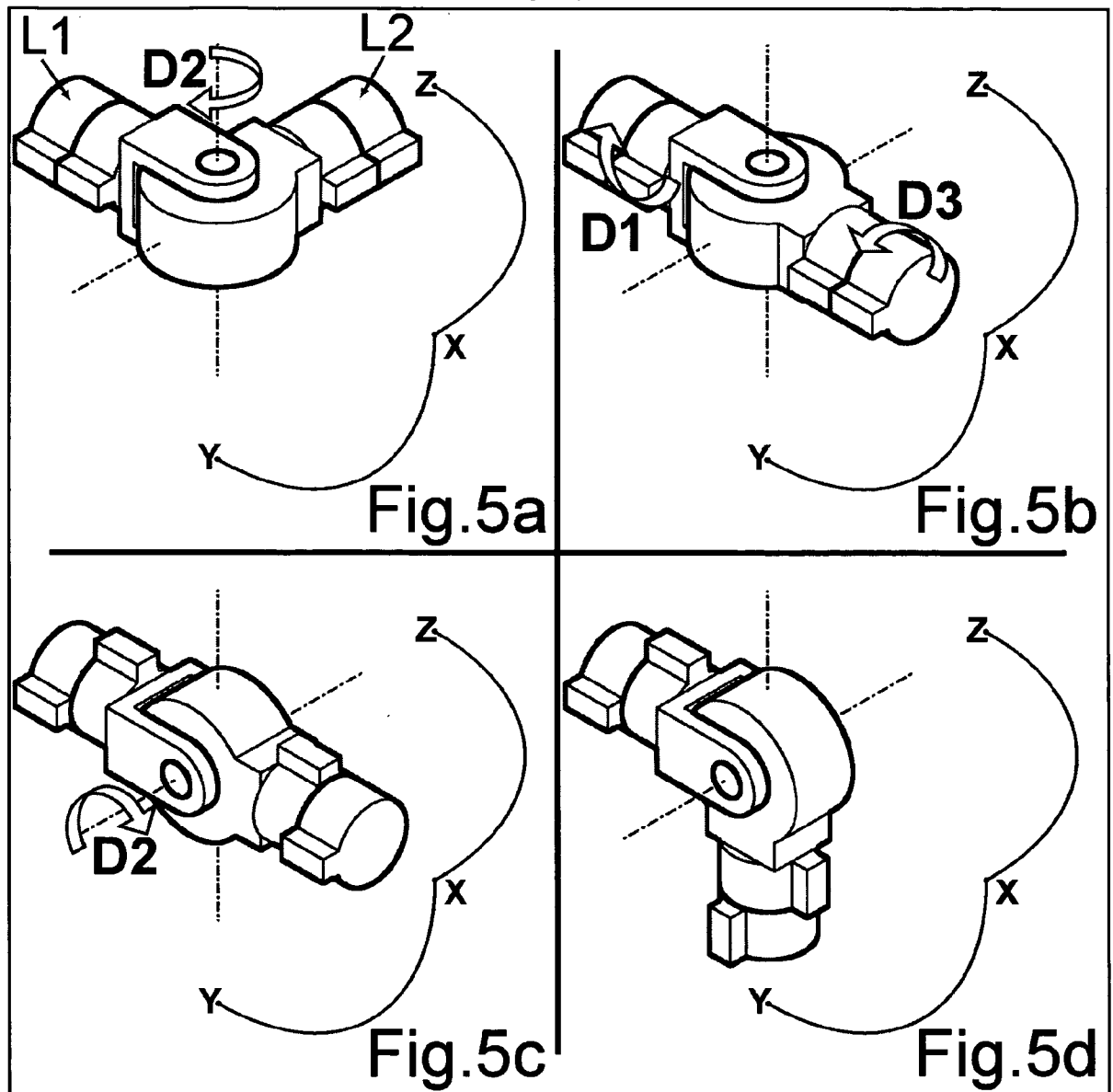
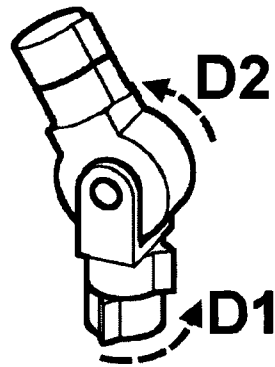


Fig.4d

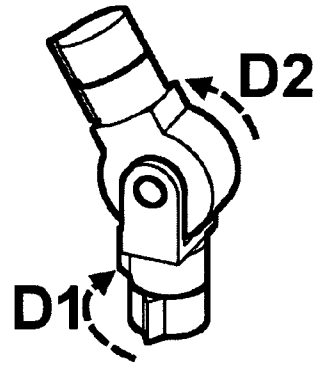
3/20



4/20

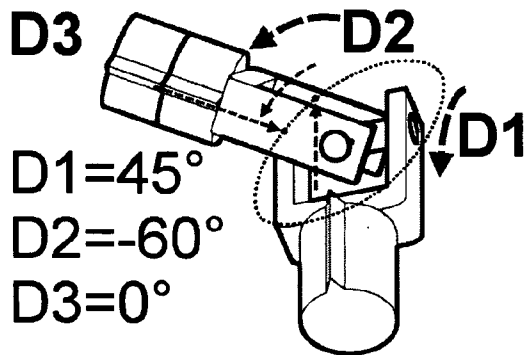


$D1=90^\circ$
 $D2=-30^\circ$
 $\phi=-90^\circ$
 $\theta=30^\circ$



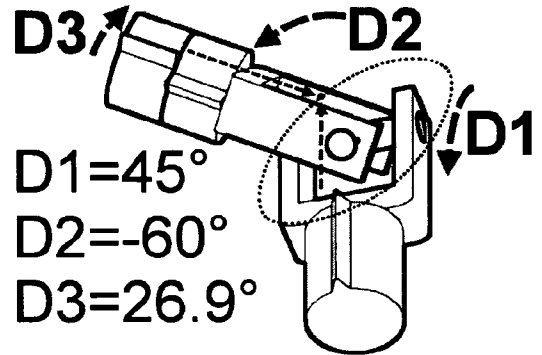
$D1=-90^\circ$
 $D2=30^\circ$
 $\phi=-90^\circ$
 $\theta=30^\circ$

Fig.7



$D1=45^\circ$
 $D2=-60^\circ$
 $D3=0^\circ$

$\tau=-26.9^\circ$ Fig.8a



$D1=45^\circ$
 $D2=-60^\circ$
 $D3=26.9^\circ$

$\tau=0^\circ$ Fig.8b

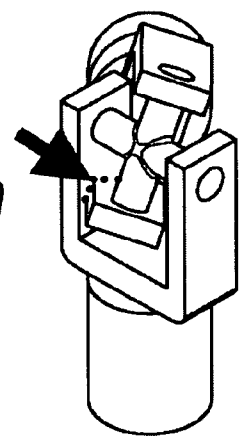
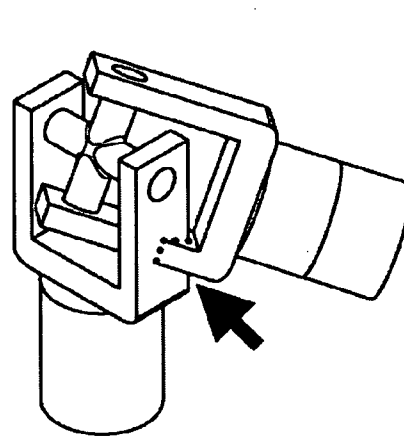
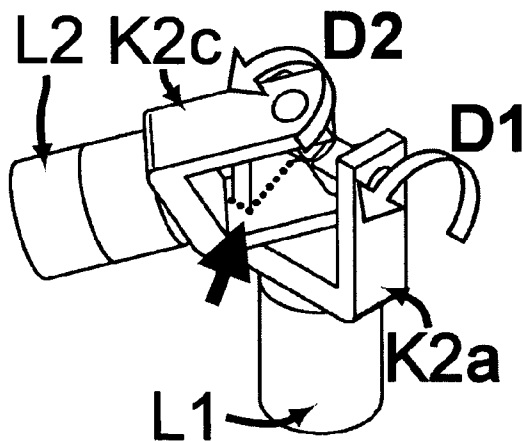


Fig.9a

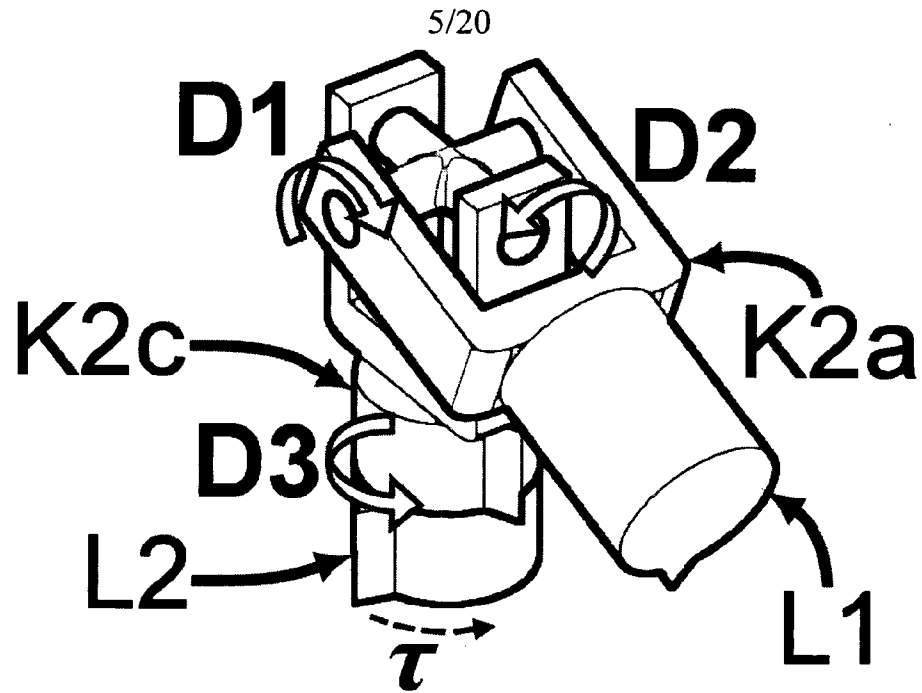


Fig. 9b

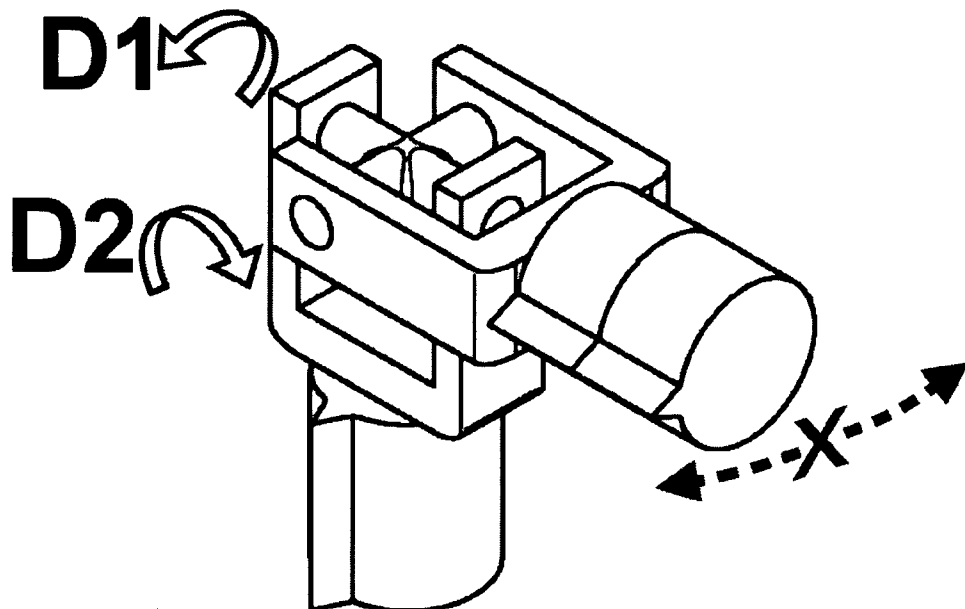
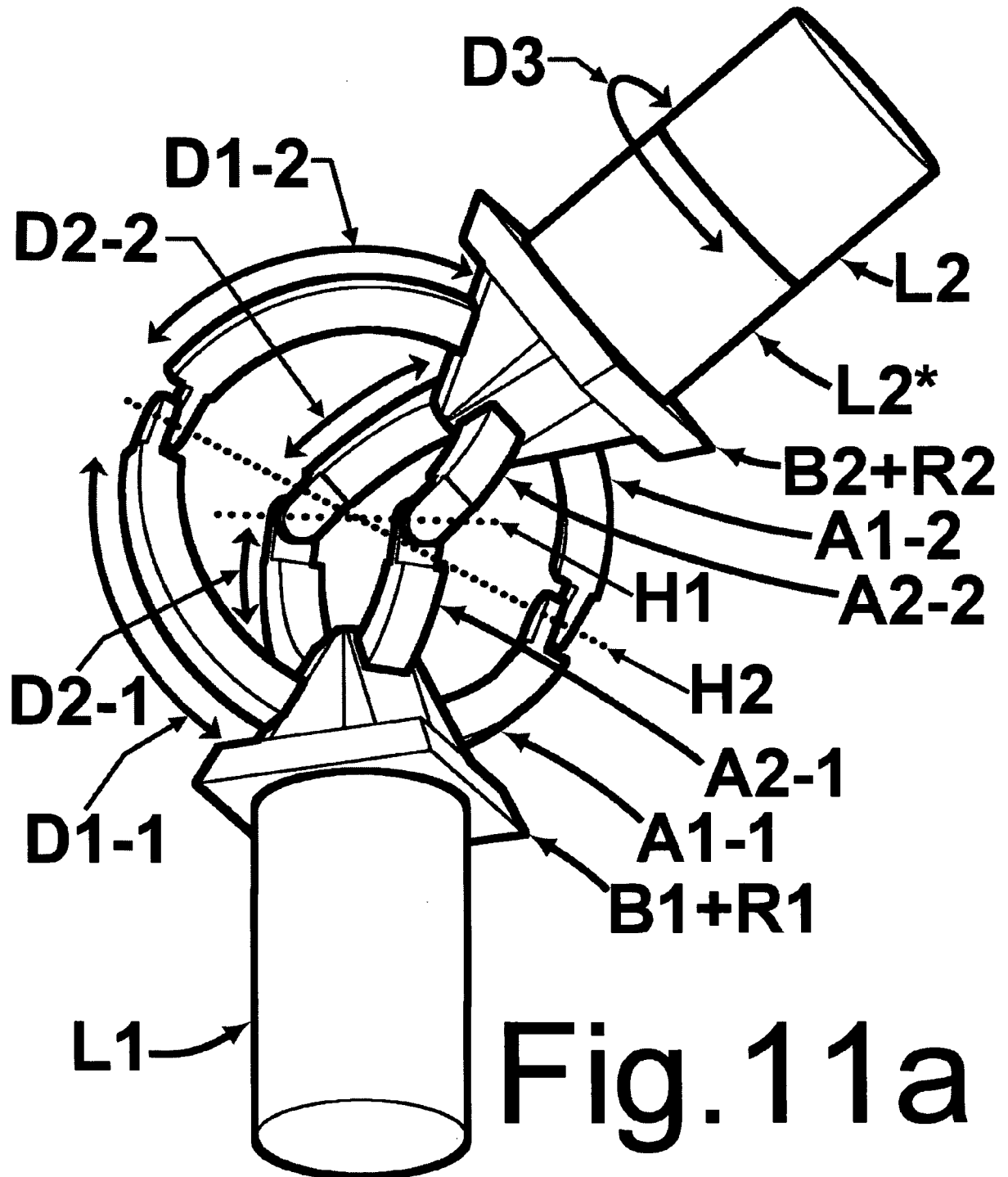


Fig. 10



7/20

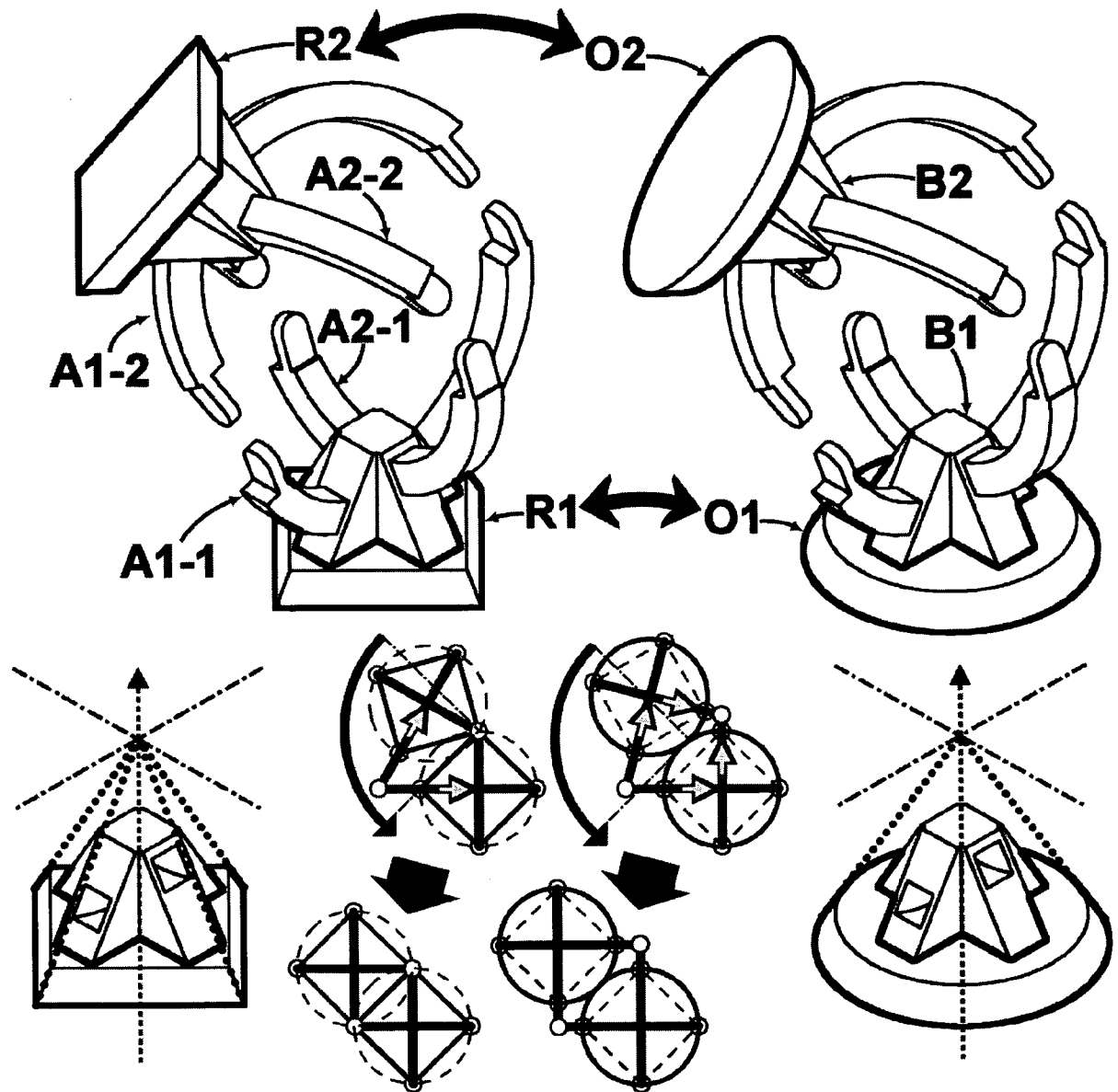
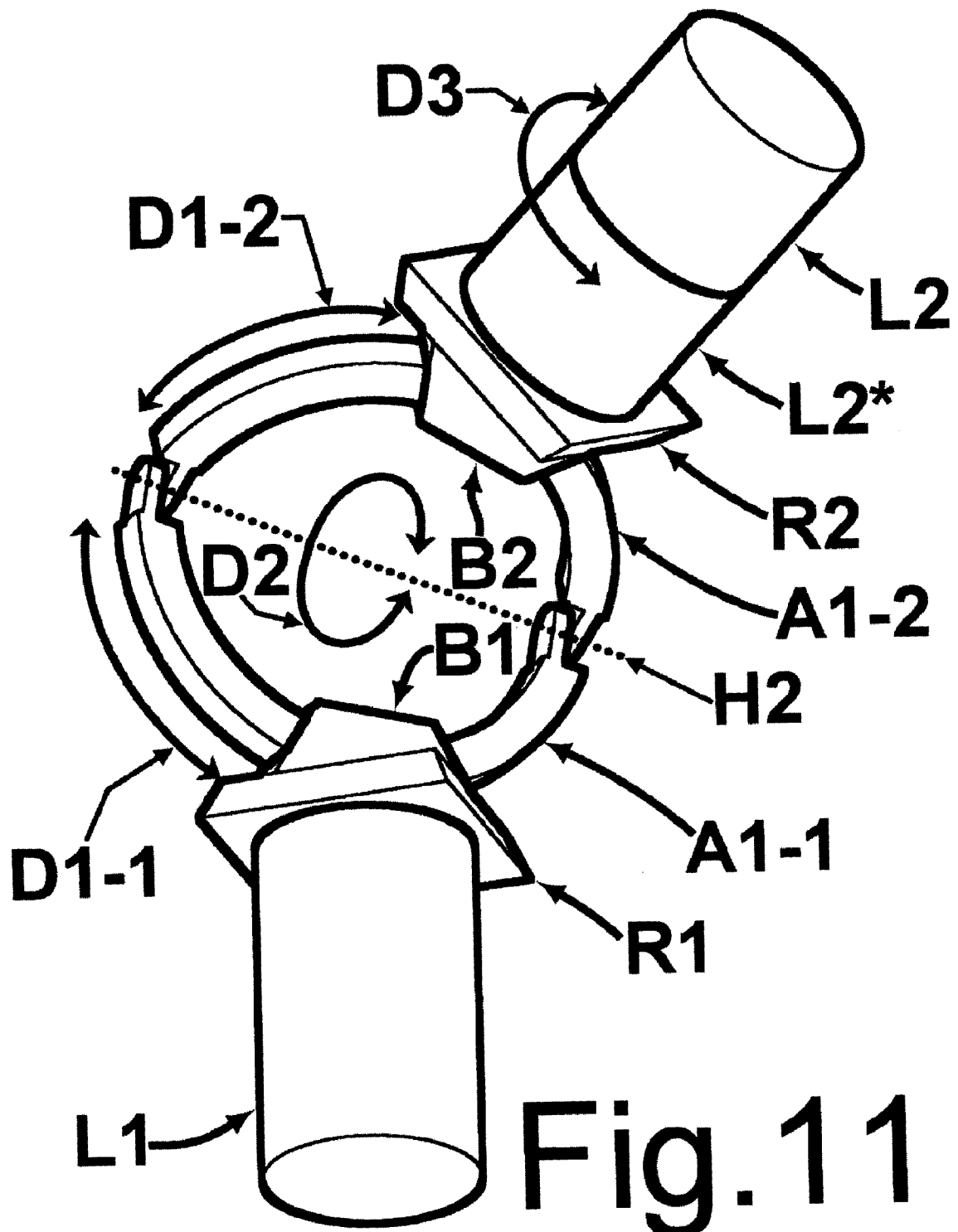


Fig. 11b

8/20



9/20

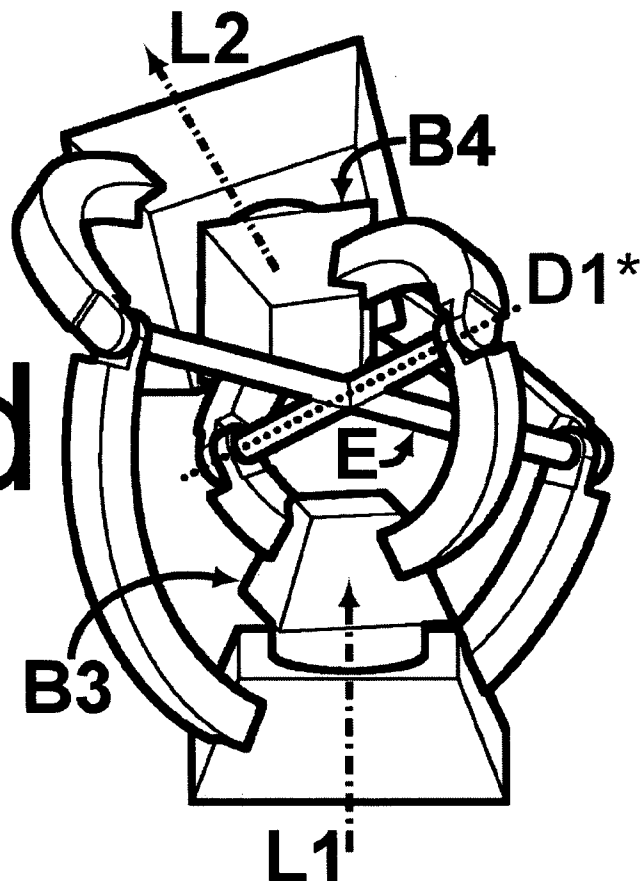
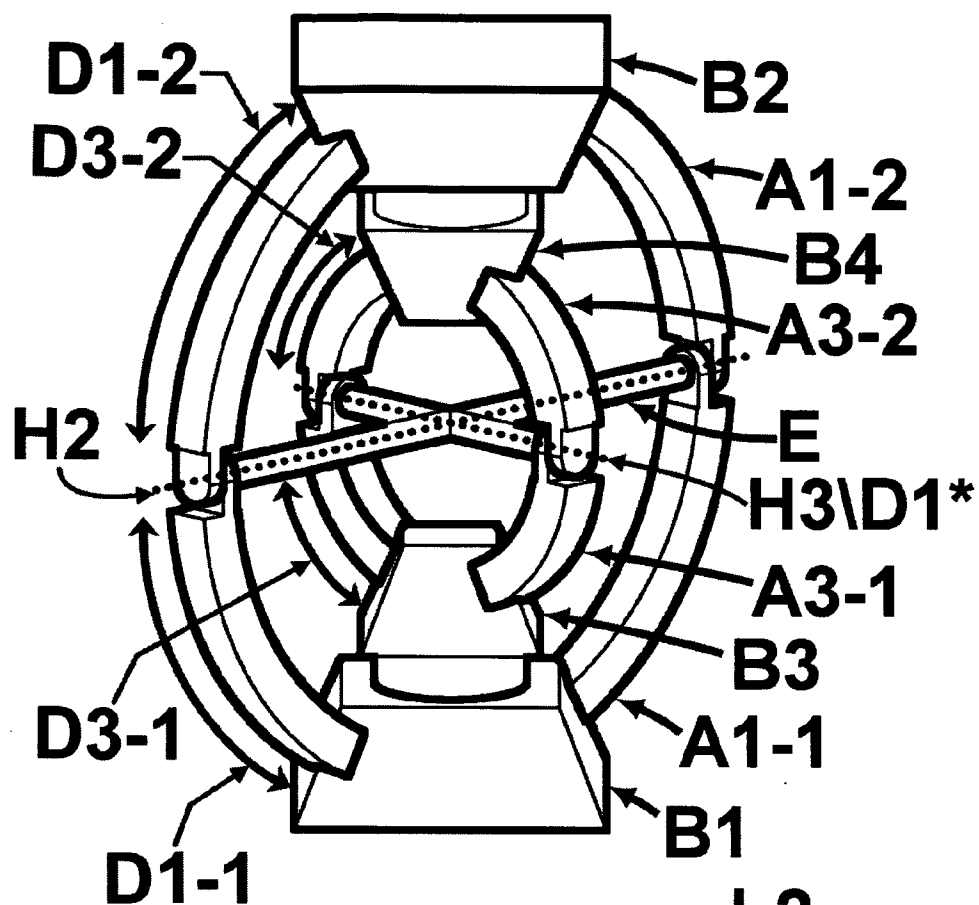
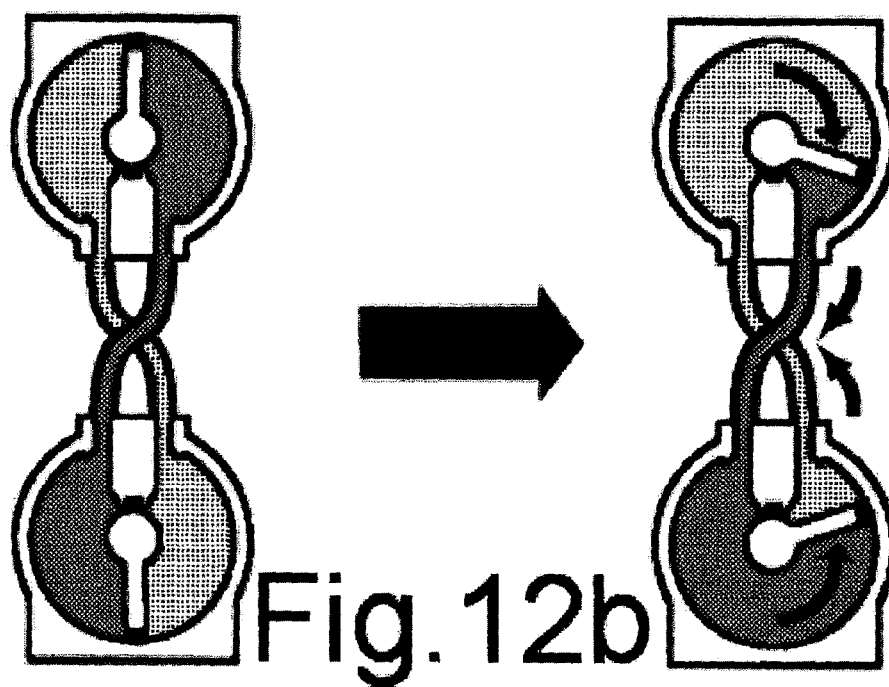
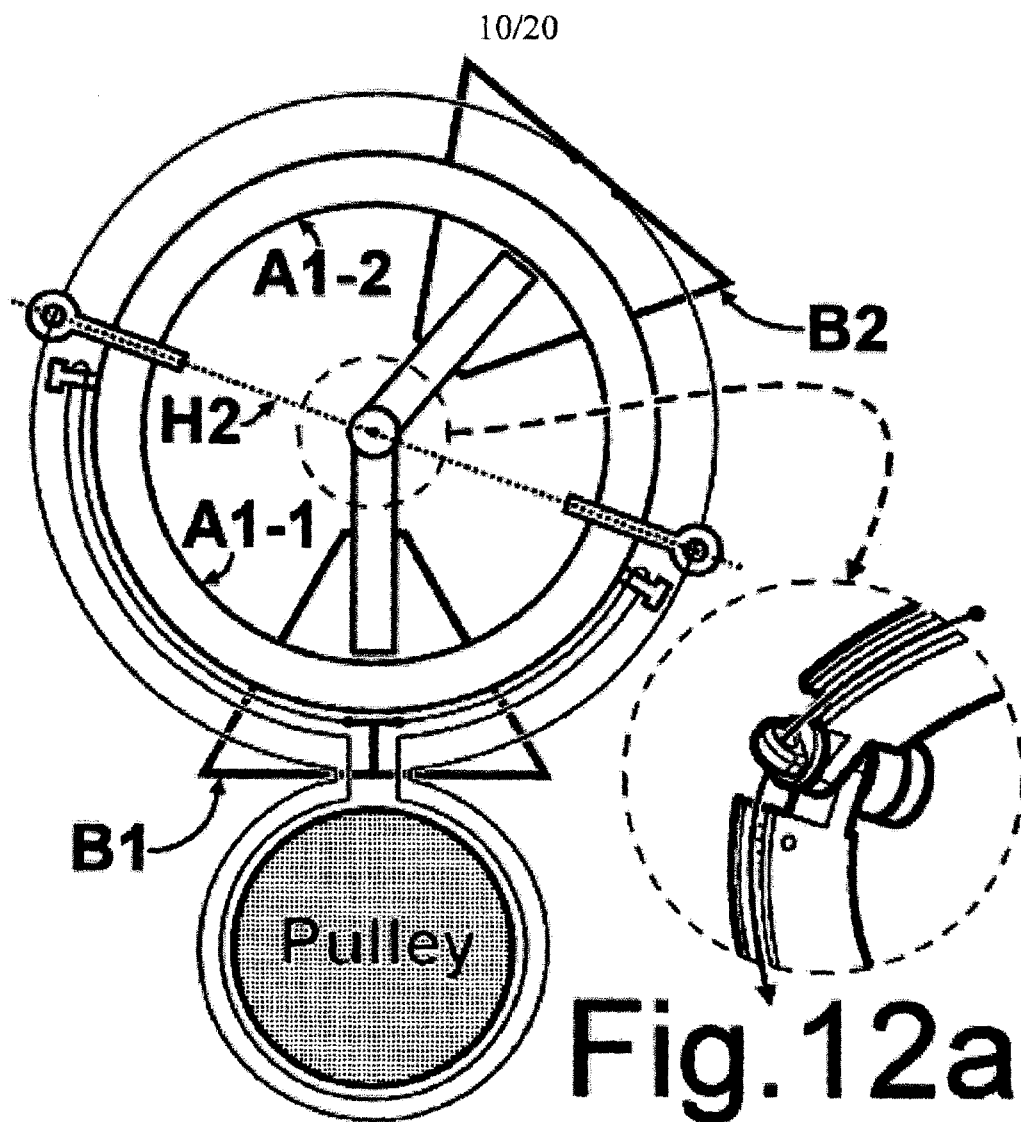


Fig. 11d



11/20

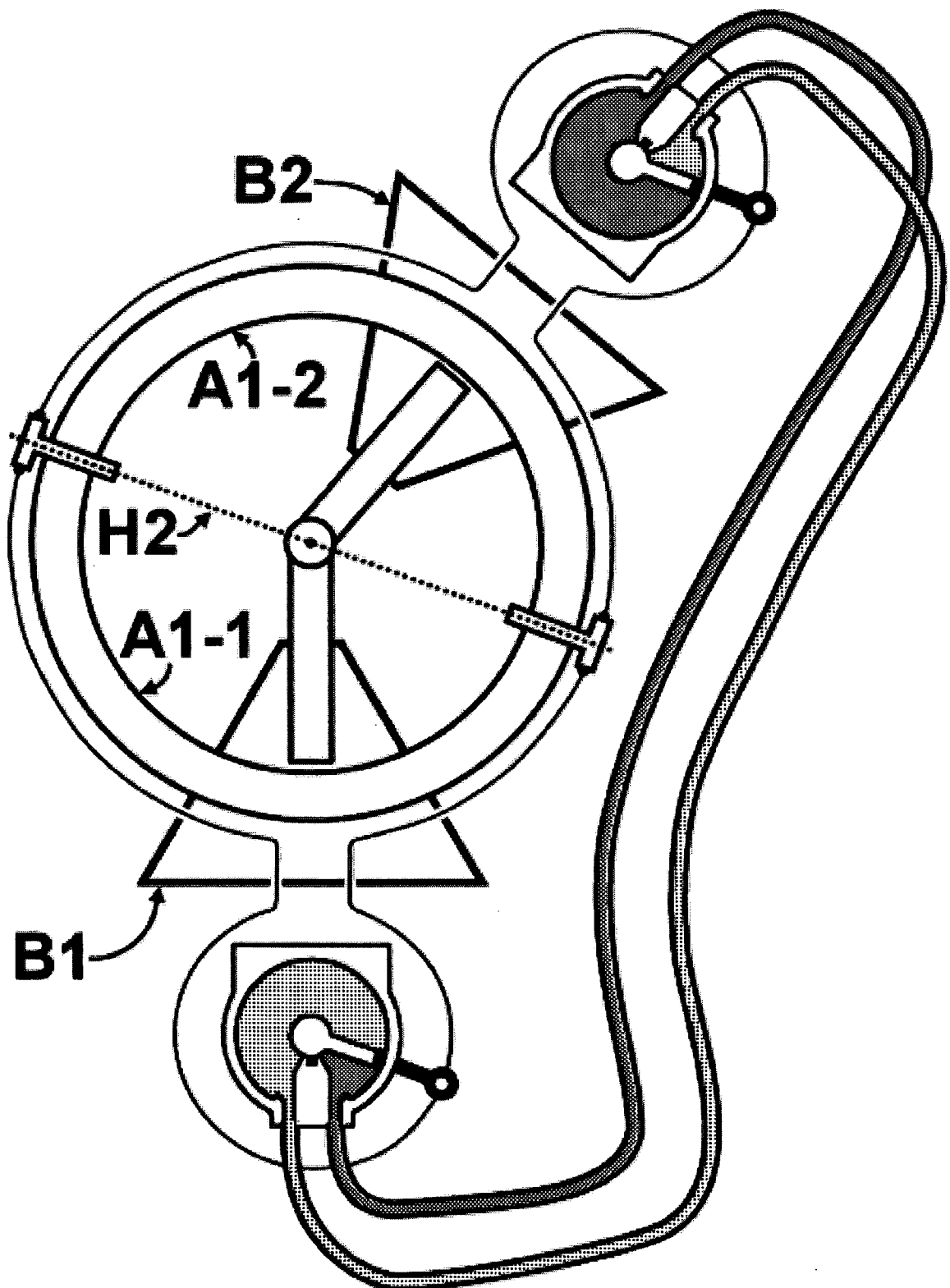
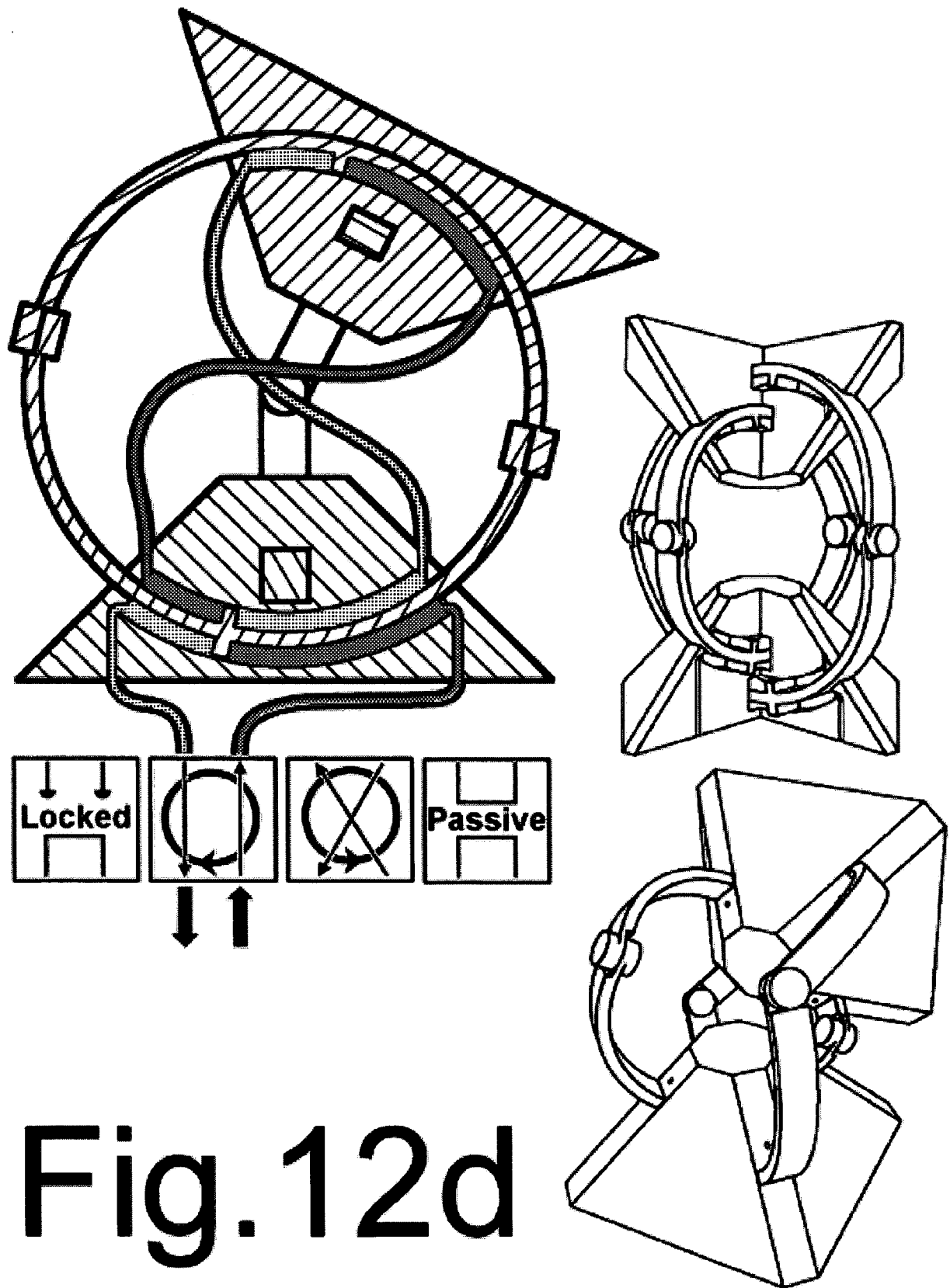


Fig. 12c

12/20



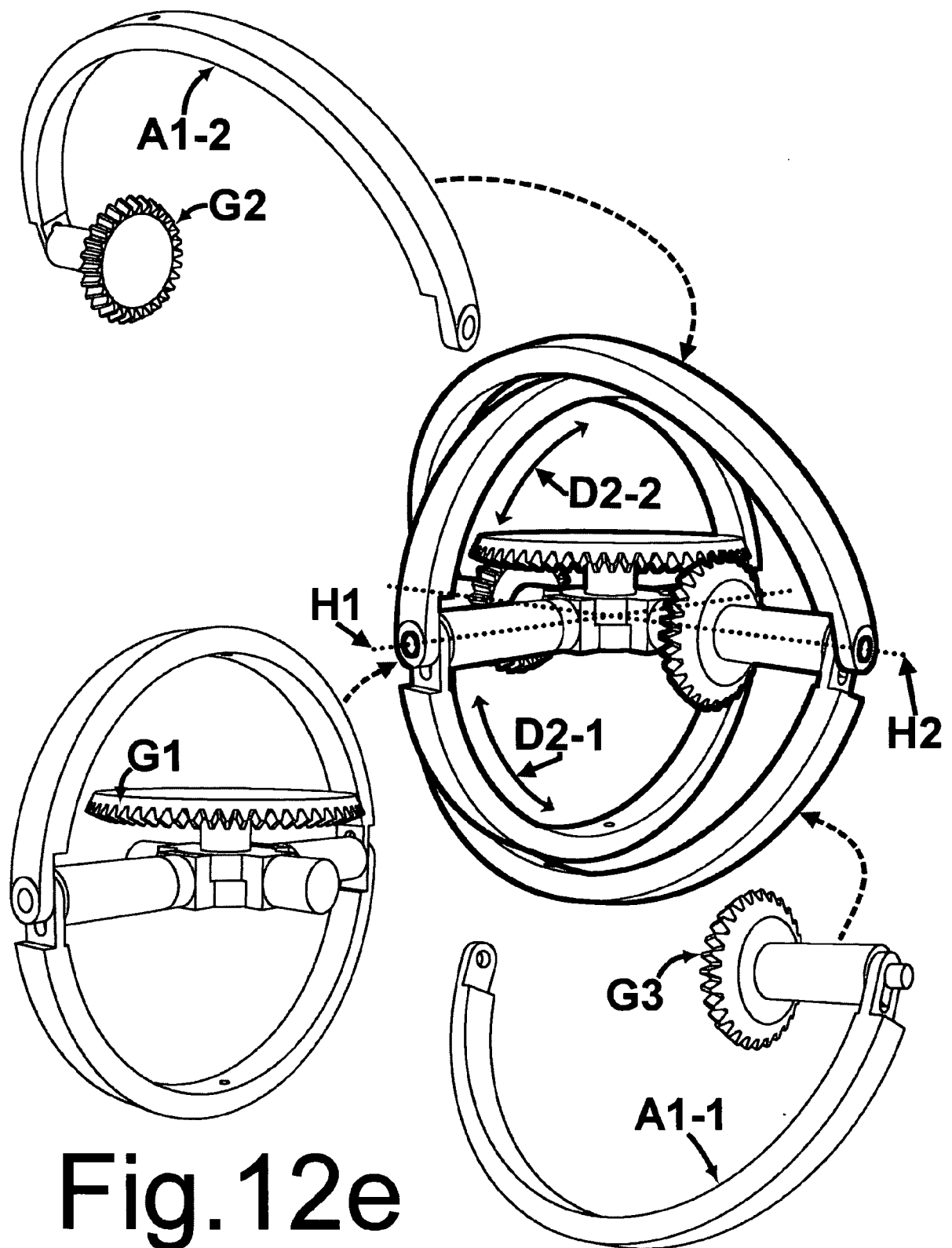
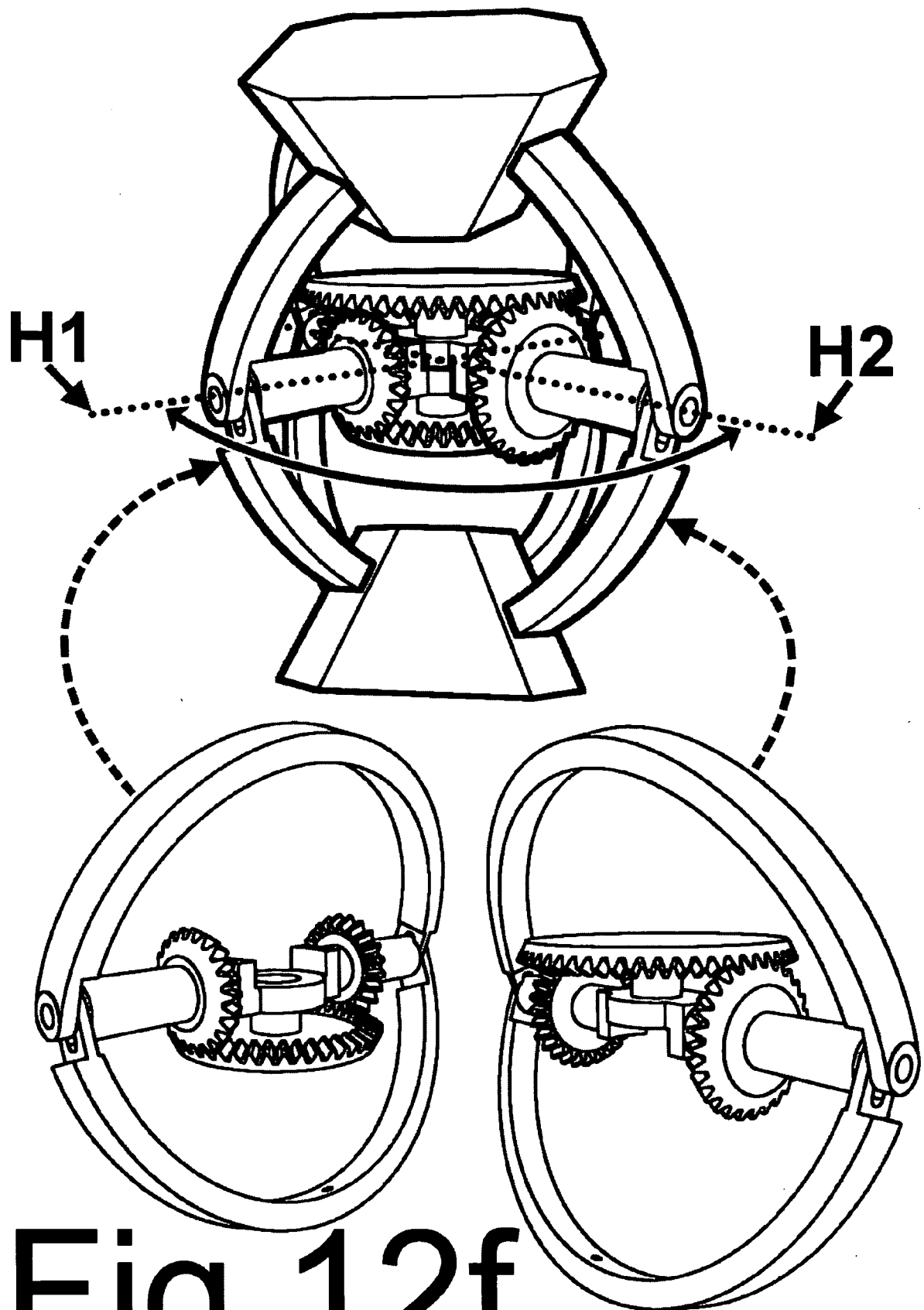


Fig.12e

14/20

**Fig. 12f**

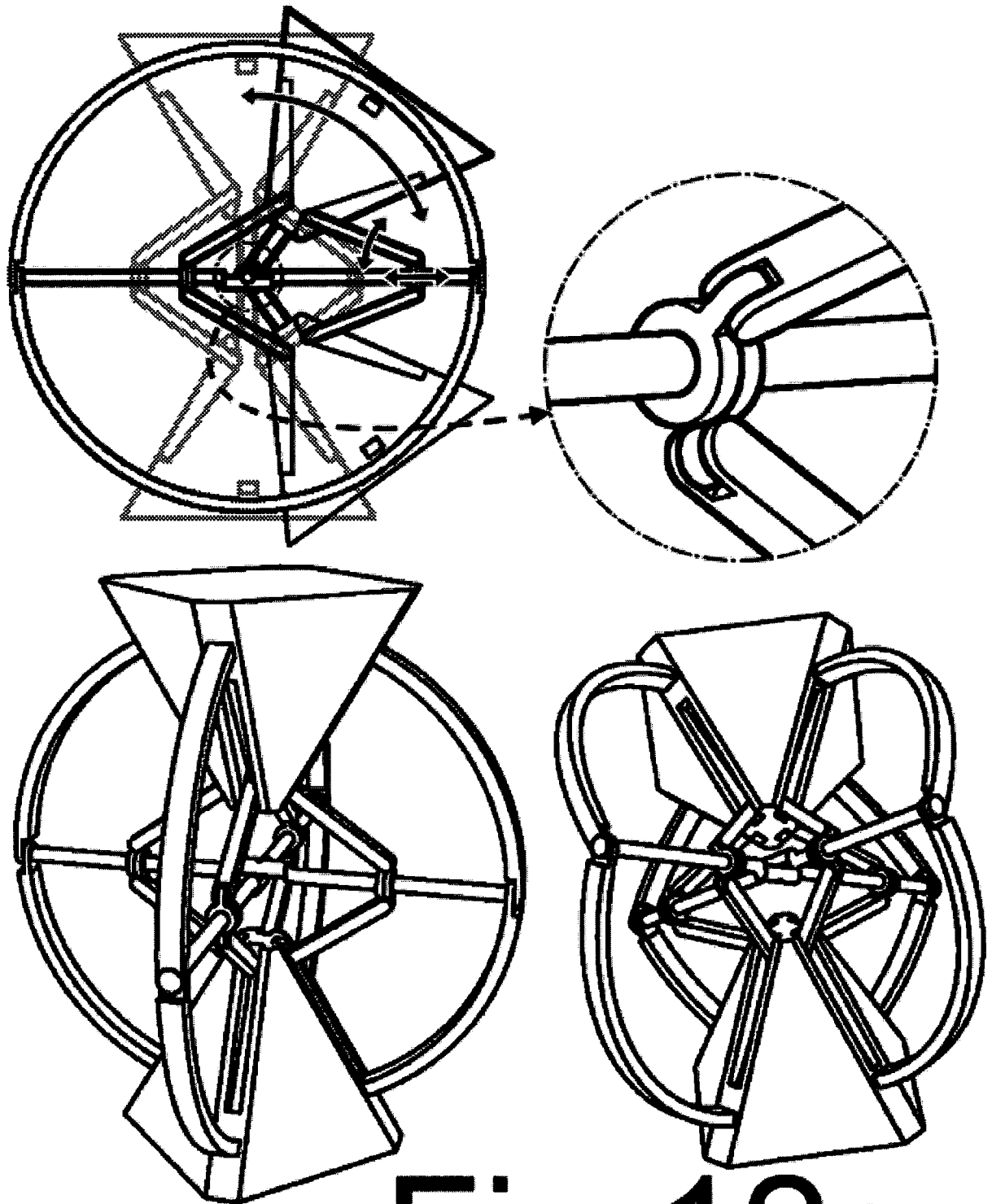


Fig. 12g

16/20

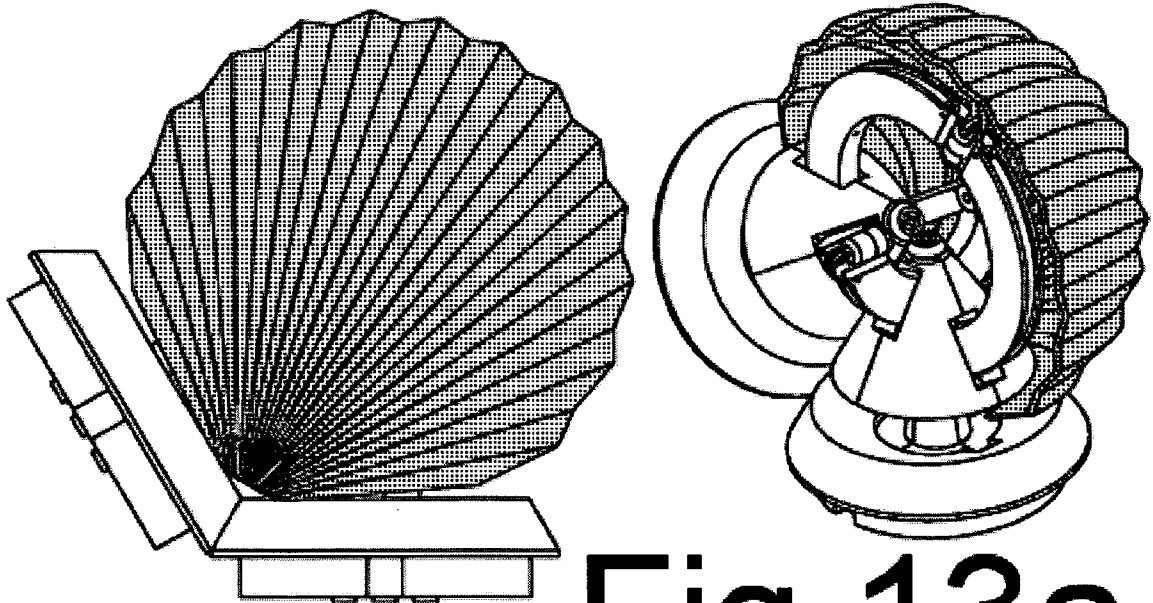


Fig. 13a

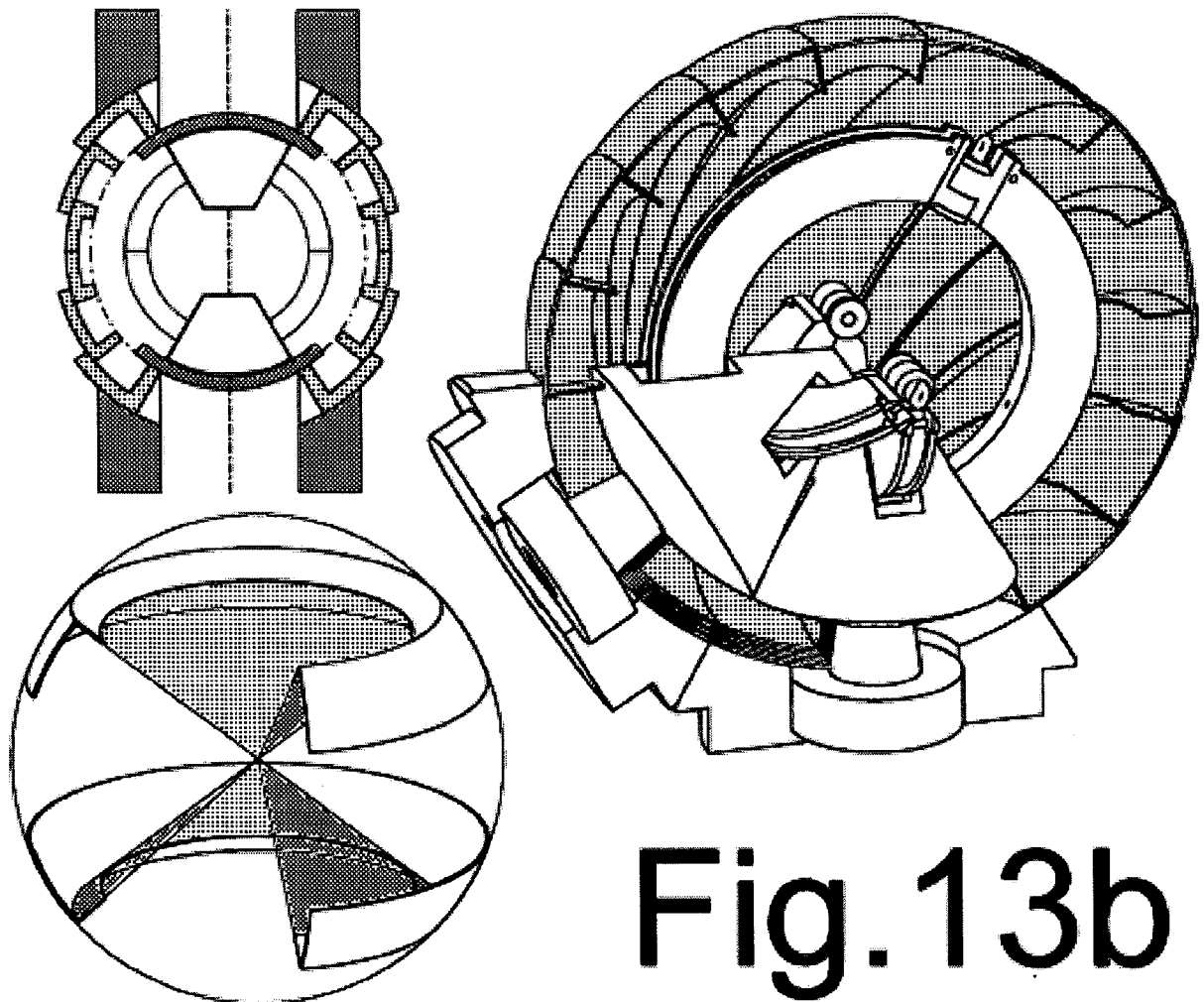


Fig. 13b

17/20

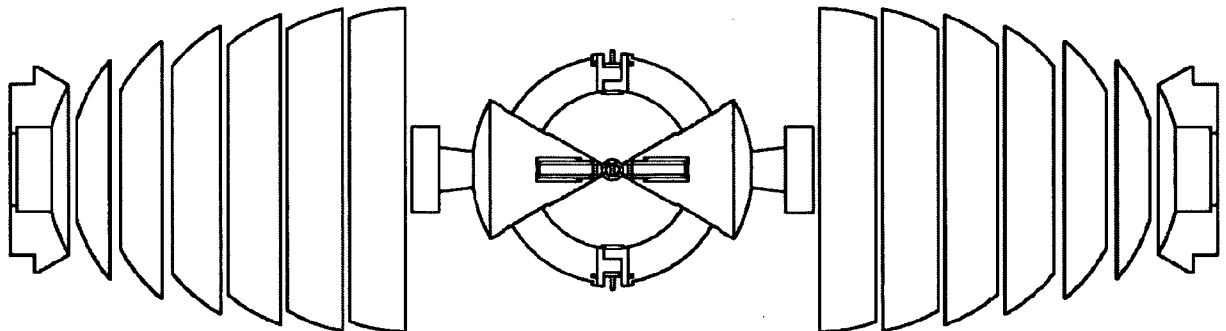


Fig. 13c

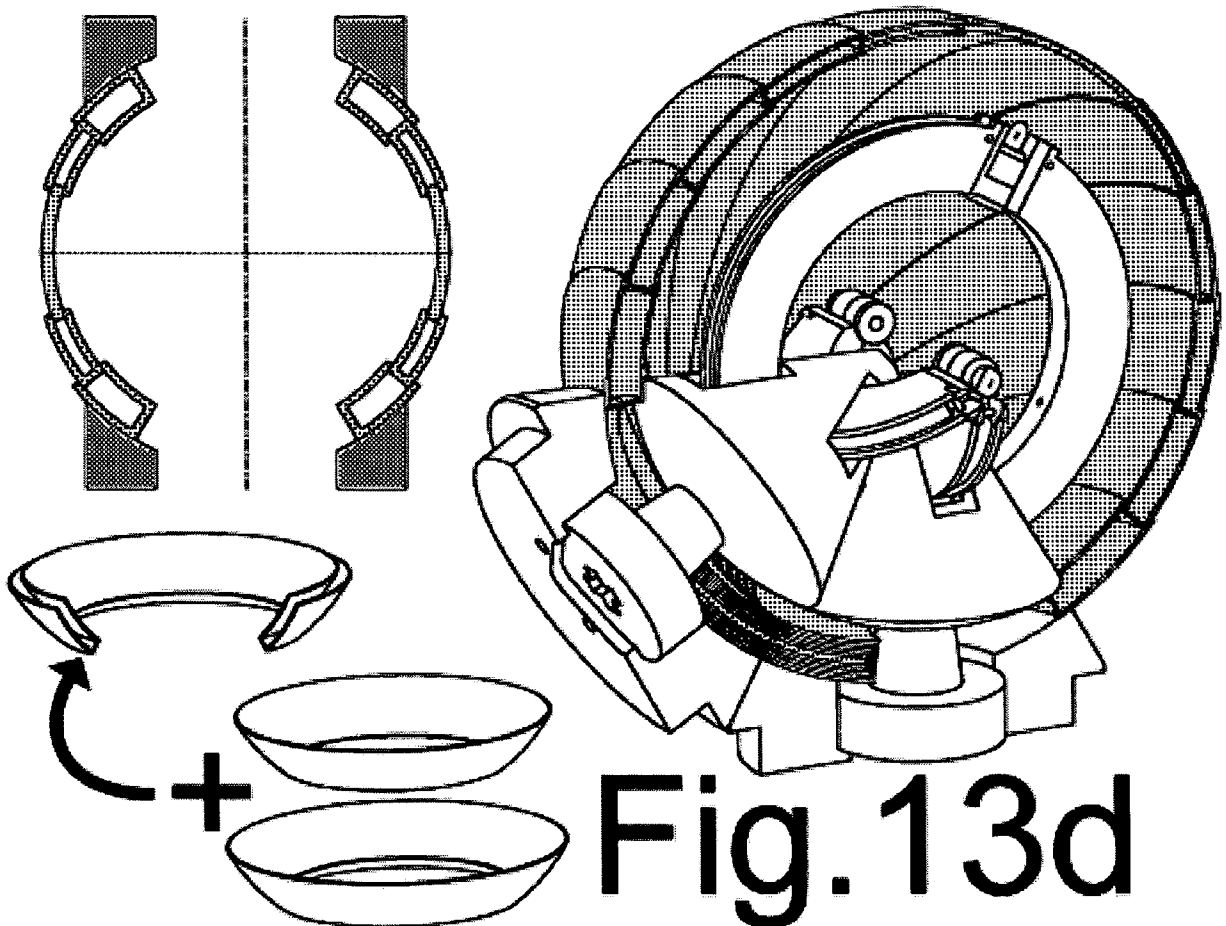


Fig. 13d

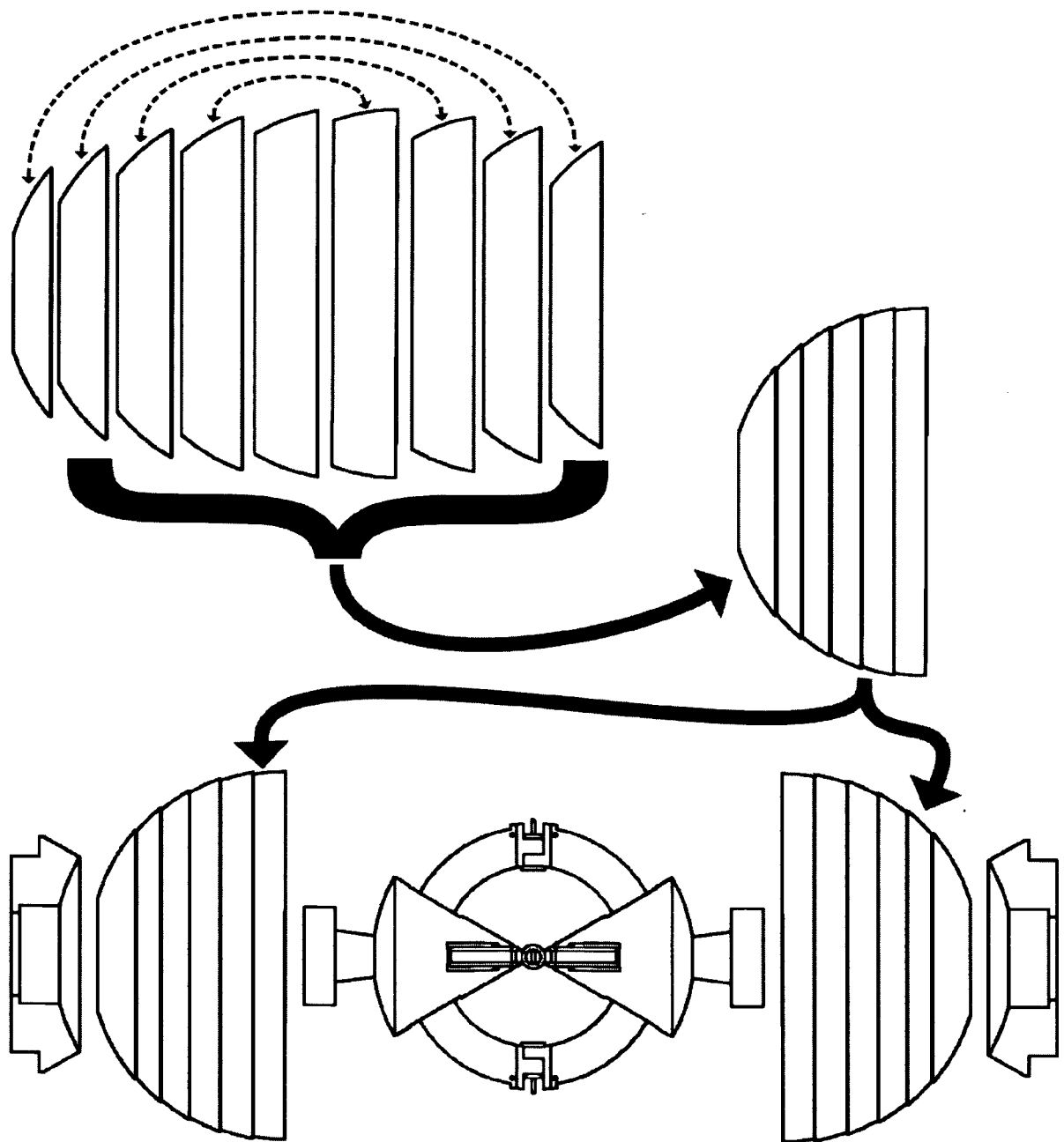


Fig. 13e

19/20

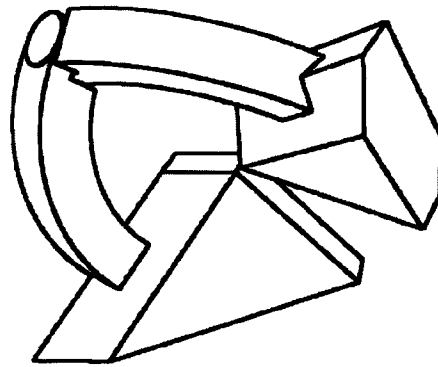
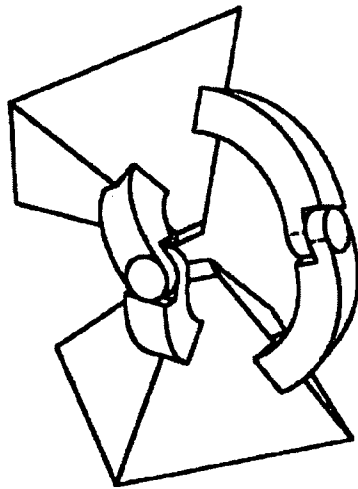


Fig. 14a

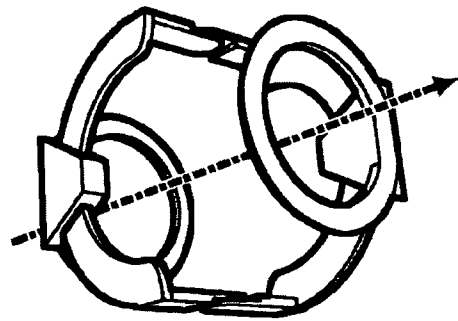
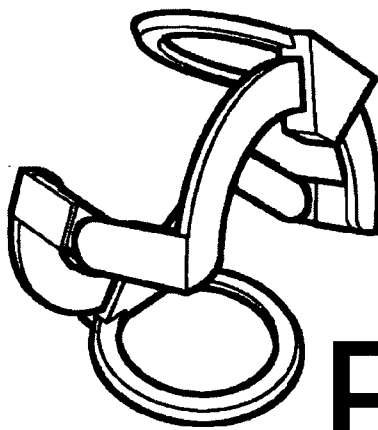


Fig. 14b

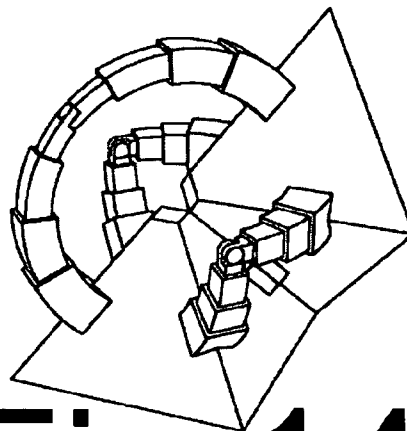
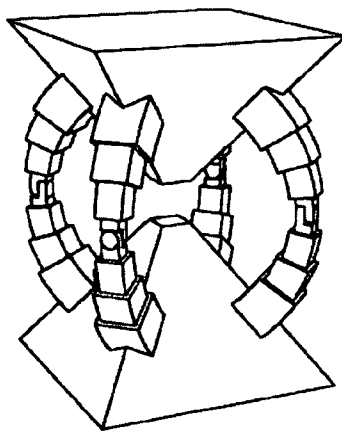
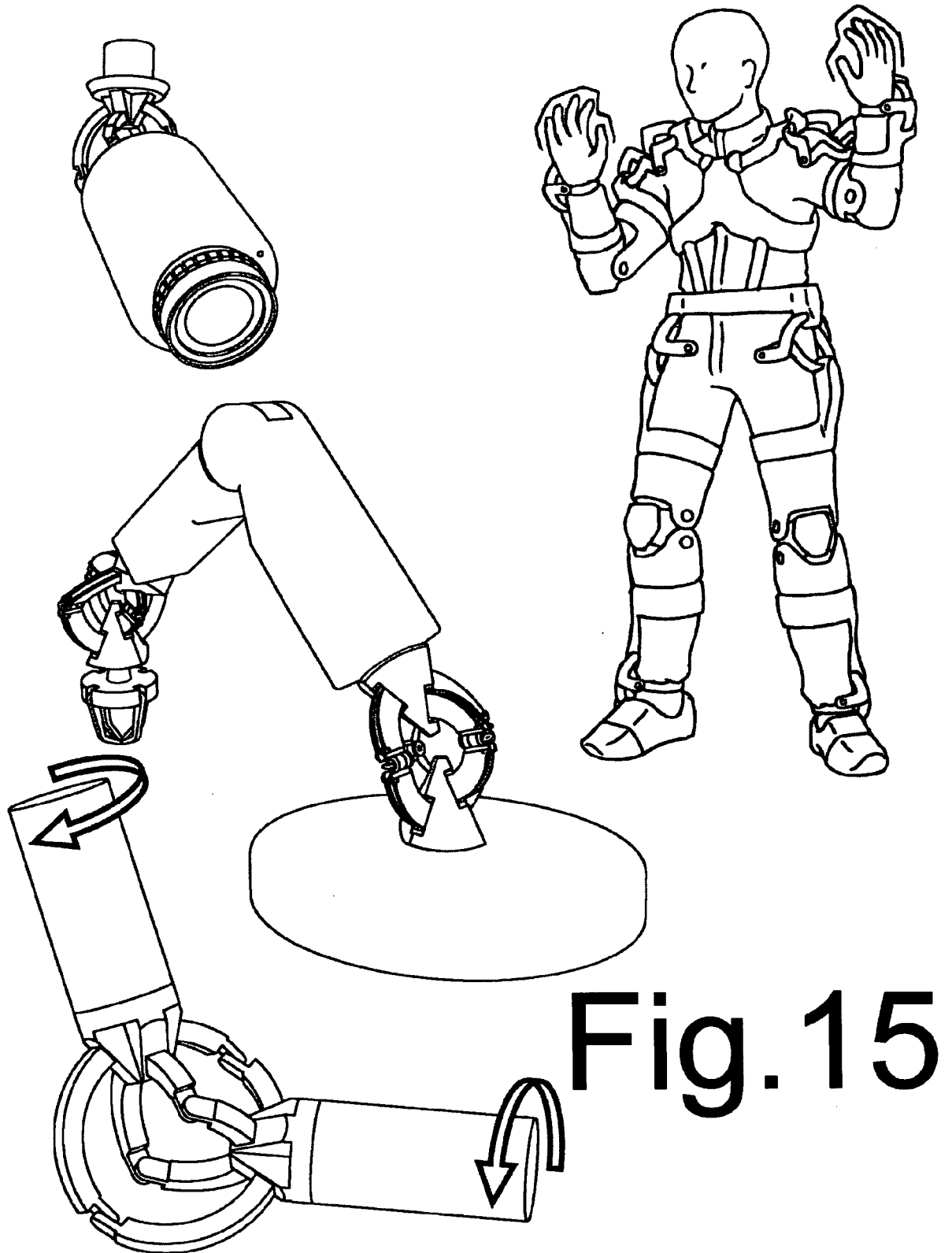


Fig. 14c

20/20



INTERNATIONAL SEARCH REPORT

International application No.

PCT / EG 2010/000037

A. CLASSIFICATION OF SUBJECT MATTER		
IPC: F16C 11/06 (2006.01); B2SJ 17/02 (2006.01); F16D 3/16 (2006.01); F16D 3/84 (2006.01)		
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)		
IPC: F16C , B25J, F16D		
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)		
EPODOC, WPI, X-FULL		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009026937 A2 (ABOZAIED, EL SAEID) 5 March 2009 (05.03.2009) Fig. 8a-8d, 13a-13d	1-9
X	US 4878393 A (DUTA , STANISIC) 7 November 1989 (07.11.1989) Fig. 2-4, 6, column 3 lines 5-24, column 3 line 49 - column 4 line 37	1-7
☒ 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		Date of mailing of the international search report
9 May 2011 (09.05.2011)		16 May 2011 (16.05.2011)
Name and mailing address of the ISA/AT		Authorized officer
Austrian Patent Office Dresdner Strasse 87, A-1200 Vienna		EHRENDORFER K.
Facsimile No. +43 / 1 / 534 24-535		Telephone No. +43 / 1 / 534 24-367

INTERNATIONAL SEARCH REPORT

International application No.

PCT / EG 2010/000037

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the national application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Subject matters of claims 1-7 (joint) on the one hand and subject matters of claims 8, 9 (cover) on the other hand deal with different inventions.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is only those claims for which fees were paid, specifically claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT / EG 2010/000037

Patent document cited in search report			Patent family member(s)			Publication date
WO	A2	2009026937	WO	A2	2009026937	2009-03-05
			WO	A9	2009026937	2010-07-29
US	A	4878393	US	A	4878393	1989-11-07