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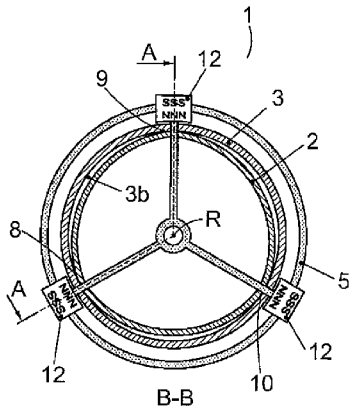


Fig. 2a

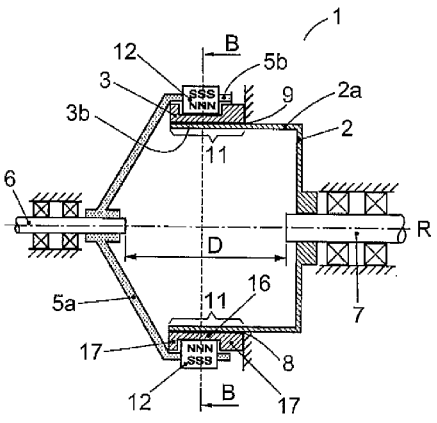


Fig. 2b

(57) **Abstract**: A harmonic traction drive (1) comprising a wave generator (4) connected to an input shaft (6), a fixed and circular spline (3), and a flex spline (2) connected to an output shaft (7) arranged to obtain a speed reduction. The wave generator (4) comprises a rotating carrier (5) arranged with at least one high-strength magnetic means (12) and the flex spline (2) comprises a magnetic part (11). The rotating carrier (5) and the flex spline (2) are arranged such that the magnetic means (12) and the magnetic part (11) of the flex spline (2) are situated on one side each of the fixed and circular spline (3). During operation, the magnetic part (11) of the flex spline (2) is deformed into frictional engagement with the circular spline (3) in at least one zone of contact (8). In this manner a 'traveling wave' is set up in the flex spline.

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Harmonic friction drive

TECHNICAL FILED

The present invention relates to harmonic friction drive units.

BACKGROUND ART

Electric motors are commonly used as prime motive power for many industrial applications. Due to its low cost and compatibility with electrical control systems, the electric motor is amongst the most commonly-used prime movers for industrial robots. However, its low-torque, high-speed characteristic is contrary to the requirements of high torque, low-speed joint actuation and so speed-reduction gearing is generally required. Robot joint actuation places high demands on gearbox performance. A solution is required that has a high reduction ratio, high torsional stiffness and low backlash while satisfying the additional constraints of low mass and low cost. The harmonic drive is considered one of the most suitable choices of gearing where performance alone is at issue, yet its relatively high cost is a major limitation where cost is the overriding criterion.

For robotic applications a typical drive solution is to use an electric motor in conjunction with a harmonic drive gear reducer. A harmonic drive is a gear reduction device that exploits material flexibility in order to achieve a high reduction ratio with minimal backlash. In comparison to conventional multi-stage spur gear trains of similar reduction ratios, the harmonic drive offers a more compact and lightweight drive of simpler construction which lends itself well to high precision applications such as robotics.

The operating principle of the harmonic drive gear reducer is shown in Figure 12. The three main components in a typical harmonic drive are a flex spline, a circular spline and a wave generator. The input, output and fixed components are interchangeable amongst these components, but in

the embodiment shown in Figure 9, the input is the wave generator, the output is the flex spline and the circular spline remains stationary. The flex spline 1 consists of a flexible tube that is closed at one end and upon whose outer surface are cut gear teeth. The wave generator is an elliptical cam 2 around whose periphery is placed a bearing 3. The wave generator locates inside the flex spline, such that the flex spline deforms elastically into an elliptical shape. The flex spline locates inside the circular spline 4, which is a rigid gear having internal teeth. There are $2n$ (where n is a positive integer) fewer teeth on the flex spline than on the circular spline. The teeth of the flex spline mesh with those of the circular points at the two lobes at either end of the major axis of the ellipse. Rotary input is applied to the wave generator cam, causing the deformed elliptical shape of the flex spline to rotate. In this manner a "traveling wave" is set up in the flex spline. Due to the disparity in the number of teeth between the two gears, rotation of the flex spline ellipse shape causes the flex spline itself to rotate in the opposite sense to the cam and at a reduced speed. The reduction ratio achievable using this drive is given by the number of teeth on the flexible spline divided by $2n$.

With the emergence of new markets for flexible automation of small assembly work, there is a growing demand for small, low cost robots. However, since gearing accounts for up to 45 % of the direct materials cost in a robot, this market will remain untapped unless a low-cost, high-performance gearing solution becomes available.

Due to the difficulty of cutting teeth into the flexspline, the elimination of teeth from this component can potentially afford a substantial reduction in the cost of the drive. Toothless versions of the harmonic drive have also been proposed. In these designs, the wave generator is typically replaced by two or more rollers which press onto the flexspline, which in turn is pressed against the circular spline.

In a traction drive transmission, torque is transferred by virtue of the frictional forces acting parallel to pairs of contacting surfaces. A preload force acting normal to the contacting surfaces generates the friction force, which is a proportional to the friction coefficient.

One common traction drive arrangement is a planetary gear. Such design offers low backlash but, generally have lower torque to mass ratios and higher cost than harmonic drives. Furthermore, since they lack the fixed relationship between input and output speed afforded by meshing teeth, all traction drives are susceptible to slip. Slip may be divided into two categories: gross slip and micro slip. Gross slip occurs when the turning moment on the output shaft exceeds the moment generated at the friction interface, and may arise as a result of, e.g. a shock load such as a collision. Micro slip arises as a result of cyclical circumferential elastic stretching and contraction of the contacting surfaces.

The preload force which presses the rollers against the flexspline is typically generated by springs (e.g.US6439081B1; DE4320901), but can also be generated by the load moment itself (e.g. US7118512). However in the latter case, the result is a unidirectional drive which "freewheels" upon reversal of the load.

US6439081 teaches a harmonic friction drive comprising a rigid ring having a cylindrical inside surface of a given circumference, the inside surface being free of gear teeth. A member having a flexible tube portion is nested in the rigid ring. The flexible tube portion has an outer surface whose circumference is smaller than the given circumference. The outer surface is also free of gear teeth. A wave generator pushes the outer surface of the flexible tube portion into frictional engagement against the inside surface of the ring, at two or more zones of contact along the inside surface and rotates the two or more zones of contact about the inside surface of the ring. The difference in circumference between the outside surface of the flexible tube portion and the inside surface of the ring causes the flexible tube portion to rotate a small amount relative to the ring upon each complete revolution of the wave generator.

US7118512 teaches a self-actuating traction drive speed changer comprising a movable force input element having a planar drive surface, and a movable force output element having a planar drive surface which is connectable to an output load. One or more movable roller elements has a planar drive surface operatively connected for movement to the input element, and are in frictional engagement with the planar drive surface of the output element so that movement of the

input element will cause the planar drive surface of the roller element to engage and frictionally move the output element.

DE4320901 teaches a friction-wheel harmonic drive. The supporting forces required for the axial adjustment of the rollers and for pressing them against the rigid wheel are introduced via conical surfaces formed integrally on the rollers. Considerable friction forces, which lower the efficiency of the drive, occur between the conical surfaces of the rollers and the mating surfaces of the bodies serving as counter supports. Alignment errors between the drive shaft and the axle of the roller holder furthermore have the effect that the angular velocity of the rollers and the forces exerted by the rollers on the elastic wheel are not exactly identical. This increases the slip. These problems are avoided if the force required for the axial displacement of the rollers is introduced directly at the roller axles and if an articulated coupling is arranged between the drive shaft and the roller axle.

In a traditional toothed harmonic drive, the flexspline is deformed into an elliptical shape by virtue of an elliptical shaped arbor rotating inside a flexible-raced ball bearing. However, if this approach is used in a toothless traction drive, then the bearing will be exposed to a greater radial preload force, which is required to generate friction at the flexspline-circular spline interface. The flexible bearing is dimensioned to withstand the forces in a toothed harmonic drive and so increased load will inevitably shorten its lifetime. It is a specialised component that is not generally available as a stock product and so to simply purchase a higher capacity bearing is not necessarily a feasible solution.

Due to the need to withstand high radial preload forces in a traction drive, a more durable wave generator solution is to use two or more individual circular rollers. Such roller bearings are widely available in a range of sizes and load capacities and are lower in cost than the specialised flexible wave generator bearings. The disadvantage of using three rollers is that a means of pressing them against the flexspline must be found. The simplest approach is to apply a constant preload sufficient to ensure that the drive does not slip at its maximum expected torque. However, this places unnecessary load on the roller bearings and contact surfaces, and impacts

upon efficiency when the drive is lightly loaded. Furthermore, since the rollers are located within the flexspline, access is limited which hinders adjustment of preload once the drive is assembled.

Thus, there is a need to reduce the manufacturing costs, the weight and size weight as well as simplifying the control of a harmonic friction drive. The prior art harmonic friction drives do not fulfill this need.

SUMMARY OF THE INVENTION

The aim of the invention is to remedy the above mentioned drawbacks with harmonic friction drives defined, as mentioned above.

The above problem is according to the first aspect of the invention solved in that a device of the kind in question has the specific features that it comprises a harmonic traction drive comprising a wave generator connected to an input shaft, a fixed and circular spline, and a flex spline connected to an output shaft arranged to obtain a speed reduction. Further, the wave generator comprises a rotating carrier arranged with at least one high-strength magnetic means, the flex spline comprises a magnetic part, the rotating carrier and the flex spline are arranged such that the magnetic means and the magnetic part of the flex spline are situated on one side each of the fixed and circular spline and the magnetic part of the flex spline is deformed into frictional engagement with the circular spline in at least one zone of contact.

The design uses high-strength magnets to generate the normal force/preload force required to produce traction in a gearless harmonic traction drive, thereby eliminating wear, heat, noise and lubrication requirement associated with contacting rollers. Further, the design employs the basic operating principle of the harmonic drive gear reducer, but through the use of traction instead of meshing teeth as the means of torque transmission, the cost is reduced. Since no bearing is required to support the flexspline, the complexity of the design is reduced in comparison to both a conventional and rolling-element traction harmonic drive.

In common with all traction drives, the design is essentially backlash-free, since there are no meshing teeth. Further, there is no back drive and accordingly no braking function.

In a conventional toothed gearing system, the ability of the gearbox to be backdriven ensures that shock loads can be absorbed to some extent. In a non-backdriveable gear train, there exists the risk that the gearbox will sustain damage in the event of a sudden shock load on the output side. However, in the case of a traction drive, damage can be avoided if slip is allowed to occur above a certain load. This provides the functionality of a torque limiter.

Traction is defined as magnetic metal attraction between a wave generator comprising at least one permanent magnet and a flex spline at least partly made of magnetic material. The rigid circular spline situated in between the at least one permanent magnet and the flex spline is made of non-magnetic material and is transparent to magnetic forces. Thus, there is no physical contact between the permanent magnet and the flex spline. The use of magnets facilitates contactless delivery of the preload force.

According to a feature of the invention, the rotating carrier comprises two magnetic means symmetrically arranged for sequentially deforming a magnetic part of the flex spline into frictional engagement in two zones of contact. This arrangement minimises the force required to deform the flexspline and ensures that radial loads on the input shaft are balanced.

Noise is reduced since the non contacting preload force delivery and toothless rolling contact between flexspline and circular spline results in the elimination of noise from meshing teeth and wave generator bearings.

According to a feature of the invention, the rotating carrier comprises three magnetic means symmetrically arranged for sequentially deforming a magnetic part of the flex spline into frictional engagement in three zones of contact. This allows self-centring of the wave generator within the flexspline. Since the magnets do not actually come into contact with the flexspline, friction and wear only occur where the flexspline is in contact with the circular spline.

According to a feature of the invention, the high-strength magnetic means is a permanent magnet made of neodymium. Due to the high magnetic flux density, small, lightweight neodymium magnets are capable of generating very high attractive forces.

Since the magnets do not actually come into contact with the flexspline, also the lubrication used in a traditional rolling-element wave generator is unnecessary.

Reduced heat generation will be achieved since the magnets do not actually come into contact with the flexspline. There is no friction at this interface and so heat will not be generated in the magnets.

In a conventional toothed harmonic drive, the maximum reduction ratio is limited by the gear tooth module size. With current technology, this is around 0.75 mm, allowing reduction ratios of up to 320 to be produced. However, this particular limitation is not present in a traction drive, which allows higher ratios to be obtained.

According to a feature of the invention, the at least one contact zone is on the inside of the circular spline. This harmonic traction drive reduces the speed such that the output rotation is in the opposite sense to input rotation.

According to a feature of the invention, the at least one contact zone is on the outside of the circular spline. This harmonic traction drive reduces the speed such that the output rotation is in the same direction as the input rotation. This requires that the magnets are internal to the flexspline, thereby providing a compact, space-efficient arrangment. Furthermore, rotational inertia of the wave generator is minimised.

According to a feature of the invention, the flex spline is arranged pre-stressed. This results in modified mechanical properties of the flexspline. The advantage is that the radial elasticity is increased while maintaining a thick section.

According to a feature of the invention, the flex spline comprises at least one part made of magnetic material. In one alternative feature the magnetic part is a continous strip of flexible magnetic material adhered to the flex spline. This solution minimizes fluctuations in output

torque. Another alternative is rectangular cross-section segments arranged in parallel providing a non continues flexing surface. The segments are of a slender cross-section, with radial dimension greater than circumferential dimension.

The magnetic means is denoted external magnets when the rotating carrier with the magnets is arranged outside the flexspline and the circular spline (e.g. Figure 5). The magnetic means are denoted internal magnets when the rotating carrier with the magnets is arranged inside the flexspline and the circular spline (e.g. Figure 7).

The above problem is according to the second aspect of the invention solved in that a method of the kind in question has the specific features that it comprises a method of operating a harmonic traction drive comprising a wave generator connected to an input shaft, a fixed and circular spline, a flex spline connected to an output shaft arranged to obtain a speed reduction. The wave generator comprises a rotating carrier arranged with at least one high-strength magnetic means (8), the flex spline comprises a magnetic part. The method comprises rotating the at least one magentic means for sequentially deforming the magnetic part of the flex spline into frictional engagement with the circular spline in at least one zone of contact such that the preload forces are delivered in a contactless manner from the at least one magnetic means to the flex spline. In this manner a “traveling wave” is set up in the flex spline.

When used as the gear reducing means in a robotic joint, the invention eliminates the requirement for a brake. This is because it is an inherent feature of the design that torque can not be transmitted from the output side of the drive to the input side. Since the output is capable of slipping with respect to the input above a given load, this feature provides in addition the functionality of a torque-overload coupling. A further advantage of the invention when used in a robotic joint is that the output torque is free of the cyclical fluctuation known as “torque ripple” which occurs in toothed geared transmissions.

According to another feature of the invention, the method comprises adjusting the magnetic force by varying a radial distance between a permanent magnetic means and the circular spline.

This avoids the wear and friction associated with rolling contact and facilitates convenient adjustment of preload by varying the gap between magnet and flexspline.

According to another feature of the invention, the method comprises reducing the speed such that the output rotation is in the opposite sense to input rotation.

According to another feature of the invention, the method comprises reducing the speed such that the output rotation is in the same direction as the input rotation.

It is within the invention to make one part of the flex spline of a magnetic material and make the rest of the flex spline of a non-magnetic material.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is an external view of a housed harmonic traction drive according to the invention,
Figure 2a is a radial cross A-A section through a harmonic traction drive according to the invention (for clarity, the housing is not shown),
Figure 2b is an axial cross section B-B through a harmonic traction drive according to the invention (for clarity, the housing is not shown),
Figure 3 is a sequence showing relative positions of points on the input (A) and output (B) sides of the drive relative to a fix point on the carrier (C),
Figure 4 is a deformed flexspline in the standard case (a) and a pre-stressed flexspline applied by shrink-fitting an outer tube over the flexspline (b).

Figure 5 is a harmonic friction drive comprising two magnetic means,

Figure 6 is an external view of a housed harmonic traction drive according to the invention,
Figure 7a is a radial cross A-A section through the harmonic traction drive in Figure 6,
Figure 7b is an axial cross section B-B through the harmonic traction drive in Figure 6,
Figure 8 is a harmonic traction drive comprising a tightening means,
Figure 9 is prior art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a harmonic traction drive 1 according to the present invention, showing the housing 1a, housing fastening means 14 e.g. bolts, input shaft 6 and output shaft 7.

As mentioned above, the three main components in a harmonic drive are a flex spline, a circular spline and a wave generator. The input, output and fixed components are interchangeable amongst these components, but in the embodiment shown in **Figure 2**, the input is the wave generator, the output is the flex spline and the circular spline remains stationary. Figure 2 is a schematic sectional view of the drive with the housing removed for the purpose of clarity.

In **Figure 2b**, the input shaft 6 and the output shaft 7 are arranged coaxial to the axis of rotation R and at an axial distance D. The rigid circular spline 3 arranged as a cylinder is arranged coaxially to the axis of rotation R and further, arranged axially between the input shaft 6 and the output shaft 7, i.e. within the axial distance D.

The wave generator comprises a rotating carrier 5 comprising substantially radial support arms 5a and a cylindrical part 5b.

In the following the features inside and outside are used and they are defined in relation to the common axis of rotation R. When the radial distances from the axis R to a first and a second feature are different, the feature on the relative shorter distance from the axis R is arranged inside the other feature. Consequently, the feature on the relative longer distance from the axis R is outside the other feature.

Considering the flexspline 2, the circular spline 3 and the tubular part 5b of the carrier in the relation to the rotation axis R the arrangement in **Figure 2a** is as follows. The flex spline 2 is arranged inside i.e. within the circular spline 3. The tubular part 5b of the carrier comprising the three permanent magnets 12 is arranged outside the circular spline 3.

The flex spline

The flex spline 2 consists of a flexible tube 2a that is closed at one end forming a cup-shape. The output shaft 7 is connected to the flex spline 2 and arranged to rotate with the flex spline 2. The

flexspline 2 comprises a part 11 made from a magnetic material, which is arranged inside the rigid circular spline 3. The entire rigid circular spline is made of a non-magnetic material. Separated from the outside 3a of the rigid circular spline 3 by a small radial clearance are three magnets 12 connected to the rotating carrier 5 arranged outside the circular spline. The rotating carrier 5 is driven by the input shaft 6. The field from each permanent magnet 12 is transmitted through the rigid circular spline 3 to the flexspline 2, which is attracted to the inner surface 3b of the circular spline 3 at three points 8, 9, 10. During rotation of the carrier with the magnets, the friction generated at the three contact points 8, 9, 10 drives the flexspline 3 in the opposite direction from the carrier 5, imparting rotation at a reduced speed to the output shaft 7.

The rigid circular spline

In order to ensure that a preload force develops at its three contact points 8, 9, 10 with the flexspline 2, the circular spline 3 is required to maintain its circular shape. This requires a high radial stiffness and implies that its section thickness must be high. However, for the magnetic field to be strongest at the flexspline 2, the distance from the magnet must be as small as possible, and hence a thin circular spline 3 section is required. One way to overcome these conflicting requirements is to employ a flanged design for the circular spline 3, as shown in section AA in **Figure 2b**. A thin section 16 directly underneath the magnet 12 allows the distance from the flexspline 2 to be small, while the flanges 17 flanking this region increase the radial stiffness of the structure as a whole.

The wave generator

The wave generator comprises a rotating carrier 5 with three external magnetic means 12, each comprising a permanent magnet 12. The rotating carrier 5 is a rigid structure comprising radial support arms 5a attached to the input shaft 6 and a tubular part 5b within which the three permanent magnets 12 are incorporated. The three permanent magnets are disposed axially at equal spaces apart in the tubular part 5b of the rotating carrier 5.

Figure 3 is a sequence showing relative positions of points on the input (A) and the output (B) sides of the drive relative to a fixed point on the carrier 5.

The three-lobe shape generated in the flexspline 2 by the magnetic forces is made to rotate by turning the input shaft 6. In the embodiment shown in **Figure 2**, the circular spline 3 is fixed. Due to the difference in undeformed diameter between the flexspline 2 and circular spline 3, the flexspline 2 is forced to rotate in the opposite direction to the carrier 5 and at a reduced speed. The reduction ratio, R, is determined from conventional harmonic drive theory as follows:

$$R = \frac{D_f}{D_f - D_c} \tag{1}$$

where D_c is the inner diameter of the circular spline and D_f is the outer diameter of the flexspline in the undeformed state. The negative result indicates that output rotation is in the opposite sense to input rotation.

In order to offer a sufficiently strong attractive force, the flexspline 2 is required to be thick-walled. However increasing wall thickness increases the radial force required to deform the flexspline and reduces the force available for preloading the flexspline 2 against the circular spline 3. A solution to these conflicting requirements is to modify the mechanical properties of the flexspline 2, such that the radial elasticity is increased while maintaining a thick section. One way to achieve this is to prestress the flexspline 2 in the inward-radial direction. A practical means of achieving the radial prestress is to shrink-fit a thin-walled tube 15 over the flexspline 2, **Figure 4a and 4b.**

Figure 5 is a harmonic friction drive comprising two magnetic means 12, arranged external to the flexspline and radially spaced apart with 180 degrees between the magnets. This arrangement minimises the force required to deform the flexspline and ensures that radial loads on the input shaft are balanced

Figure 6 is a harmonic traction drive 21 according to the present invention , showing the housing 21a, fastening means 34 e.g. bolts, input shaft 26 and output shaft 27. **Figure 7** is the harmonic traction drive 21 comprising a flex spline 22, a rigid circular spline 23, a wave generator 24, an input shaft 26 and an output shaft 27. For the purposes of clarity, the housing is not shown. The

input shaft 26 and the output shaft 27 are arranged coaxial to the axis of rotation R and at an axial distance E (**Figure 7b**). The rigid circular spline 23 arranged as a cylinder is arranged coaxially to the axis of rotation R and further, arranged axially between the input shaft 26 and the output shaft 27, i.e. within the axial distance E. In this arrangement, the magnets are arranged inside the flexspline. This ensures efficient utilisation of space within the flexspline and minimises the rotational inertia of the wave generator

Considering the flexspline 22, the circular spline 23 and the tubular part 25b of the carrier 25 in the relation to the rotation axis R, the arrangement is as follows (**Figure 7a**). The tubular part 25b of the carrier 25 comprising the three permanent magnets 32 is arranged closest to the axis R, i.e. inside the circular spline 23. The flex spline 22 is arranged at the longest distance from the axis R, i.e. outside the circular spline 23.

The three-lobe shape generated in the flexspline 22 by the magnetic forces is made to rotate by turning the input shaft 26. In the embodiment shown in Figure 11, the circular spline 23 is fixed. Due to the difference in undeformed diameter between the flexspline 22 and circular spline 23, the flexspline 22 is forced to rotate in the opposite direction to the carrier 25 and at a reduced speed. The reduction ratio, R, is determined from conventional harmonic drive theory as follows:

$$R = \frac{D_f}{D_f - D_c} \qquad (3)$$

where D_c is the outer diameter of the circular spline and D_f is the inner diameter of the flexspline in the undeformed state. Since the diameter D_f is greater than D_c, the result is positive, which indicates that the output rotates in the same direction as the input.

Figure 8 is a harmonic traction drive comprising tightening means 35. A magnetic force adjustment is achieved by varying the radial distance F between the magnet 12 and the circular spline 3. In **Figure 8a**, the distance F is relatively long, which gives a relatively low magnetic force. In **Figure 8b**, the distance F is relatively short, which gives a relatively high magnetic force.

CLAIMS

1. A harmonic traction drive (1) comprising a wave generator (4) connected to an input shaft (6), a fixed and circular spline (3), and a flex spline (2) connected to an output shaft (7) arranged to obtain a speed reduction , **characterized in that** the wave generator (4) comprises a rotating carrier (5) arranged with at least one high-strength magnetic means (12), the flex spline (2) comprises a magnetic part (11), the rotating carrier (5) and the flex spline (2) are arranged such that the magnetic means (12) and the magnetic part (11) of the flex spline (2) are situated on one side each of the fixed and circular spline (3) and the magnetic part (11) of the flex spline (2) is deformed into frictional engagement with the circular spline (3) in at least one zone of contact (8).

2. A harmonic traction drive according to claim 1, wherein the rotating carrier (5) comprises two magnetic means (12) symmetrically arranged for sequentially deforming the magnetic part (11) of the flex spline (2) into frictional engagement in two zones of contact (9).

3. A harmonic traction drive according to claim 1, wherein the rotating carrier (5) comprises three magnetic means (12) symmetrically arranged for sequentially deforming the magnetic part (11) of the flex spline (2) into frictional engagement in three zones of contact (9).

4. A harmonic traction drive according to any of claim 1-3, wherein the magnetic means (12) is a permanent magnet.

5. A harmonic traction drive according to claim 1-3, wherein the said magnetic means (12) is a neodymium magnet.

6. A harmonic traction drive according to any of the preceding claims, wherein the at least one contact zone is on the inside (3b) of the circular spline (2).

7. A harmonic traction drive according to any of the preceding claim 1-5, wherein the at least one contact zone is on the outside (3a) of the circular spline (2).

8. A harmonic traction drive according to any of the preceding claims, wherein the flex spline (2) is arranged prestressed.

9. A harmonic traction drive according to any of the preceding claims, wherein the flex spline (2) comprises at least one part (11) made of magnetic material.

10. A method of operating a harmonic traction drive (1) comprising a wave generator (4) connected to an input shaft (6), a fixed and circular spline (3), a flex spline (2) connected to an output shaft (7) arranged to obtain a speed reduction, where the wave generator (4) comprises a rotating carrier (5) arranged with at least one high-strength magnetic means (12), the flex spline (2) comprises a magnetic part (11), the method comprises rotating the at least one magentic means (12) for sequentially deforming the magnetic part (11) of the flex spline (2) into frictional engagement with the circular spline (3) in at least one zone of contact (9) such that the preload forces are delivered in a contactless manner from the at least one magnetic means (12) to the flex spline (2).

11. A method according to claim 8, comprising adjusting the magnetic force by varying a radial distance (F) between a magnetic means (12) and the circular spline (3).

12. A method according to claim 8 or 9, comprising reducing the speed such that the output rotation is in the opposite sense to input rotation.

13. A method according to claim 8 or 9, comprising reducing the speed such that the output rotation is in the same direction as the input rotation.

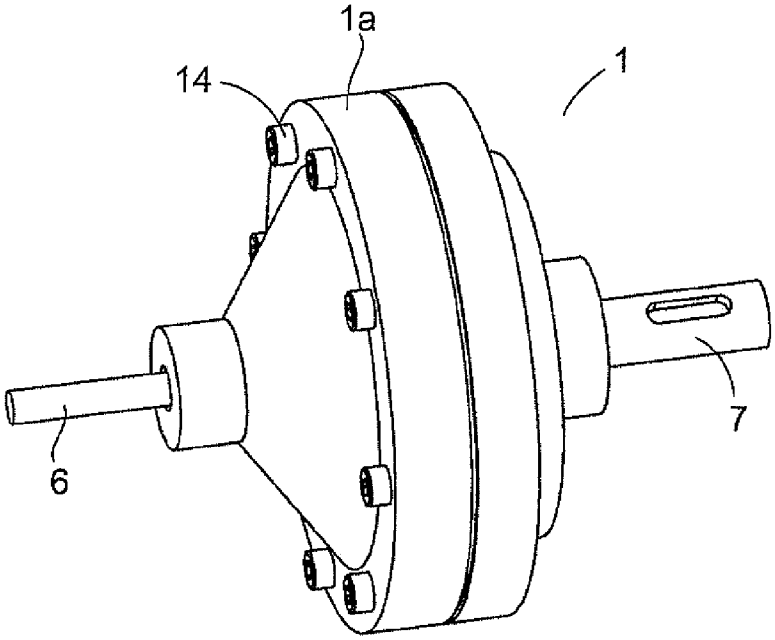


Fig. 1

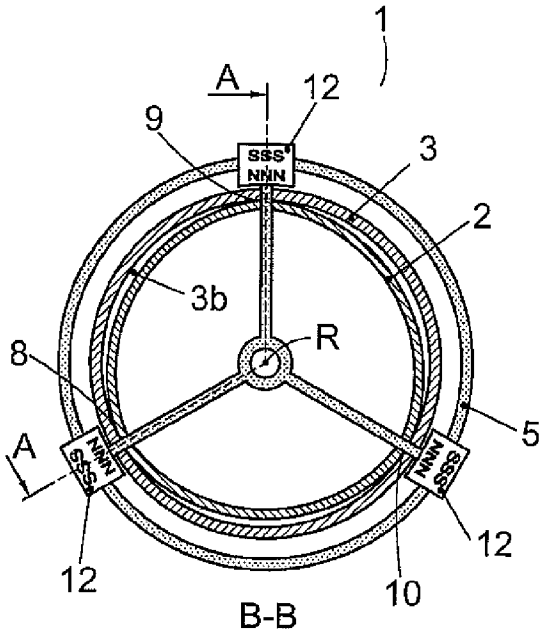


Fig. 2a

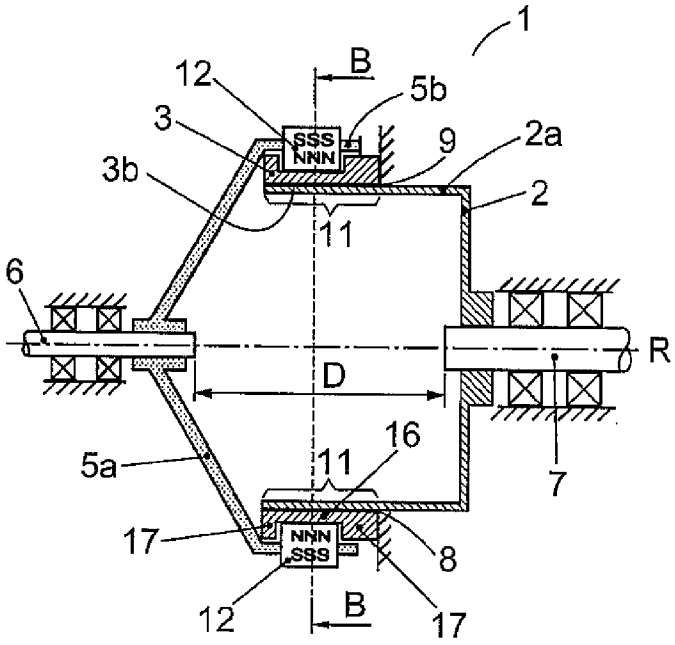


Fig. 2b

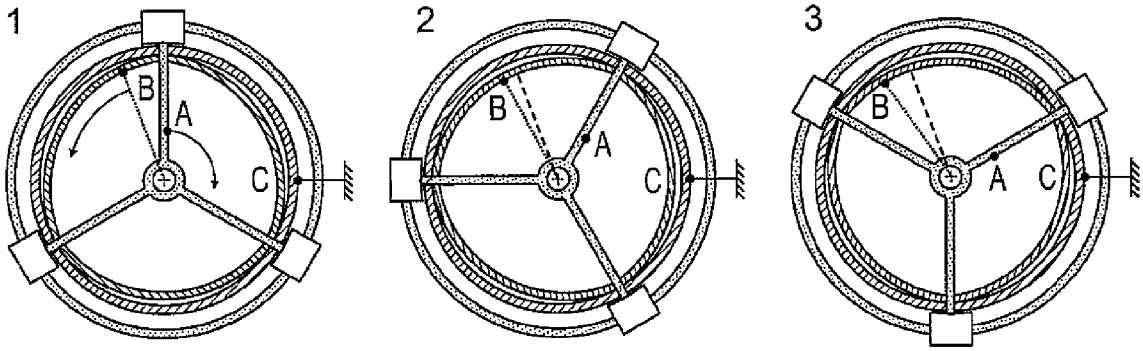


Fig. 3

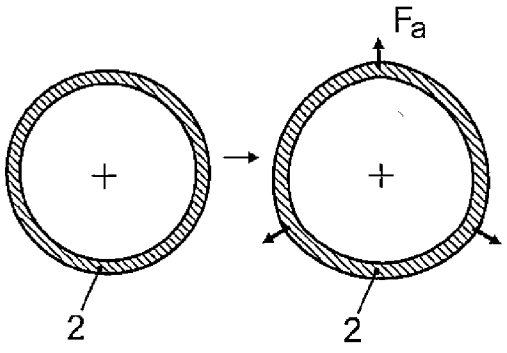
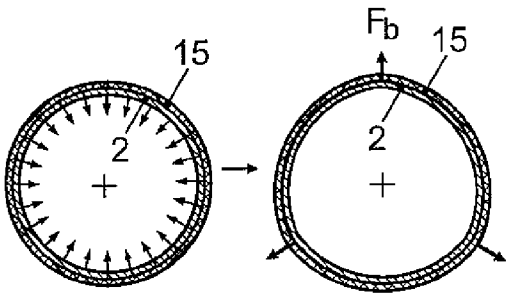


Fig. 4a



$F_b < F_a$

Fig. 4b

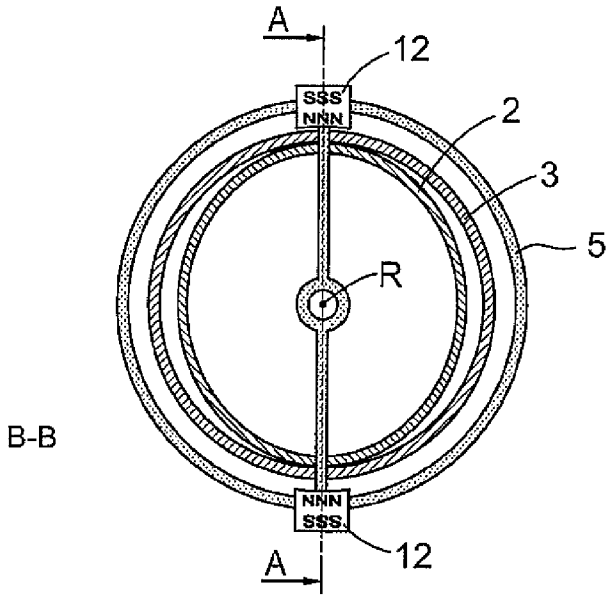


Fig. 5

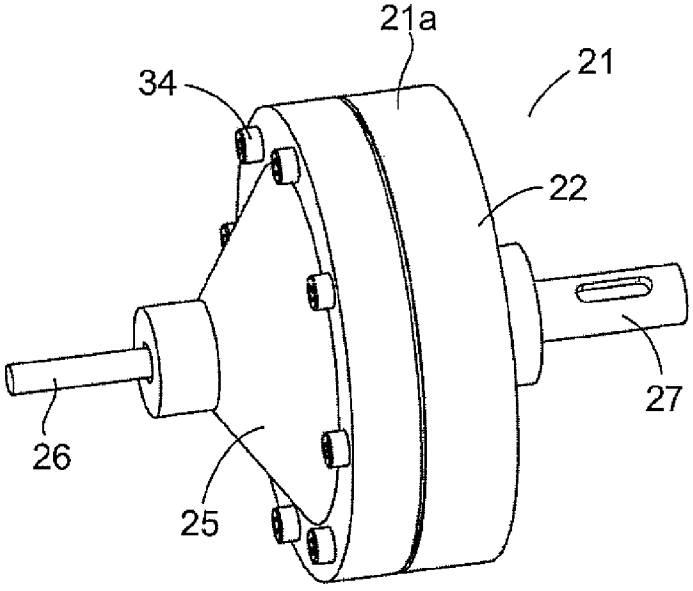


Fig. 6

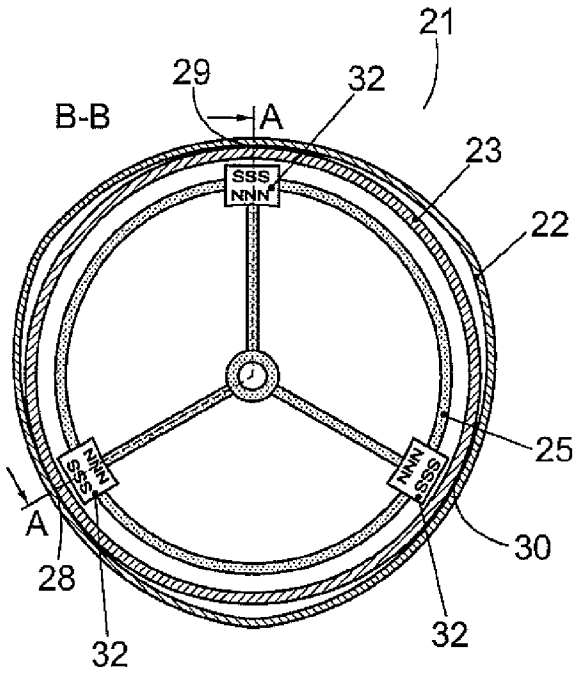

21
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32
B-B
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SSS
NNN
25
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A
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Fig. 7a

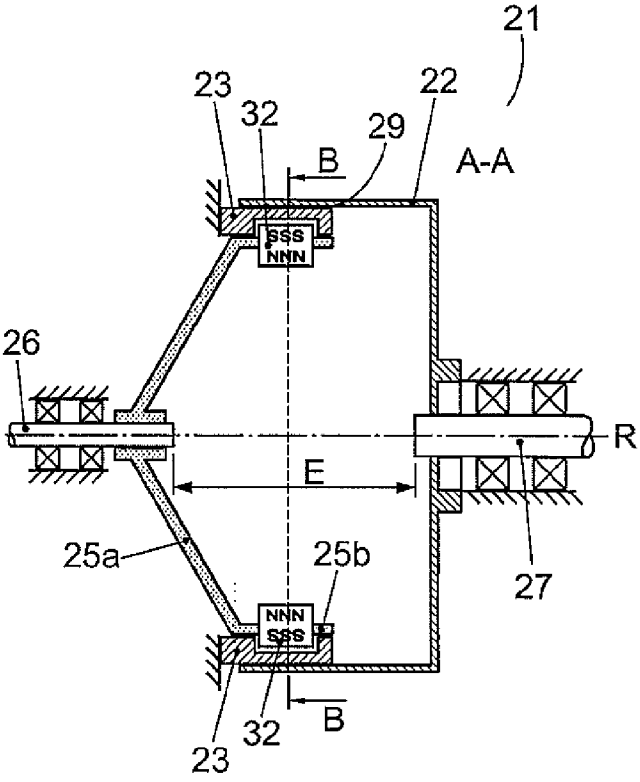

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E
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25b
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NNN
SSS
B
32
23

Fig. 7b

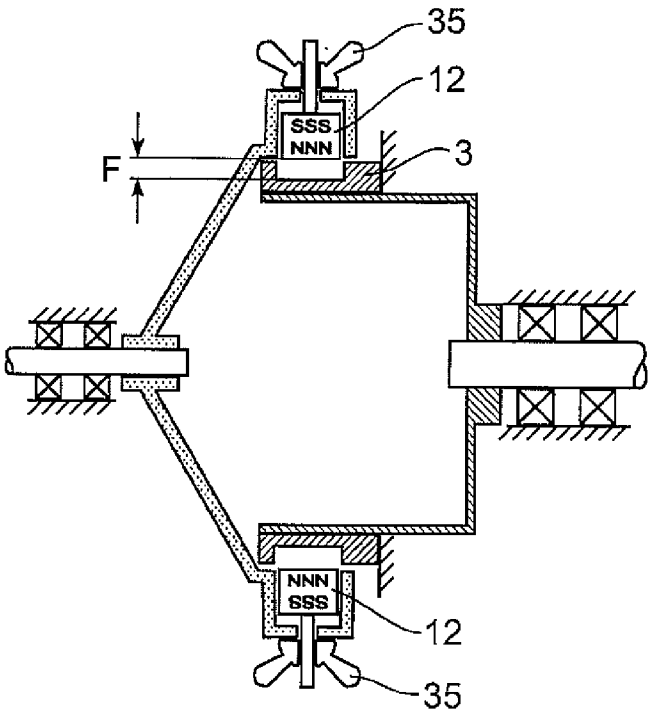


Fig. 8a

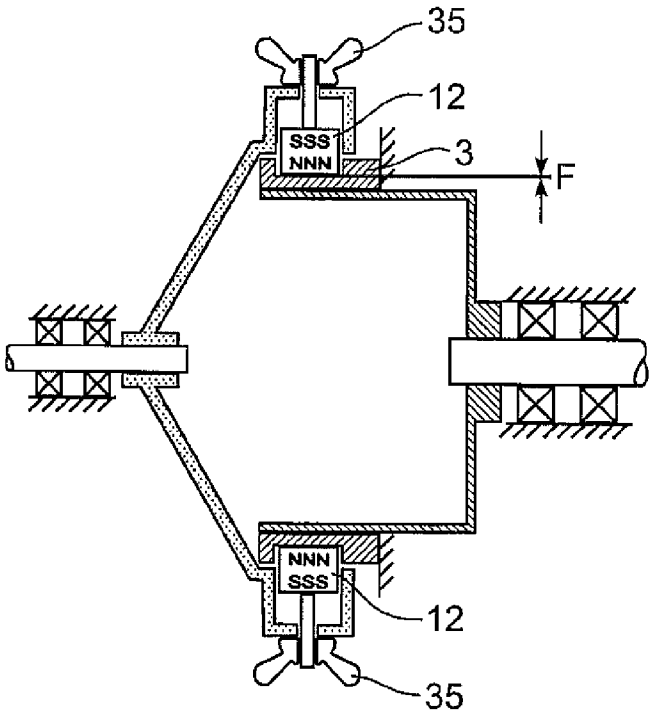


Fig. 8b

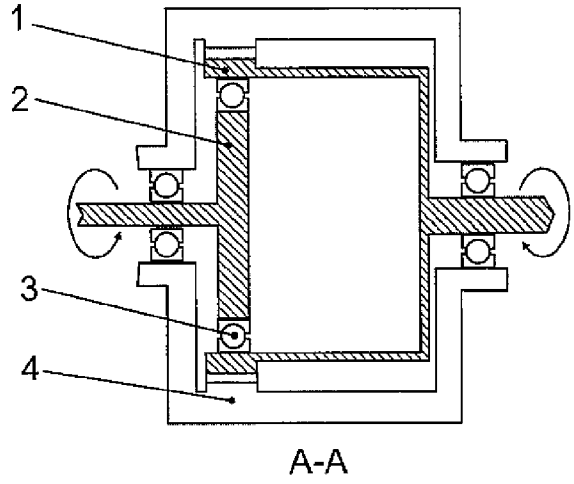


Fig. 9a

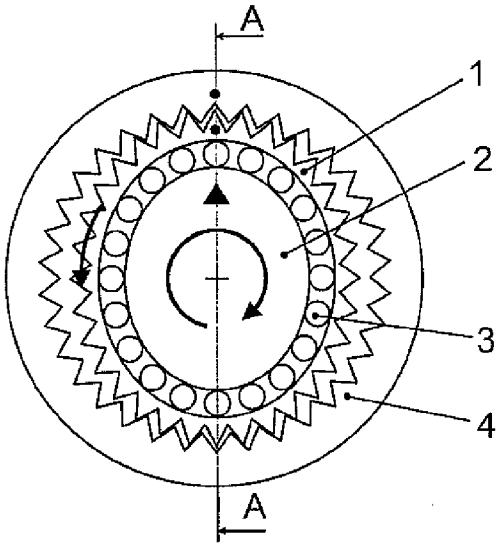


Fig. 9b

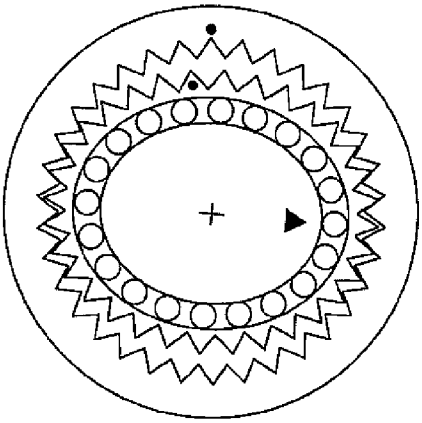


Fig. 9c

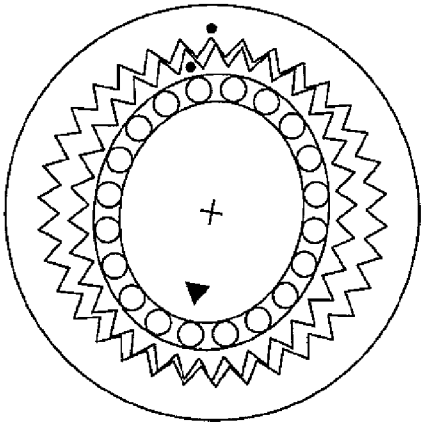


Fig. 9d

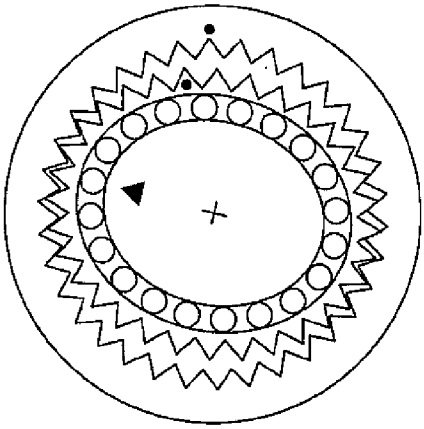


Fig. 9e

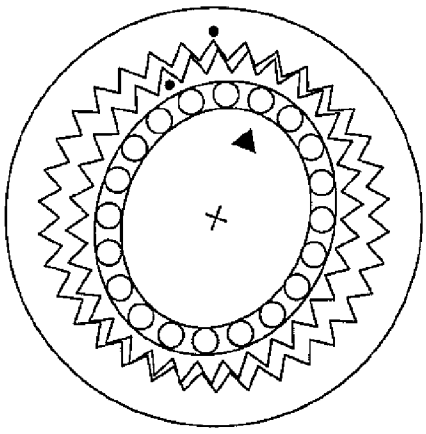


Fig. 9f

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/058399

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16H49/00

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)
F16H H02K

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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	DE 43 20 901 A1 (UNIV MAGDEBURG TECH [DE]) 5 January 1995 (1995-01-05) cited in the application the whole document	1,10
A	US 3 796 898 A (KLEINWAECHTER H) 12 March 1974 (1974-03-12) column 7, line 9 - column 8, line 64; figures 6-9	1,10
A	DE 101 37 230 C1 (FALKENSTEIN JENS [DE]) 24 April 2003 (2003-04-24) paragraph [0022]; figure 3	1,10
A	CH 443 804 A (UNITED SHOE MACHINERY CORP [US]) 15 September 1967 (1967-09-15) claims 1-9; figures 1,9,10	1,10

-/--

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

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 2009	04/03/2009

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/058399

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 6 439 081 B1 (DUFF DAVID G [US]) 27 August 2002 (2002-08-27) cited in the application the whole document	1,10
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International application No
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