



(51) International Patent Classification:

F16H 13/14 (2006.01) F16H 15/28 (2006.01)

(21) International Application Number:

PCT/US2018/032032

(22) International Filing Date:

10 May 2018 (10.05.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/504,865 11 May 2017 (11.05.2017) US

(71) Applicant: DANA LIMITED [US/US]; 3939 Technology Drive, PO Box 1000, Maumee, OH 43537 (US).

(72) Inventors: HORAK, Joseph, J.; 1401 Northridge Drive, Austin, TX 78723 (US). NELMS, Ryan, D.; 1506 Payne Ave-unit B, Austin, TX 78757 (US).

(74) Agent: EVANS, Stephen, P. et al.; MARSHALL & MEL-HORN, LLC, Four Seagate - 8th Floor, Toledo, OH 43604 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: AXIAL CLAMP FORCE ASSEMBLY FOR A BALL VARIATOR CONTINUOUSLY VARIABLE TRANSMISSION

(57) Abstract: Provided herein is a continuously variable transmission (CVT) having a plurality of balls, each having a tiltable axis of rotation, a first traction ring assembly in contact with each ball, a second traction ring assembly in contact with each ball, and an idler assembly in contact with each ball, the idler assembly located radially inward of the first traction ring assembly and the second traction ring assembly. In some embodiments, the idler assembly is provided with an axial force generator configured to transfer an axial force to the traction contacts of the CVT. In some embodiments, the axial force generator is an electromagnetic device. In some embodiments, the axial force generator is a hydro-mechanical device.



AXIAL CLAMP FORCE ASSEMBLY FOR A BALL VARIATOR CONTINUOUSLY VARIABLE TRANSMISSION

RELATED APPLICATIONS

5 The present application claims the benefit of U.S. Provisional Application No. 62/504,865 filed May 11, 2017, which is incorporated herein by reference in its entirety.

BACKGROUND

10 Automatic and manual transmissions are commonly used in motor vehicles. Such transmissions have become more complicated since the engine speed has to be adjusted to limit fuel consumption and the emissions of the vehicle. A vehicle having a driveline including a tilting ball variator allows an operator of the vehicle or a control system of the vehicle to vary a drive ratio in
15 a stepless manner. A variator is an element of a Continuously Variable Transmission (CVT) or an Infinitely Variable Transmission (IVT).

 Transmissions that use a variator can decrease the transmission's gear ratio as engine speed increases. This keeps the engine within its optimal efficiency while gaining ground speed, or trading speed for torque during hill
20 climbing, for example. Efficiency in this case can be fuel efficiency, decreasing fuel consumption and emissions output, or power efficiency, allowing the engine to produce its maximum power over a wide range of speeds. That is, the variator keeps the engine turning at constant RPMs over a wide range of
25 vehicle speeds.

SUMMARY

 Provided herein is a continuously variable transmission (CVT), including: a first traction ring; a second traction ring; a plurality of balls, each ball having a tiltable axis of rotation, each ball in contact with the first traction ring and
30 second traction ring; a first idler ring located radially inward of the first traction ring and the second traction ring, the first idler ring in contact with each ball; a second idler ring located radially inward of the first traction ring and the second traction ring, the second idler ring in contact with each ball; an idler race

operably coupled to the first idler ring and the second idler ring, the idler race located radially inward of the first idler ring and the second idler ring; and an axial force generator operably coupled to the second idler ring.

5 In some embodiments, the axial force generator is an electromagnetic device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.

In some embodiments, the continuously variable transmission further includes a slip ring operably coupling the electromagnetic device to a grounded member of the CVT.

10 In some embodiments, the axial force generator is a hydraulic device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.

In some embodiments, the hydraulic device further includes a fluid cavity contained with the second idler ring.

15 In some embodiments, the fluid cavity is supplied with a pressurized fluid.

In some embodiments, the continuously variable transmission of further includes a spring member located in the fluid cavity.

20 In some embodiments, the axial force generator is a mechanical device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.

In some embodiments, the continuously variable transmission further includes a spring member located within the second idler ring.

25 Provided herein is a vehicle driveline including: a power source, a variable transmission of any one of CVTs described herein drivingly engaged with the power source, and a vehicle output drivingly engaged with the variable transmission.

In some embodiments, the power source is drivingly engaged with the vehicle output.

30 Provided herein is a vehicle including the variable transmission of any one of the CVT's described herein.

Provided herein is a method including providing a variable transmission of any one of the CVTs described herein.

Provided herein is a method including providing a vehicle driveline described herein.

Provided herein is a method including providing a vehicle described herein.

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INCORPORATION BY REFERENCE

All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

10

BRIEF DESCRIPTION OF THE DRAWINGS

Novel features of the preferred embodiments are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present embodiments will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the embodiments are utilized, and the accompanying drawings of which:

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Figure 1 is a side sectional view of a ball-type variator.

20

Figure 2 is a plan view of a carrier member that is used in the variator of Figure 1.

Figure 3 is an illustrative view of different tilt positions of the ball-type variator of Figure 1.

25

Figure 4 is a schematic diagram of an idler assembly having an electromagnetic axial force generator.

Figure 5 is a schematic diagram of an idler assembly having a hydraulic axial force generator.

Figure 6 is a schematic diagram of an idler assembly having a hydro-mechanical axial force generator.

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Figure 7 is a schematic diagram of an idler assembly having a mechanical axial force generator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments will now be described with reference to the accompanying figures, wherein like numerals refer to like elements throughout. The terminology used in the descriptions below is not to be interpreted in any limited or restrictive manner simply because it is used in conjunction with detailed descriptions of certain specific embodiments. Furthermore, the preferred embodiments includes several novel features, no single one of which is solely responsible for its desirable attributes or which is essential to practicing the embodiments described.

Provided herein are configurations of CVTs based on a ball-type variators, also known as CVP, for continuously variable planetary. Basic concepts of a ball-type Continuously Variable Transmissions are described in United States Patent No. 8,469,856 and 8,870,711 incorporated herein by reference in their entirety. Such a CVT, adapted herein as described throughout this specification, includes a number of balls (planets, spheres) 1, depending on the application, two ring (disc) assemblies with a conical surface in contact with the balls, an first traction ring 2, an second traction ring 3, and an idler (sun) assembly 4 as shown on FIG. 1. The balls are mounted on tiltable axles 5, themselves held in a carrier (stator, cage) assembly having a first carrier member 6 operably coupled to a second carrier member 7. The first carrier member 6 rotates with respect to the second carrier member 7, and vice versa. In some embodiments, the first carrier member 6 is fixed from rotation while the second carrier member 7 is configured to rotate with respect to the first carrier member, and vice versa. In some embodiments, the first carrier member 6 is provided with a number of radial guide slots 8. The second carrier member 7 is provided with a number of radially offset guide slots 9, as illustrated in FIG. 2. The radial guide slots 8 and the radially offset guide slots 9 are adapted to guide the tiltable axles 5. The axles 5 are adjusted to achieve a desired ratio of input speed to output speed during operation of the CVT. In some embodiments, adjustment of the axles 5 involves control of the position of the first and second carrier members 6, 7 to impart a tilting of the axles 5 and thereby causing a tilting of the balls' axes of rotation to adjust the speed ratio of the variator. Other types of ball CVTs also exist, but are slightly different.

The working principle of such a CVP of FIG. 1 is shown on FIG. 3. The CVP itself works with a traction fluid. The lubricant between the ball and the conical rings acts as a solid at high pressure, transferring the power from the first traction ring, through the balls, to the second traction ring. By tilting the balls' axes, the ratio is changed between input and output. When the axis is horizontal the ratio is one-to-one (1:1) illustrated in FIG. 3. When the axis is tilted the distance between the axis and the contact point change, modifying the overall ratio. All the balls' axes are tilted at the same time with a mechanism included in the carrier and/or idler. Embodiments disclosed here are related to the control of a variator and/or a CVT using generally spherical planets each having a tiltable axis of rotation that are adjusted to achieve a desired ratio of input speed to output speed during operation.

In some embodiments, adjustment of said axis of rotation involves angular misalignment of the planet axis in a first plane in order to achieve an angular adjustment of the planet axis in a second plane that is perpendicular to the first plane, thereby adjusting the speed ratio of the variator. The angular misalignment in the first plane is referred to here as "skew", "skew angle", and/or "skew condition". In one embodiment, a control system coordinates the use of a skew angle to generate forces between certain contacting components in the variator that will tilt the planet axis of rotation. The tilting of the planet axis of rotation adjusts the speed ratio of the variator.

Currently, CVT and Infinitely Variable Transmissions (IVT) often use some form of mechanical clamping mechanism, typically including a ball-and-cam mechanism to generate axial clamping forces necessary to facilitate the transmission of torque between or among transmission components via traction or friction, often referred to as clamping force mechanisms or generators. At high torques and low speeds, a standard ball-and-cam clamping force mechanism determines the clamp load. Examples of ball-and-cam clamping force mechanism are found in United States Patent No. 9,086,145, which is hereby incorporated by reference.

Clamping force generators typically fall into three general categories: Non-Torque Reactive, Torque Reactive, and Active/Programmable. Non-Torque Reactive clamping means are generally defined as ratio dependent,

speed dependent and fixed (fully preloaded). Torque Reactive clamping means are generally defined by axial forces due to external influences or loads, torque reaction on floating elements, screws and cams, or passive hydraulic.

Active/Programmable clamping means wherein hydraulic or other means are actively applied to a clamping means to create axial clamping forces.

Depending on the configuration used, the clamping force mechanism used in a transmission with a Continuously Variable Ball Planetary (CVP) variator provides a load to the first and/or second traction ring to ensure adequate clamping force between the drive ring(s) and the traction planets.

Unfortunately, traditional clamping force mechanisms are limited in their ability to provide high clamping loads at high speeds and low torque. There remains a need for a system that can deliver consistently high clamping forces at high speeds in a CVP.

For description purposes, the term "radial" is used here to indicate a direction or position that is perpendicular relative to a longitudinal axis of a transmission or variator. The term "axial" as used here refers to a direction or position along an axis that is parallel to a main or longitudinal axis of a transmission or variator. For clarity and conciseness, at times similar components labeled similarly (for example, bearing 1011A and bearing 1011B) will be referred to collectively by a single label (for example, bearing 1011).

As used here, the terms "operationally connected," "operationally coupled", "operationally linked", "operably connected", "operably coupled", "operably linked," "operably coupleable" and like terms, refer to a relationship (mechanical, linkage, coupling, etc.) between elements whereby operation of one element results in a corresponding, following, or simultaneous operation or actuation of a second element. It is noted that in using said terms to describe the embodiments, specific structures or mechanisms that link or couple the elements are typically described. However, unless otherwise specifically stated, when one of said terms is used, the term indicates that the actual linkage or coupling take a variety of forms, which in certain instances will be readily apparent to a person of ordinary skill in the relevant technology.

It should be noted that reference herein to "traction" does not exclude applications where the dominant or exclusive mode of power transfer is through

“friction.” Without attempting to establish a categorical difference between traction and friction drives here, generally these are typically understood as different regimes of power transfer. Traction drives usually involve the transfer of power between two elements by shear forces in a thin fluid layer trapped between the elements. The fluids used in these applications usually exhibit traction coefficients greater than conventional mineral oils. The traction coefficient (μ) represents the maximum available traction force which would be available at the interfaces of the contacting components and is the ratio of the maximum available drive torque per contact force. Typically, friction drives generally relate to transferring power between two elements by frictional forces between the elements. For the purposes of this disclosure, it should be understood that the CVTs described here operate in both tractive and frictional applications. For example, in the embodiment where a CVT is used for a bicycle application, the CVT operates at times as a friction drive and at other times as a traction drive, depending on the torque and speed conditions present during operation.

Referring now to FIGS. 4-7, in some embodiments, the idler assembly 4 depicted in Figure 3 is configured to provide an axial clamp force between traction components of the CVP.

In some embodiments, the axial clamp force is actively controlled by an electronic control unit and supporting electrical hardware and software.

In some embodiments, the axial clamp force is controlled by mechanical feedback from traction members of the CVP.

Turning now to FIG. 4, in some embodiments, an idler assembly 20 is provided with a first idler ring 21 and a second idler ring 22 supported by a bearing 23 and an idler race 24. The idler race 24 is operably coupled to and supported by a main shaft 25 of the CVP.

In some embodiments, the second idler ring 22 is provided with an electromagnetic axial force generator 26 having a first pole member 27 and a second pole member 28 each operably coupled to the second idler ring 22. The pole members 27, 28 are arranged so that each pole member is either a north or south pole such that the north and south poles alternate with the respect to the pole adjacent to it.

In some embodiments, the second idler ring 22 is adapted to have a radially outward member 22A in contact with the balls 1 and a radially inward member 22B operably coupled to the idler race 24.

The electromagnetic axial force generator 26 is supplied with power from a slip ring 29 and supporting electronic software. The slip ring 29 is optionally provided with a rotatable component 29A interfacing with a stationary component 29B.

In some embodiments, the stationary component 29B is operably coupled to a grounded member of the CVP. During operation of a CVP equipped with the idler assembly 20, an axial force is applied between the radially outward member 22A and the radially inward member 22B by the electromagnetic axial force generator 26. Said axial force is transferred to the balls 1 and other traction members of the CVP proportional to speed and torque transmitted through the CVP.

Passing now to FIG. 5, in some embodiments, an idler assembly 30 is provided with a first idler ring 31 and a second idler ring 32 supported by a bearing 33 and an idler race 34. The idler race 34 is operably coupled to and supported by a main shaft 35 of the CVP.

In some embodiments, the second idler ring 32 is provided with a hydraulic axial force generator 36 located in the second idler ring 32.

In some embodiments, the second idler ring 32 is adapted to have a radially outward member 32A in contact with the balls 1 and a radially inward member 32B operably coupled to the idler race 34.

The hydraulic axial force generator 36 is a fluid cavity formed in the second idler ring 32 that is supplied with a pressurized fluid through a passage 37.

In some embodiments, the fluid cavity is a pocket formed between the radially outward member 32A and the radially inward member 32B.

In some embodiments, the passage 37 is in fluid communication with the main shaft 35.

During operation of a CVP equipped with the idler assembly 30, an axial force is applied between the radially outward member 32A and the radially inward member 32B by the hydraulic axial force generator 36. Said axial force

is transferred to the balls 1 and other traction members of the CVP proportional to speed and torque transmitted through the CVP.

Referring now to FIG. 6, in some embodiments, an idler assembly 40 is provided with a first idler ring 41 and a second idler ring 42 supported by a bearing 43 and an idler race 44. The idler race 44 is operably coupled to and supported by a main shaft 45 of the CVP.

In some embodiments, the second idler ring 42 is provided with a hydro-mechanical axial force generator 46 located in the second idler ring 42. The second idler ring 42 is optionally adapted to have a radially outward member 42A in contact with the balls 1 and a radially inward member 42B operably coupled to the idler race 44. The hydro-mechanical axial force generator 46 is a fluid cavity located within the second idler ring 42 and is supplied with a pressurized fluid through a passage 47. In some embodiments, the fluid cavity is a pocket formed between the radially outward member 42A and the radially inward member 42B. In some embodiments, the passage 47 is in fluid communication with the main shaft 45. The hydro-mechanical axial force generator 46 includes a spring member 48 coupled to the radially outward member 42A and the radially inward member 42B. The spring member 48 is located within the fluid cavity. During operation of a CVP equipped with the idler assembly 40, an axial force is applied between the radially outward member 42A and the radially inward member 42B by the hydro-mechanical axial force generator 46. Said axial force is transferred to the balls 1 and other traction members of the CVP proportional to speed and torque transmitted through the CVP.

Referring now to FIG. 7, in some embodiments, an idler assembly 50 is provided with a first idler ring 51 and a second idler ring 52 supported by a bearing 53 and an idler race 54. The idler race 54 is operably coupled to and supported by a main shaft 55 of the CVP.

In some embodiments, the second idler ring 52 is provided with a mechanical axial force generator 56 located in the second idler ring 52.

In some embodiments, the second idler ring 52 is adapted to have a radially outward member 52A in contact with the balls 1 and a radially inward member 52B operably coupled to the idler race 54.

The mechanical axial force generator 56 includes a spring member coupled to the radially outward member 52A and the radially inward member 52B. During operation of a CVP equipped with the idler assembly 50, an axial force is applied between the radially outward member 52A and the radially inward member 52B by the mechanical axial force generator 56. Said axial force is transferred to the balls 1 and other traction members of the CVP proportional to speed and torque transmitted through the CVP.

While preferred embodiments have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the preferred embodiments. It should be understood that various alternatives to the embodiments described herein may be employed in practicing the preferred embodiments. It is intended that the following claims define the scope of the preferred embodiments and that methods and structures within the scope of these claims and their equivalents be covered thereby.

Aspects of the described invention include:

Aspect 1. A continuously variable transmission (CVT), comprising: a first traction ring; a second traction ring; a plurality of balls, each ball having a tiltable axis of rotation, each ball in contact with the first traction ring and second traction ring; a first idler ring located radially inward of the first traction ring and the second traction ring, the first idler ring in contact with each ball; a second idler ring located radially inward of the first traction ring and the second traction ring, the second idler ring in contact with each ball; an idler race operably coupled to the first idler ring and the second idler ring, the idler race located radially inward of the first idler ring and the second idler ring; and an axial force generator operably coupled to the second idler ring.

Aspect 2. The continuously variable transmission of Aspect 1, wherein the axial force generator is an electromagnetic device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.

Aspect 3. The continuously variable transmission of Aspect 2, further comprising a slip ring operably coupling the electromagnetic device to a grounded member of the CVT.

Aspect 4. The continuously variable transmission of Aspect 1, wherein the axial force generator is a hydraulic device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.

5 Aspect 5. The continuously variable transmission of Aspect 4, wherein the hydraulic device further comprises a fluid cavity contained with the second idler ring.

Aspect 6. The continuously variable transmission of Aspect 4, wherein the fluid cavity is supplied with a pressurized fluid.

10 Aspect 7. The continuously variable transmission of Aspect 5, further comprising a spring member located in the fluid cavity.

Aspect 8. The continuously variable transmission of Aspect 1, wherein the axial force generator is a mechanical device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.

15 Aspect 9. The continuously variable transmission of Aspect 7, further comprising a spring member located within the second idler ring.

Aspect 10. A vehicle driveline comprising: a power source, a variable transmission of any one of Aspects 1-9 drivingly engaged with the power source, and a vehicle output drivingly engaged with the variable transmission.

20 Aspect 11. The vehicle driveline of Aspect 10, wherein the power source is drivingly engaged with the vehicle output.

Aspect 12. A vehicle comprising the variable transmission of any one of Aspects 1-9.

Aspect 13. A method comprising providing a variable transmission of any one of Aspects 1-9.

25 Aspect 14. A method comprising providing a vehicle driveline of Aspect 10 or 11.

Aspect 15. A method comprising providing a vehicle of Aspect 12.

WHAT IS CLAIMED IS:

1. A continuously variable transmission (CVT), comprising:
 - a first traction ring;
 - 5 a second traction ring;
 - a plurality of balls, each ball having a tiltable axis of rotation, each ball in contact with the first traction ring and second traction ring;
 - a first idler ring located radially inward of the first traction ring and the second traction ring, the first idler ring in contact with each ball;
 - 10 a second idler ring located radially inward of the first traction ring and the second traction ring, the second idler ring in contact with each ball;
 - an idler race operably coupled to the first idler ring and the second idler ring, the idler race located radially inward of the first idler ring and the second idler ring; and
 - 15 an axial force generator operably coupled to the second idler ring.
2. The continuously variable transmission of Claim 1, wherein the axial force generator is an electromagnetic device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.
- 20 3. The continuously variable transmission of Claim 2, further comprising a slip ring operably coupling the electromagnetic device to a grounded member of the CVT.
- 25 4. The continuously variable transmission of Claim 1, wherein the axial force generator is a hydraulic device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.
- 30 5. The continuously variable transmission of Claim 4, wherein the hydraulic device further comprises a fluid cavity contained with the second idler ring.
6. The continuously variable transmission of Claim 4, wherein the fluid cavity is supplied with a pressurized fluid.

7. The continuously variable transmission of Claim 5, further comprising a spring member located in the fluid cavity.
8. The continuously variable transmission of Claim 1, wherein the axial force generator is a mechanical device adapted to provide an axial force between the balls, the first traction ring, and the second traction ring.
9. The continuously variable transmission of Claim 7, further comprising a spring member located within the second idler ring.
10. A vehicle driveline comprising: a power source, a variable transmission of any one of Claims 1-9 drivingly engaged with the power source, and a vehicle output drivingly engaged with the variable transmission.
11. The vehicle driveline of Claim 10, wherein the power source is drivingly engaged with the vehicle output.
12. A vehicle comprising the variable transmission of any one of Claims 1-9.
13. A method comprising providing a variable transmission of any one of Claims 1-9.
14. A method comprising providing a vehicle driveline of Claim 10 or 11.
15. A method comprising providing a vehicle of Claim 12.

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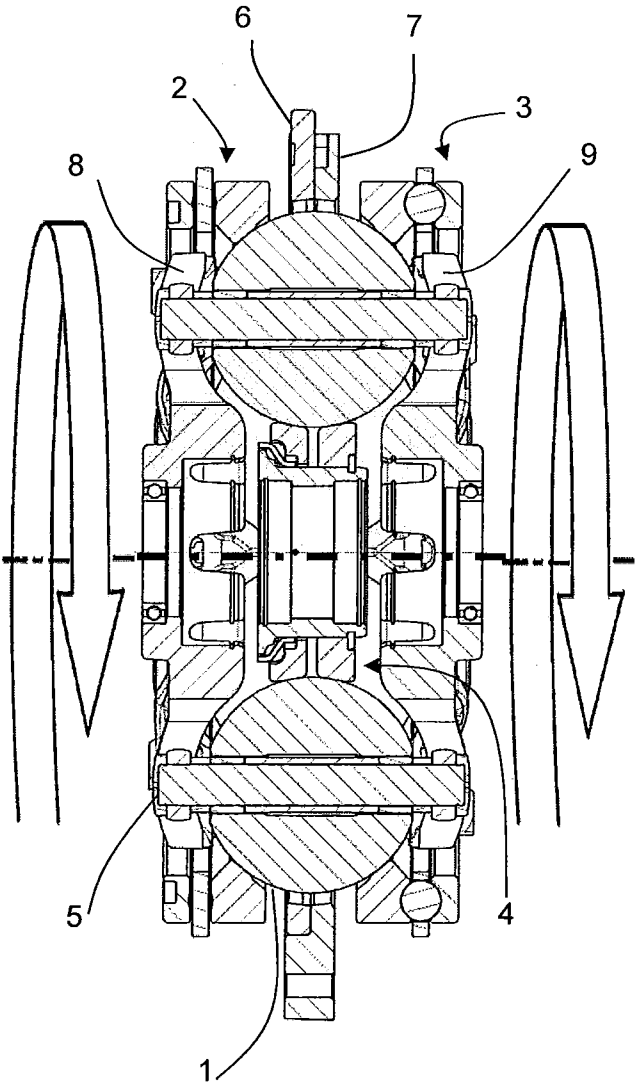


Figure 1

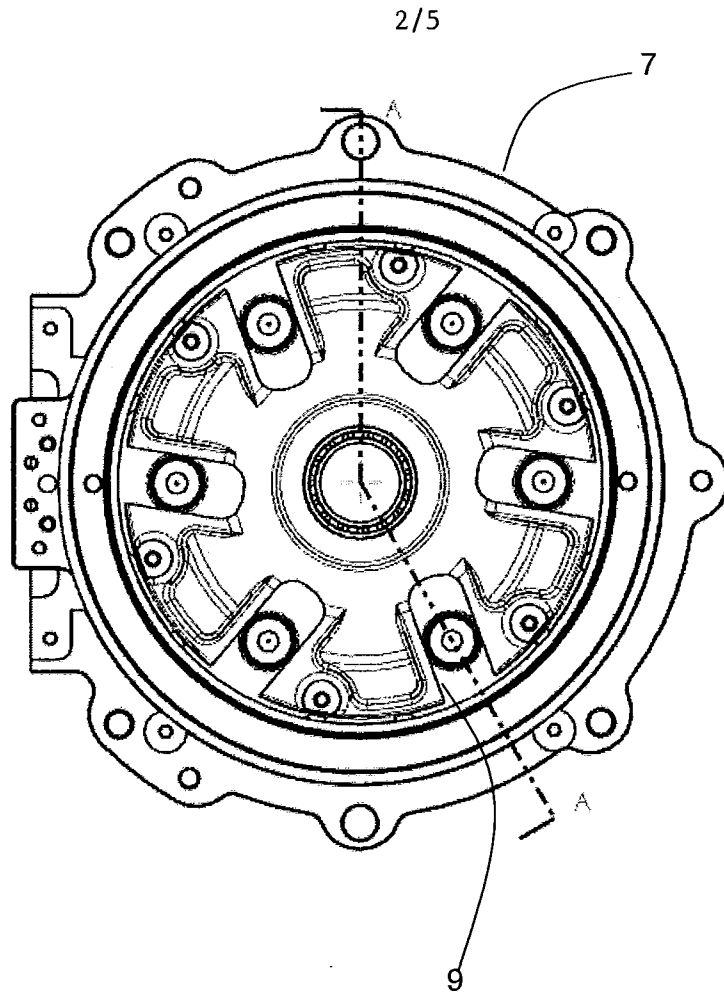


Figure 2

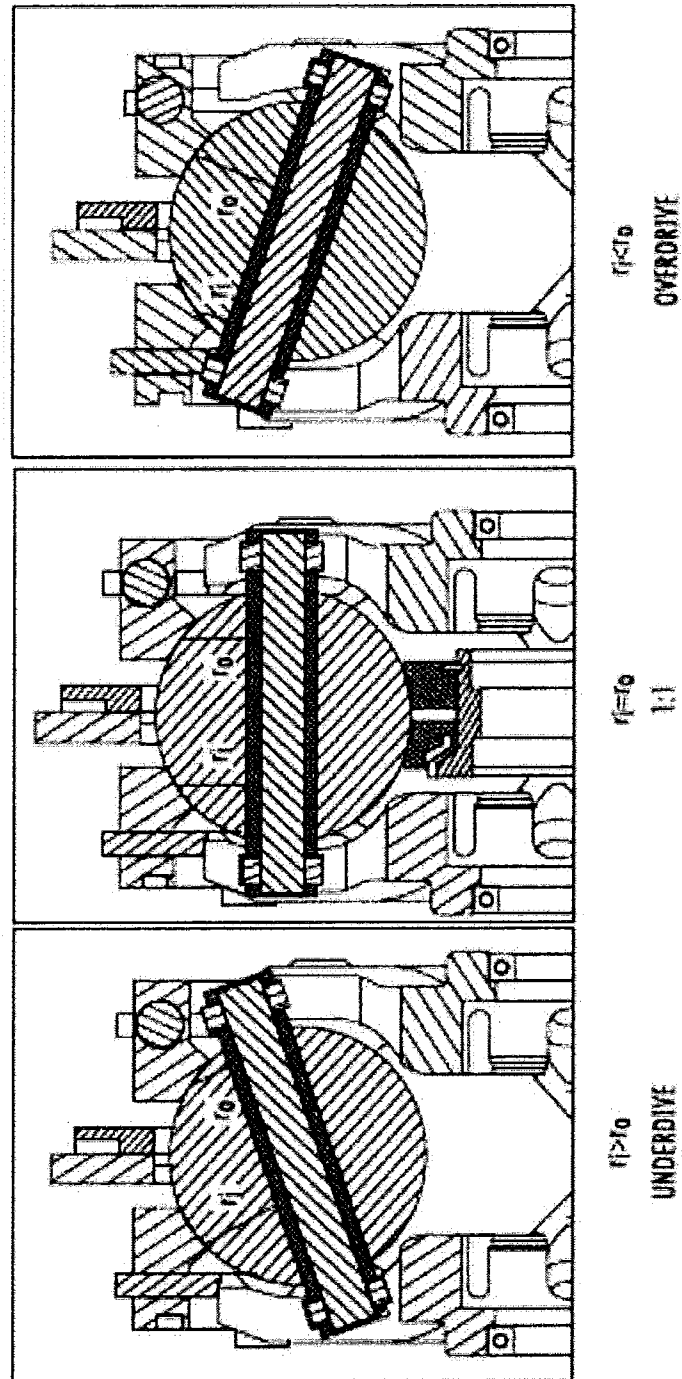


FIG. 3

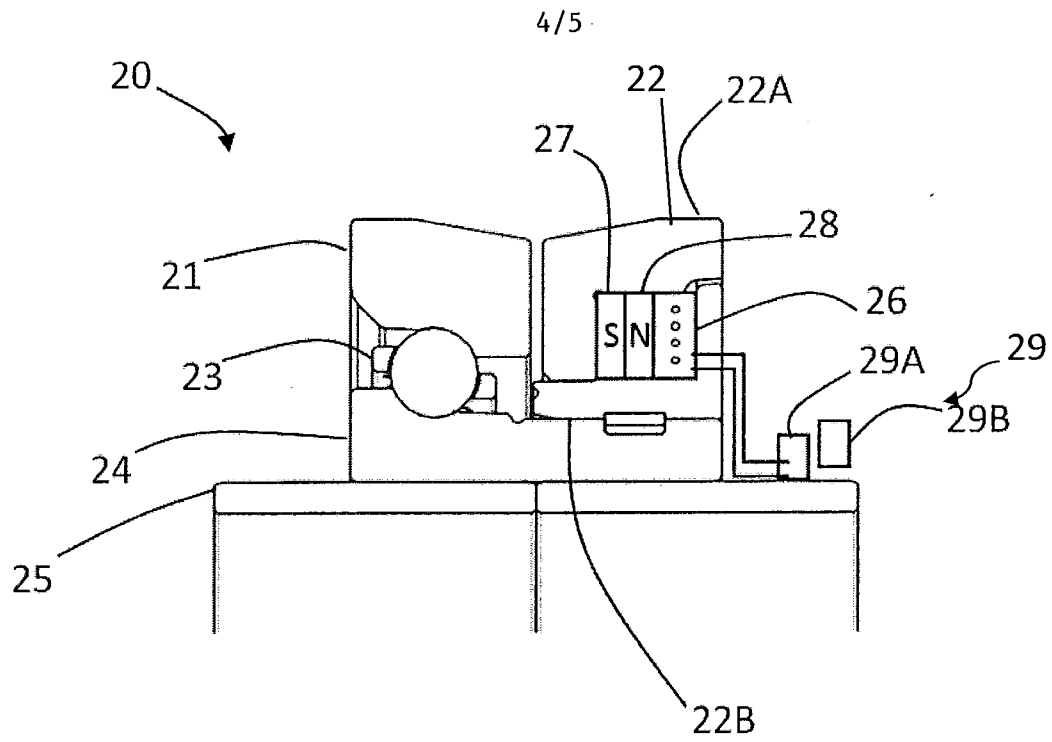


Figure 4

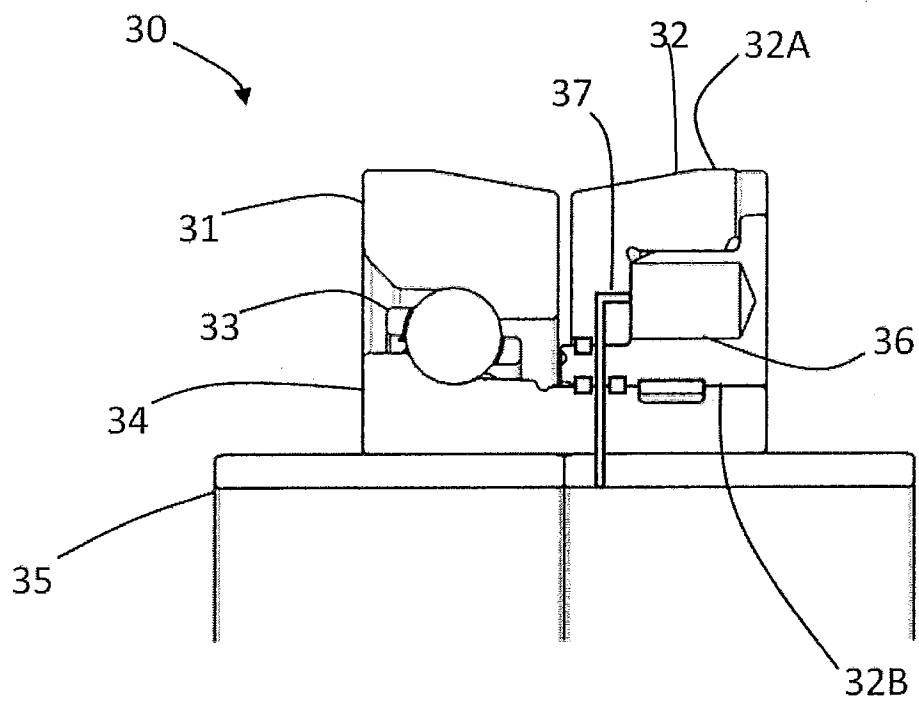


Figure 5

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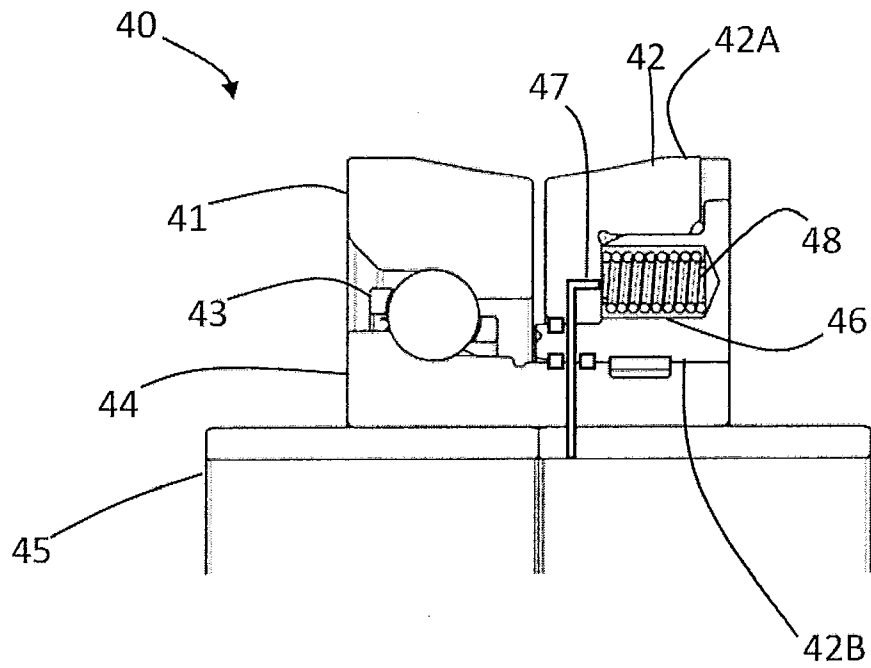


Figure 6

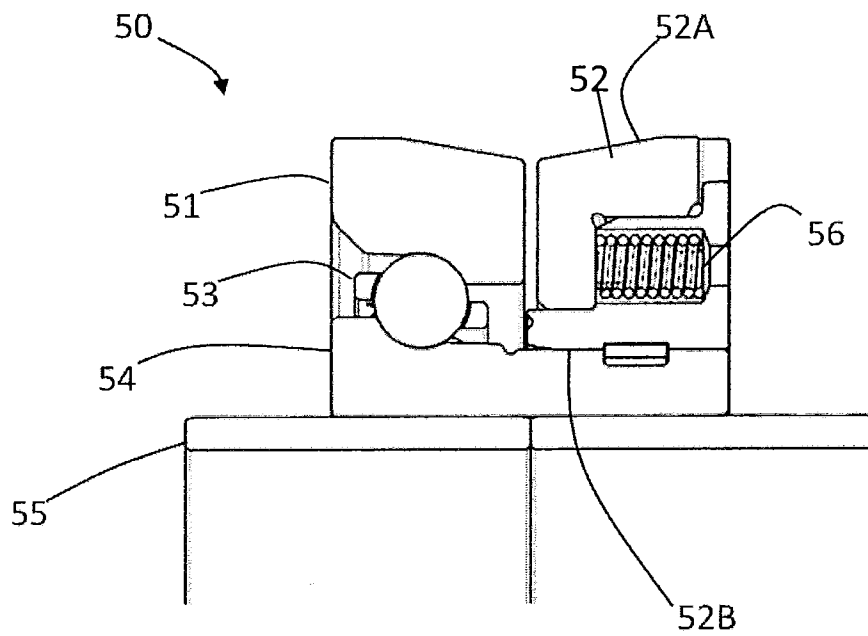


Figure 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/032032

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16H13/14 F16H15/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F16H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017/089434 A1 (WALTZ WILLIAM F [US] ET AL) 30 March 2017 (2017-03-30)	1,4-8, 10-15
Y	paragraphs [0002], [0111], [0144]; figures 1,2	2,3
X	WO 2016/160360 A1 (FALLBROOK IP CO LLC [US]) 6 October 2016 (2016-10-06) figures 2A,4A,4C,7	1,7-9
X	US 2015/072827 A1 (LOHR CHARLES B [US] ET AL) 12 March 2015 (2015-03-12) paragraph [0029]; figures 2,3	1
Y	JP 2003 065209 A (NTN TOYO BEARING CO LTD) 5 March 2003 (2003-03-05) paragraph [0029]; figure 1	2,3
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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"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

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"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

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Date of the actual completion of the international search

29 August 2018

Date of mailing of the international search report

05/09/2018

Name and mailing address of the ISA/

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

Authorized officer

Martínez Hurtado, L

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/032032

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP H07 54947 A (HITACHI METALS LTD; JISHAKU YUSO SYS KAIHATSU KK) 28 February 1995 (1995-02-28) figure 1 -----	2,3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2018/032032

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