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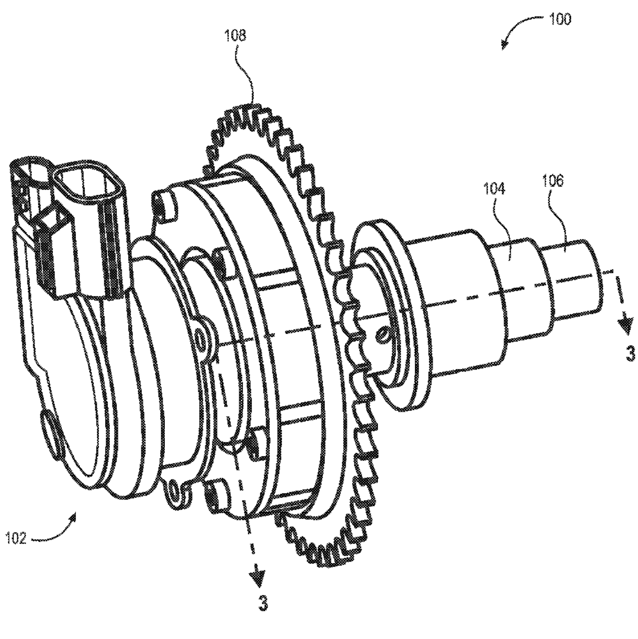

Fig. 2

(57) Abstract: A concentric cam shaft assembly, including: a first camshaft; a second camshaft including at least a portion disposed radially within the first camshaft; and at least one phasing assembly including first and second electric motors and a first input gear arranged to rotate at a first speed in response to receiving rotational torque from a crankshaft of an engine. The rotational torque is arranged to rotate the first and second camshafts. The first electric motor is arranged to circumferentially off-set the first camshaft with respect to the first input gear. The second electric motor is arranged to circumferentially off-set the second camshaft with respect to the first input gear.

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ELECTRIC PHASING OF A CONCENTRIC CAMSHAFT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 61/604,042, filed February 28, 2012 which application is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates generally to electrically phased concentric camshafts. The present disclosure also relates to concentric camshafts phased using electrically driven harmonic drives. The present disclosure further relates to concentric camshafts in which each camshaft is separately electrically phased, in particular, with harmonic drives.

BACKGROUND

[0003] Camshafts are used in internal combustion engines in order to actuate gas exchange valves. The camshaft in an internal combustion engine includes a plurality of cams that engage cam followers (i.e. bucket tappets, finger levers or rocker arms). When the camshaft rotates, the cams lift or depress the cam followers which in turn actuate gas exchange valves (intake, exhaust). The position and shape of the cams dictate the opening period and amplitude as well as the opening and closing time of the gas exchange valves.

[0004] Separate intake and exhaust camshaft assemblies are known in which each camshaft and its related cam lobes separately operate intake valves and exhaust valves, respectively.

[0005] Concentric camshaft assemblies are also known in which separate intake and exhaust camshafts are concentrically arranged by providing a hollow outer camshaft in which an inner camshaft is located, with the inner camshaft cam lobes being rotatable on the outer camshaft, and connected through slots in the hollow outer camshaft to the inner camshaft. This allows the use of separate camshafts for intake and exhaust valve actuation within generally the same space required for a single camshaft.

[0006] Camshaft phasers are used to advance or retard the opening or closing period, phasing the camshaft with respect to the crankshaft rotation. Camshaft phasers generally comprise a timing gear, which can be a chain, belt or gear wheel connected in fixed rotation to a crankshaft by a chain, belt or gear drive, respectively, acting as an input to the phaser. The phaser includes an output connection to the inner or outer camshaft in a concentric camshaft arrangement, or, alternatively, an output connection to an exhaust or intake camshaft. A phasing input is also provided in the form of a hydraulic, pneumatic or electric drive in order to phase or adjust the output rotation of the camshaft relative to the input rotation of the crankshaft.

[0007] Camshaft phasers are generally known in two forms, a piston-type phaser with an axially displaceable piston and a vane-type phaser with vanes that can be acted upon and pivoted in the circumferential direction. With either type, the camshaft phaser is fixedly mounted on the end of a camshaft. Camshaft phasers that operate according to the vane-cell principle for use on single camshafts are known in the art. It is also known to use camshaft phasers in connection with concentric camshaft assemblies for controlling the phase position of the inner camshaft, the outer camshaft, or both relative to each other.

[0008] Vane-cell type phasers employ a supply of hydraulic fluid, normally engine oil, to opposing chambers in the phaser in order to shift the vanes within the phaser circumferentially and thus selectively phase cam timing. Camshaft phasers are subject to oil loss from the phaser through leakage. During normal engine operation engine oil pressure generated by the engine oil pump is sufficient to keep the cam phaser full of oil and, therefore, functioning properly. However, when the engine is not operating, oil leakage from the cam phaser may leave the cam phaser chambers filled with air. This lack of controlling oil pressure and the presence of air in the chambers during engine start conditions, before the engine oil pump generates enough oil pressure and flow, may cause the phaser to oscillate excessively due to lack of oil. This oscillation may, in turn cause noise or damage to the cam phaser mechanism. In addition, it is desirable to have the cam phaser locked in a particular position during engine start-up.

SUMMARY

[0009] According to aspects illustrated herein, there is provided a concentric cam shaft assembly, including: an electric motor; a first camshaft; a second camshaft including at least a portion disposed radially within the first camshaft; an input gear non-rotatably connected to the first camshaft and arranged to rotate at a first speed, with respect to an axis of rotation for the first and second camshafts, in response to receiving rotational torque from a crankshaft of an engine; an output gear non-rotatably connected to the second camshaft; and a harmonic drive including a wave generator; and a flexible gear radially disposed about the wave generator and including a radially inner circumference in contact with the wave generator, and a radially outer circumference with a plurality of drive teeth. The input gear is arranged to rotate the first and second camshafts at the first speed. The electric motor is arranged to rotate the wave generator, with respect to the flexible gear, about an axis of rotation for the wave generator: to change respective radial distances of a plurality of points on the outer circumference of the flexible gear with respect to an axis of rotation for the flexible gear; to urge only a respective portion of the plurality of drive teeth, and not all of the drive teeth, into contact with the one of the input or output gears; and to circumferentially off-set, using an engagement of the respective portion of the plurality of drive teeth with the one of the input or output gears, the second camshaft with respect to the first camshaft.

[0010] According to aspects illustrated herein, there is provided a concentric cam shaft assembly, including: a first camshaft; a second camshaft including at least a portion disposed radially within the first camshaft; and at least one phasing assembly including first and second electric motors and a first input gear arranged to rotate at a first speed in response to receiving rotational torque from a crankshaft of an engine. The rotational torque is arranged to rotate the first and second camshafts. The first electric motor is arranged to circumferentially off-set the first camshaft with respect to the first input gear. The second electric motor is arranged to circumferentially off-set the second camshaft with respect to the first input gear.

[0011] According to aspects illustrated herein, there is provided a method of operating a concentric cam shaft assembly including an electric motor, a first camshaft, a second camshaft including at least a portion disposed radially within the first camshaft, an input gear non-rotatably connected to the first camshaft, an output gear non-rotatably connected to the second camshaft, and a harmonic drive including a wave generator and a flexible gear radially disposed about the wave generator and including a radially inner circumference in contact with the wave generator, and a radially outer circumference with a plurality of drive teeth, the method including: receiving, with the input gear, rotational torque from a crankshaft of an engine; rotating, with the input gear, the first and second camshafts; rotating, with the electric motor, the wave generator, with respect to the flexible gear, about an axis of rotation for the wave generator; changing, with the wave generator, respective radial distances of a plurality of points on the outer circumference of the flexible gear with respect to an axis of rotation for the flexible gear; urging, with the wave generator, only respective portions of the plurality of drive teeth, and not all of the drive teeth, into contact with one of the input or output gears; engaging the plurality of drive teeth with the one of the input or output gears; and circumferentially off-setting, using an engagement of the respective portion of the plurality of drive teeth with the one of the input or output gears, the second camshaft with respect to the first camshaft.

[0012] According to aspects illustrated herein, there is provided a method of operating a concentric cam shaft assembly including a first camshaft; a second camshaft including at least a portion disposed radially within the first camshaft; and at least one phasing assembly including first and second electric motors and a first input gear, the method including: receiving, with the input gear, rotational torque from a crankshaft of an engine; rotating the input gear at a first speed, with respect to an axis of rotation for the first and second camshafts; rotating, with the rotational torque, the first and second camshafts; circumferentially off-setting, using the first electric motor, the first camshaft with respect to the first input gear; and circumferentially off-setting, using the second electric motor, the second camshaft with respect to the first input gear.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The nature and mode of operation of the present invention will now be more fully described in the following detailed description of the invention taken with the accompanying figures, in which:

Figure 1A is a perspective view of a cylindrical coordinate system demonstrating spatial terminology used in the present application;

Figure 1B is a perspective view of an object in the cylindrical coordinate system of Figure 1A demonstrating spatial terminology used in the present application;

Figure 2 is a perspective view of a concentric cam shaft assembly with electric phasing;

Figure 3 is a cross-sectional view of the concentric cam shaft assembly of Figure 2, with the electric motor removed, generally along line 3-3 in Figure 2;

Figure 4 is a schematic representation of the concentric cam shaft assembly of Figure 2;

Figures 5A and 5B are schematic end views of a harmonic drive;

Figure 6A is a schematic representation showing the output gear with more teeth than the flexible gear and Figure 6A is a schematic representation shown the output gear with fewer teeth than the flexible gear;

Figure 7 is a perspective view of a concentric cam shaft assembly with electric phasing;

Figure 8 is a cross-sectional view of the concentric cam shaft assembly of Figure 7, with the electric motor removed, generally along line 8-8 in Figure 7;

Figure 9 is a schematic representation of the concentric cam shaft assembly of Figure 7;

Figure 10 is a schematic representation of a concentric cam shaft assembly with electric phasing and nested phasing assemblies; and,

Figure 11 is a schematic representation of a concentric cam shaft assembly with electric phasing and nested phasing assemblies.

DETAILED DESCRIPTION

[0014] At the outset, it should be appreciated that like drawing numbers on different drawing views identify identical, or functionally similar, structural elements of the invention. While the present invention is described with respect to what is presently considered to be the preferred aspects, it is to be understood that the invention as claimed is not limited to the disclosed aspect. The present invention is intended to include various modifications and equivalent arrangements within the spirit and scope of the appended claims.

[0015] Furthermore, it is understood that this invention is not limited to the particular methodology, materials and modifications described and as such may, of course, vary. It is also understood that the terminology used herein is for the purpose of describing particular aspects only, and is not intended to limit the scope of the present invention, which is limited only by the appended claims.

[0016] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this invention belongs. Although any methods, devices or materials similar or equivalent to those described herein can be used in the practice or testing of the invention, the preferred methods, devices, and materials are now described.

[0017] Harmonic drives, also known as strain wave gearing, are known and information provided below is limited to that necessary to understand the structure and operation of concentric cam shaft assemblies included in the present disclosure. Information regarding harmonic drives is found in the following references:

1. Sclater, Nicholas (2007). *Mechanisms and Mechanical Devices Sourcebook.* ISBN 0-07-146761-0.
2. Lauletta, Anthony (April 2006). "The Basics of Harmonic Drive Gearing" (PDF). *Gear Product News*: 32–36.
3. Tuttle, Timothy D. (1992). Understanding and Modeling the Behavior of a Harmonic Drive Gear Transmission (Report). Massachusetts Institute of Technology. http://hdl.handle.net/1721.1/6803.

[0018] Figure 1A is a perspective view of cylindrical coordinate system **80** demonstrating spatial terminology used in the present application. The present invention is at least partially described within the context of a cylindrical coordinate system. System **80** has a longitudinal axis **81**, used as the reference for the directional and spatial terms that follow. The adjectives “axial,” “radial,” and “circumferential” are with respect to an orientation parallel to axis **81**, radius **82** (which is orthogonal to axis **81**), and circumference **83**, respectively. The adjectives “axial,” “radial” and “circumferential” also are regarding orientation parallel to respective planes. To clarify the disposition of the various planes, objects **84**, **85**, and **86** are used. Surface **87** of object **84** forms an axial plane. That is, axis **81** forms a line along the surface. Surface **88** of object **85** forms a radial plane. That is, radius **82** forms a line along the surface. Surface **89** of object **86** forms a circumferential plane. That is, circumference **83** forms a line along the surface. As a further example, axial movement or disposition is parallel to axis **81**, radial movement or disposition is parallel to radius **82**, and circumferential movement or disposition is parallel to circumference **83**. Rotation is with respect to axis **81**.

[0019] The adverbs “axially,” “radially,” and “circumferentially” are with respect to an orientation parallel to axis **81**, radius **82**, or circumference **83**, respectively. The adverbs “axially,” “radially,” and “circumferentially” also are regarding orientation parallel to respective planes.

[0020] Figure 1B is a perspective view of object **90** in cylindrical coordinate system **80** of Figure 1A demonstrating spatial terminology used in the present application. Cylindrical object **90** is representative of a cylindrical object in a cylindrical coordinate system and is not intended to limit the present invention in any manner. Object **90** includes axial surface **91**, radial surface **92**, and circumferential surface **93**. Surface **91** is part of an axial plane, surface **92** is part of a radial plane, and surface **93** is a circumferential surface.

[0021] Figure 2 is a perspective view of concentric cam shaft assembly **100** with electric phasing.

[0022] Figure 3 is a cross-sectional view of concentric cam shaft assembly **100** of Figure 2, with the electric motor removed, generally along line 3-3 in Figure 2.

[0023] Figure 4 is a schematic representation of concentric cam shaft assembly **100** of Figure 2.

[0024] Figures 5A and 5B are schematic end views of a harmonic drive. The following should be viewed in light of Figures 2 through 5B. Assembly **100** includes electric motor **102**, camshafts **104** and **106**, input gear **108**, output gear **110**, and harmonic drive **112**. At least a portion of camshaft **106** is disposed radially within camshaft **104**. Gear **108** is non-rotatably connected to camshaft **104** and arranged to rotate, with respect to axis of rotation **AR1** for camshafts **104** and **106**, at a first speed in response to receiving rotational torque from crankshaft **114** of engine **116**. Gear **110** is non-rotatably connected to camshaft **106**. The harmonic drive includes wave generator **118** and flexible gear **120** radially disposed about the wave generator and having a plurality of drive teeth **122** forming radially outer circumference **124**. Inner circumference **126** of the flexible gear is in contact with outer race **128** of the wave generator, which forms an outer circumference of the wave generator. The torque from the input gear rotates camshafts **104** and **106** to operate valve train **130** for the engine.

[0025] The electric motor is arranged to rotate the wave generator, with respect to the flexible gear, about axis of rotation **AR2** for the wave generator, which is co-linear with output shaft **132** for the electric motor. The rotation of the wave generator with respect to the flexible gear changes respective radial distances of a plurality of points on the outer circumference of flexible gear **118** with respect to an axis of rotation for flexible gear **118**, as further described below. The contact of the wave generator with the flexible gear urges only respective portions of drive teeth **122**, and not all of drive teeth **122**, into contact with gears **108** and **110** at any point in time. The engagement of drive teeth **122** with one of input gear **108** or output gear **110** is arranged to circumferentially off-sets camshaft **106** with respect to camshaft **104**, that is, the rotation of the wave generator and the engagement of gear **120** with gear **108** or **110** controls phasing of camshaft **106** with respect to camshaft **104** and input gear **108**. The following description of an example embodiment is directed to the case in which contact between flexible gear **120** and output gear **110** is used to off-set camshaft **106**. However, it should be understood that the description is applicable to the case in which contact between flexible gear **120** and input gear **108** is used to off-set camshaft **106**.

[0026] In Figure 5, portions **124A** and **124B** of circumference **124** are maximally extended in a radial direction, orthogonal to axis **AR2**, by contact with the wave generator and are in contact with gears **108** and **110**. Portions **124C** and **124D** are radially inwardly drawn by the "stretching" of the wave generator and are not in contact with gears **108** or **110**. Portions of circumference **124** engaged with gears **108** or **110** are aligned with each other via straight line **134** passing through axis **AR2**. Thus, portions **124A** and **124B** are radially further from the axis for flexible gear **118**, which is co-linear with axis **AR2**, than portions **124C** and **124D**. The rotation of wave generator **118** with respect to flexible gear **120** changes radial distances **RAD1** and **RAD2** of points **P1** and **P2** on the outer circumference of flexible gear **118** with respect to the axis of rotation for flexible gear **118**. That is, the wave generator flexes and changes the shape of the outer circumference.

[0027] In Figure 5A, **RAD1** is clearly greater than **RAD2**. In Figure 5B, the wave generator has rotated in direction **RD1** and **RAD1** is clearly less than **RAD2**. Therefore, the shapes of circumference **124** in Figures 5A and 5B are completely different from each other. It should be understood that Figures 5A and 5B are static illustrations and that the shape of circumference **124** continuously changes, for example, as the wave generator rotates in direction **RD1**. It should be understood that the shapes in Figure 5 are for purposes of illustration only and that other shapes are possible for gears **108**, **110**, and **120** and the wave generator. Gear **110** is shown in Figures 5A and 5B; however, it should be understood that the discussion for Figures 5A and 5B is applicable when gear **108** is shown in place of gear **110**.

[0028] Gear **108** includes plurality of teeth **136** and gear **110** includes plurality of teeth **138**. In an example embodiment, there are a same number of teeth **136** as teeth **122** in a same circumferential span of respective portions of gears **108** and **120** including teeth **136** and **122**, respectively. That is, each respective tooth **136** engages a same valley between adjacent teeth **122** during a full rotation of the wave generator. As a result, the flexible gear rotates at the same speed as the input gear. That is, each tooth **122** engages a same tooth **136** for each revolution of the wave generator. Note that the above discussion is applicable to the case in which there are a same number of teeth **138** as teeth **122** in a same circumferential span of respective portions of gears **110** and **120** including teeth **138** and **122**, respectively, which results in the flexible gear rotating at the same speed as the output gear.

[0029] Figure 6A is a schematic representation showing the output gear with more teeth than the flexible gear. The following should be viewed in light of Figures 2 through 6A. In an example embodiment as shown in Figure 6A, there are more teeth **138** than teeth **122** in a same circumferential span of respective portions of gears **110** and **120** including teeth **138** and **122**, respectively. As a result, there is not a one-to-one engagement of teeth **138** with valleys **140** of the flexible gear. If gear **110** is superimposed on gear **120**, overlap areas **142** occur. For a direction of rotation of **RD1** and example tooth **122A**, there is an overlap with example tooth **138A**. This overlap is biased toward forward valley **140A** on the forward rotational side of tooth **122A**. Since teeth **122** and **138** are circumferentially aligned, the overlap shown in Figure 6A cannot occur. Instead, as tooth **138A** begins to contact tooth **122A**, tooth **138A** is bumped into forward valley **140A** to relieve the pressure between teeth **138A** and **122A**, which circumferentially offsets gear **110** and camshaft **106** in direction **RD1** (advances camshaft **106**) with respect to gear **108** and camshaft **104**.

[0030] In like manner, overlaps between other pairs of teeth **138** and **122** cause respective teeth **138** to slide into respective forward valleys in an on-going process which maintains the circumferential off-set. The circumferential off-set noted above phases camshaft **106** with respect to input gear **108** and camshaft **104**. The above discussion is applicable to the case in which there are more teeth **136** than teeth **122** in a same circumferential span of respective portions of gears **108** and **120** including teeth **136** and **122**, respectively. This case also results in camshaft **106** being circumferentially off-set as described above.

[0031] Figure 6B is a schematic representation showing the output gear with fewer teeth than the flexible gear. The following should be viewed in light of Figures 2 through 6B. In an example embodiment as shown in Figure 6B, there are fewer teeth **138** than teeth **122** in a same circumferential span of teeth **138** and **122**. As a result, there is not a one-to-one engagement of teeth **138** with valleys **140** of the flexible gear. If gear **110** is superimposed on gear **120**, overlap areas **142** occur. For a direction of rotation of **RD1** and example tooth **122B**, there is an overlap with example teeth **138B**. This overlap is biased toward reverse valley **140B** on the reverse rotational side of the tooth **122B**. Since teeth **122** and **138** are circumferentially aligned, the overlap shown in Figure 6B cannot occur. Instead, as tooth **138B** begins to engage tooth **122B**, tooth **138B** is bumped into reverse valley **140B** to relieve the pressure between teeth **138B** and **122B**, which circumferentially off-sets camshaft **106** in a direction opposite **RD1** (retards camshaft **106**) In like manner, overlaps between other pairs of teeth **138** and **122** cause respective teeth **138** to slide into respective reverse valleys to maintain the circumferential off-set. The circumferential off-set noted above phases camshaft **106** with respect to input gear **108** and camshaft **104**. The above discussion is applicable to the case in which there are a fewer teeth **136** than teeth **122** in a same circumferential span of respective portions of gears **108** and **120** including teeth **136** and **122**, respectively. This case also results in camshaft **106** being circumferentially off-set as described above.

[0032] For the example of Figure 6A, increasing the speed of rotation of the wave generator increases the circumferential off-set of camshaft **106** with respect to camshaft **104** and further advances the phasing of camshaft **106**. Decreasing the speed of rotation of the wave generator decreases the circumferential off-set of camshaft **106** with respect to camshaft **104** and retards the phasing of camshaft **106**. For the example of Figure 6B, increasing the speed of rotation of the wave generator decreases the circumferential off-set of camshaft **106** with respect to camshaft **104** and further retards the phasing of camshaft **106**. Decreasing the speed of rotation of the wave generator increases the circumferential off-set of camshaft **106** with respect to camshaft **104** and advances the phasing of camshaft **106**. The above discussion is applicable to the case in which there are a different number of teeth **136** than teeth **122** in a same circumferential span of respective portions of gears **108** and **120** including teeth **136** and **122**, respectively.

[0033] Figure 7 is a perspective view of concentric cam shaft assembly **200** with electric phasing.

[0034] Figure 8 is a cross-sectional view of concentric cam shaft assembly **200** of Figure 7, with the electric motor removed, generally along line 8-8 in Figure 7.

[0035] Figure 9 is a schematic representation of concentric cam shaft assembly **200** of Figure 7. The following should be viewed in light of Figures 2 through 9. Assembly **200** includes camshaft **202**, camshaft **204** including at least a portion disposed radially within camshaft **202**, phasing assembly **206A**, and phasing assembly **206B**. Phasing assembly **206A** includes electric motor **208A**, input gear **210A**, and output gear **212A**. Gear **210A** is arranged to rotate at a first speed in response to receiving rotational torque from crankshaft **213** of engine **214**. Gear **212A** is non-rotatably connected to camshaft **204**. Phasing assembly **206B** includes electric motor **208B**, input gear **210B**, and output gear **212B**. Gear **210B** is non-rotatably connected to camshaft **202**. Gear **212B** is non-rotatably connected to camshaft **202**. Motor **208A** is arranged to circumferentially off-set camshaft **204** with respect to input gear **210A** and phase camshaft **204** with respect to rotation of the crankshaft. Motor **208B** is arranged to circumferentially off-set camshaft **202** with respect to camshaft **204** and phase camshaft **202** with respect to rotation of the crankshaft. As shown in Figure 8, output gear **212A** is connected to axial end **E1** of camshaft **204** and input gear **210B** is connected to axial end **E2**, opposite the end **E1**, of camshaft **204**. “Axial” is defined with respect to an axis of rotation **AR3** for camshafts **202** and **204**.

[0036] In an example embodiment, phasing assembly **206A** includes harmonic drive **215A** with wave generator **216A**, and flexible gear **218A** radially disposed about wave generator **216A**. Gear **218A** includes a plurality of drive teeth **220A**. The discussion regarding the structure and operation of electric motor **102**, harmonic drive **112**, wave generator **118**, flexible gear **120**, and drive teeth **122** is applicable to electric motor **208A**, harmonic drive **215A**, wave generator **216A**, flexible gear **218A**, and drive teeth **220A**. In an example embodiment, phasing assembly **206B** includes a harmonic drive **215B** wave generator **216B**, and flexible gear **218B** radially disposed about wave generator **216B**. Gear **218B** includes a plurality of drive teeth **220B**. The discussion regarding the structure and operation of electric motor **102**, harmonic drive **112**, wave generator **118**, flexible gear **120**, and drive teeth **122** is applicable to electric motor **208B**, harmonic drive **215B**, wave generator **216B**, flexible gear **218B**, and drive teeth **220B**. The discussion for Figure 5 is applicable to harmonic drives **214A** and **214B**.

[0037] Electric motor **208A** is arranged to rotate wave generator **216A**, with respect to flexible gear **218A**, about axis of rotation **AR4** for wave generator **216A**, which is co-linear with output shaft **222A** for electric motor **208A**. The discussion for Figure 5 is applicable to harmonic drive **215A**, that is, the rotation of wave generator **216A** with respect to flexible gear **218A** continually changes a shape of the outer circumference of flexible gear **218A** in a radial direction, as described for wave generator **118** and flexible gear **120**. The contact of wave generator **216A** with flexible gear **218A** urges only respective portions of drive teeth **220A**, and not all of drive teeth **220A**, into contact with gears **210A** and **212A** at any point in time. The engagement of drive teeth **220A** with output gear **212A** is arranged to circumferentially off-set output gear **212A** with respect to input gear **210A**, which circumferentially off-sets camshaft **204** with respect to camshaft **202**.

[0038] Electric motor **208B** is arranged to rotate wave generator **216B**, with respect to flexible gear **218B**, about axis of rotation **AR5** for wave generator **216B**, which is co-linear with output shaft **222B** for electric motor **208B**. The discussion for Figure 5 is applicable to harmonic drive **215B**, that is, the rotation of wave generator **216B** with respect to flexible gear **218B** continually changes a shape of the outer circumference of flexible gear **218B** in a radial direction, as described for wave generator **118** and flexible gear **120**. The contact of wave generator **216B** with flexible gear **218B** urges only respective portions of drive teeth **220B**, and not all of drive teeth **220B**, into contact with gears **210B** and **212B** at any point in time. The engagement of drive teeth **220B** with output gear **212B** is arranged to circumferentially off-set output gear **212B** with respect to input gear **210B**, which circumferentially off-sets camshaft **202** with respect to camshaft **204**.

[0039] Input gears **210A/B** include respective pluralities of teeth **224A/B** and output gears **212A/B** include respective pluralities of teeth **226A/B**. In an example embodiment, the number of teeth **222A** per a circumferential extent of gear **218A** is equal to the number of teeth **224A** per a same circumferential extent of gear **210A**. That is, each respective tooth **224A** engages a same valley between adjacent teeth **222A** during a full rotation of wave generator **216A**. As a result, flexible gear **218A** rotates at the same speed as input gear **210A**. In an example embodiment, the number of teeth **222B** per a circumferential extent of gear **218B** is equal to the number of teeth **224B** per a same circumferential extent of gear **210B**. That is, each respective tooth **224B** engages a same valley between adjacent teeth **222B** during a full rotation of wave generator **216B**. As a result, flexible gear **218B** rotates at the same speed as input gear **210B**. The above discussion is applicable to the case in which there are a same number of teeth for output gear **212A** as teeth **222A** in a same circumferential span of respective portions of output gear **212A** and gears **218A**; and to the case in which there are a same number of teeth for output gear **212B** as teeth **222B** in a same circumferential span of respective portions of output gear **212B** and gears **218B**.

[0040] The discussion of Figures 6A and 6B is applicable to harmonic drive **215A**. For example, in case in which there are more teeth **226A** than teeth **220A** in a same circumferential span of gears **218A** and **212A**, camshaft **204** is advanced with respect to camshaft **202**. Increasing the speed of rotation of wave generator **216A** advances the phasing of camshaft **204**. Decreasing the speed of rotation of wave generator **216A** retards the phasing of camshaft **204**.

[0041] For example, in case in which there are fewer teeth **226A** than teeth **220A** in a same circumferential span of gears **218A** and **212A**, camshaft **204** is retarded with respect to camshaft **202**. Increasing the speed of rotation of wave generator **216A** further retards the phasing of camshaft **204**. Decreasing the speed of rotation of wave generator **216A** advances the phasing of camshaft **204**. The above discussion regarding Figures 6A and 6B is applicable to the case in which there are a different number of teeth for input gear **210A** than teeth **222A** in a same circumferential span of respective portions of input gear **210A** and gears **218A**; and to the case in which there are a different number of teeth for input gear **210B** than teeth **222B** in a same circumferential span of respective portions of input gear **210B** and gears **218B**.

[0042] The discussion of Figures 6A and 6B is applicable to harmonic drive **215B**. For example, in case in which there are more teeth **226B** than teeth **220B** in a same circumferential span of gears **218B** and **212B**, camshaft **202** is advanced with respect to camshaft **204**. Increasing the speed of rotation of wave generator **216B** advances the phasing of camshaft **202**. Decreasing the speed of rotation of wave generator **216B** retards the phasing of camshaft **202**.

[0043] For example, in case in which there are fewer teeth **226B** than teeth **220B** in a same circumferential span of gears **218B** and **212B**, camshaft **202** is retarded with respect to camshaft **204**. Increasing the speed of rotation of wave generator **216B** further retards the phasing of camshaft **202**. Decreasing the speed of rotation of wave generator **216B** advances the phasing of camshaft **202**. The preceding discussion is applicable to the cases in there are more or fewer teeth **224A/B** than teeth **220A/B** in a same circumferential span of gears **210A/B** and **218A/B**.

[0044] Figure 10 is a schematic representation of concentric cam shaft assembly **300** with electric phasing and nested phasing assemblies. The following should be viewed in light of Figures 2 through 6B and 10. Assembly **300** includes camshaft **302**, camshaft **304** including at least a portion disposed radially within camshaft **302**, and phasing assemblies **306A** and **306B**. Phasing assembly **306A** includes electric motor **308A**, input gear **310**, and output gear **312A**. Gear **310** is arranged to rotate at a first speed in response to receiving rotational torque from crankshaft **313** of engine **314**. Gear **312A** is non-rotatably connected to camshaft **302**. Phasing assembly **306B** includes electric motor **308B**, input gear **310**, and output gear **312B**. Gear **312B** is non-rotatably connected to camshaft **304**.

[0045] Motor **308A** is arranged to rotate camshaft **302** with respect to input gear **310** and phase camshaft **302** with respect to input gear **310** and rotation of the crankshaft. Motor **308B** is arranged to rotate camshaft **304** with respect to input gear **310** and phase camshaft **304** with respect to input gear **310** and rotation of the crankshaft. Thus, camshafts **302** and **304** are separately and individually phaseable with respect to input gear **310**.

[0046] In an example embodiment, phasing assembly **306A** includes harmonic drive **315A** with wave generator **316A**, and flexible gear **318A** radially disposed about wave generator **316A**. Gear **318A** includes a plurality of drive teeth **320A**. The discussion regarding the structure and operation of electric motor **102**, harmonic drive **112**, wave generator **118**, flexible gear **120**, and drive teeth **122** is applicable to electric motor **308A**, harmonic drive **315A**, wave generator **316A**, flexible gear **318A**, and drive teeth **320A**. In an example embodiment, phasing assembly **306B** includes a harmonic drive **315B**, wave generator **316B**, and flexible gear **318B** radially disposed about wave generator **316B**. Gear **318B** includes a plurality of drive teeth **320B**. The discussion regarding the structure and operation of electric motor **102**, harmonic drive **112**, wave generator **118**, flexible gear **120**, and drive teeth **122** is applicable to electric motor **308B**, harmonic drive **315B**, wave generator **316B**, flexible gear **318B**, and drive teeth **320B**. The discussion for Figure 5 is applicable to harmonic drives **314A** and **314B**.

[0047] Electric motor **308A** is arranged to rotate wave generator **316A**, with respect to flexible gear **318A**, about axis of rotation **AR6** for wave generator **316A**, which is co-linear with output shaft **322A** for electric motor **308A**. The rotation of wave generator **316A** with respect to flexible gear **318A** continually changes a shape of the outer circumference of flexible gear **318A** in a radial direction, as described for wave generator **118** and flexible gear **120**. The contact of wave generator **316A** with flexible gear **318A** urges only respective portions of drive teeth **320A**, and not all of drive teeth **320A**, into contact with gears **310A** and **312A** at any point in time. The engagement of drive teeth **320A** with output gear **312A** is arranged to circumferentially off-set output gear **312A** with respect to input gear **310**, which circumferentially off-sets camshaft **302** with respect to gear **310**.

[0048] Electric motor **308B** is arranged to rotate wave generator **316B**, with respect to flexible gear **318B**, about axis of rotation **AR7** for wave generator **316B**, which is co-linear with output shaft **322B** for electric motor **308B**. The rotation of wave generator **316B** with respect to flexible gear **318B** continually changes a shape of the outer circumference of flexible gear **318B** in a radial direction, as described for wave generator **118** and flexible gear **120**. The contact of wave generator **316B** with flexible gear **318B** urges only respective portions of drive teeth **320B**, and not all of drive teeth **320B**, into contact with gears **310B** and **312B** at any point in time. The engagement of drive teeth **320B** with output gear **312B** is arranged to circumferentially off-set output gear **312B** with respect to input gear **310**, which circumferentially off-sets camshaft **304** with respect to input gear **310**. In an example embodiment, shaft **322B** is nested within shaft **322A**.

[0049] Input gear **310** include a plurality of teeth **324** and output gears **312A/B** include respective pluralities of teeth **326A/B**. In an example embodiment, the number of teeth **322A** per a circumferential extent of gear **318A** is equal to the number of teeth **324** per a same circumferential extent of gear **310**. That is, each respective tooth **324** engages a same valley between adjacent teeth **322A** during a full rotation of wave generator **316A**. As a result, flexible gear **318A** rotates at the same speed as input gear **310**. In an example embodiment, the number of teeth **322B** per a circumferential extent of gear **318B** is equal to the number of teeth **324** per a same circumferential extent of gear **310**. That is, each respective tooth **324** engages a same valley between adjacent teeth **322B** during a full rotation of wave generator **316B**. As a result, flexible gear **318B** rotates at the same speed as input gear **310**. The above discussion is applicable to the case in which there are a same number of teeth for output gear **312A** as teeth **322A** in a same circumferential span of respective portions of output gear **312A** and gears **318A**; and to the case in which there are a same number of teeth for output gear **312B** as teeth **322B** in a same circumferential span of respective portions of output gear **312B** and gears **318B**.

[0050] The discussion of Figures 6A and 6B is applicable to harmonic drive **315A**. For example, in case in which there are more teeth **326A** than teeth **220A** in a same circumferential span of gears **318A** and **312A**, camshaft **302** is advanced with respect to gear **310**. Increasing the speed of rotation of wave generator **316A** advances the phasing of camshaft **302**. Decreasing the speed of rotation of wave generator **316A** retards the phasing of camshaft **302**.

[0051] For example, in case in which there are fewer teeth **326A** than teeth **320A** in a same circumferential span of gears **318A** and **312A**, camshaft **302** is retarded with respect to gear **310**. Increasing the speed of rotation of wave generator **316A** further retards the phasing of camshaft **302**. Decreasing the speed of rotation of wave generator **316A** advances the phasing of camshaft **302**.

[0052] The discussion of Figures 6A and 6B is applicable to harmonic drive **315B**. For example, in case in which there are more teeth **326B** than teeth **320B** in a same circumferential span of gears **318B** and **312B**, camshaft **304** is advanced with respect to gear **310**. Increasing the speed of rotation of wave generator **316B** advances the phasing of camshaft **304**. Decreasing the speed of rotation of wave generator **316B** retards the phasing of camshaft **304**.

[0053] For example, in case in which there are fewer teeth **326B** than teeth **320B** in a same circumferential span of gears **318B** and **312B**, camshaft **304** is retarded with respect to gear **310**. Increasing the speed of rotation of wave generator **316B** further retards the phasing of camshaft **304**. Decreasing the speed of rotation of wave generator **316B** advances the phasing of camshaft **304**. The above discussion regarding Figures 6A and 6B is applicable to the case in which there are a different number of teeth for input gear **310** than teeth **322A** or **322B** in a same circumferential span of respective portions of input gear **310** and gears **318A** or **318B**.

[0054] Figure 11 is a schematic representation of concentric cam shaft assembly **400** with electric phasing and nested phasing assemblies. The following should be viewed in light of Figures 2 through 6B, and 11. Assembly **400** includes camshaft **402**, camshaft **404** including at least a portion disposed radially within camshaft **402**, and phasing assemblies **406A** and **406B**. Phasing assembly **406A** includes electric motor **408A**, input gear **410**, and output/input gear **411**. Gear **410** is arranged to rotate at a first speed in response to receiving rotational torque from crankshaft **413** of engine **414**. Gear **411** is non-rotatably connected to camshaft **402**. Phasing assembly **406B** includes electric motor **408B**, output/input gear **411**, and output gear **412**. Gear **412** is non-rotatably connected to camshaft **404**.

[0055] Motor **408A** is arranged to circumferentially off-set camshaft **402** with respect to input gear **410** and phase camshaft **402** with respect to rotation of input gear **410** and the crankshaft. Motor **408B** is arranged to circumferentially off-set camshaft **404** with respect to output/input gear **411** and phase camshaft **404** with respect to output/input gear **411** and camshaft **402**.

[0056] In an example embodiment, phasing assembly **406A** includes harmonic drive **415A** with wave generator **416A**, and flexible gear **418A** radially disposed about wave generator **416A**. Gear **418A** includes a plurality of drive teeth **420A**. The discussion regarding the structure and operation of electric motor **102**, harmonic drive **112**, wave generator **118**, flexible gear **120**, and drive teeth **122** is applicable to electric motor **408A**, harmonic drive **415A**, wave generator **416A**, flexible gear **418A**, and drive teeth **420A**. In an example embodiment, phasing assembly **406B** includes a harmonic drive **415B** wave generator **416B**, and flexible gear **418B** radially disposed about wave generator **416B**. Gear **418B** includes a plurality of drive teeth **420B**. The discussion regarding the structure and operation of electric motor **102**, harmonic drive **112**, wave generator **118**, flexible gear **120**, and drive teeth **122** is applicable to electric motor **408B**, harmonic drive **415B**, wave generator **416B**, flexible gear **418B**, and drive teeth **420B**. The discussion for Figure 5 is applicable to harmonic drives **414A** and **414B**.

[0057] Electric motor **408A** is arranged to rotate wave generator **416A**, with respect to flexible gear **418A**, about axis of rotation **AR8** for wave generator **416A**, which is co-linear with output shaft **422A** for electric motor **408A**. The rotation of wave generator **416A** with respect to flexible gear **418A** continually changes a shape of the outer circumference of flexible gear **418A**

in a radial direction, as described for wave generator **118** and flexible gear **120**. The contact of wave generator **416A** with flexible gear **418A** urges only respective portions of drive teeth **420A**, and not all of drive teeth **420A**, into contact with gears **410** and **411** at any point in time. The engagement of drive teeth **420A** with output gear **410** is arranged to circumferentially off-set output gear **410** with respect to input/output gear **411**, which circumferentially off-sets camshaft **402** with respect to gear **411**.

[0058] Electric motor **408B** is arranged to rotate wave generator **416B**, with respect to flexible gear **418B**, about axis of rotation **AR9** for wave generator **416B**, which is co-linear with output shaft **422B** for electric motor **408B**. The rotation of wave generator **416B** with respect to flexible gear **418B** continually changes a shape of the outer circumference of flexible gear **418B** in a radial direction, as described for wave generator **118** and flexible gear **120**. The contact of wave generator **416B** with flexible gear **418B** urges only respective portions of drive teeth **420B**, and not all of drive teeth **420B**, into contact with gears **411** and **412** at any point in time. The engagement of drive teeth **420B** with output gear **412** is arranged to circumferentially off-set output gear **412** with respect to input/output gear **411**, which circumferentially off-sets camshaft **404** with respect to gear **411**.

[0059] Input gear **410** includes a plurality of teeth **424**, output/input gear **411** includes a plurality of teeth **426A**, and output gear **412** includes a plurality of teeth **426B**. In an example embodiment, the number of teeth **424** is equal to the number of teeth **420A**, in a same circumferential span of gears **418A** and **410**. As a result, flexible gear **418A** rotates at the same speed as input gear **410**. In an example embodiment, the number of teeth **426B** is equal to the number of teeth **420B**, in a same circumferential span of gears **418A** and **411**. As a result, flexible gear **418B** rotates at the same speed as output/input gear **411**. The above discussion is applicable to the case in which there are a same number of teeth for gear **411** as teeth **422A** in a same circumferential span of respective portions of gear **411** and gear **418A**; and to the case in which there are a same number of teeth for gear **411** as teeth **422B** in a same circumferential span of respective portions of gear **411** and gear **418B**.

[0060] The discussion of Figures 6A and 6B is applicable to harmonic drive **415A**. For example, in case in which there are more teeth **426A** than teeth **420A** in a same circumferential span of gears **418A** and **411**, camshaft **402** is advanced with respect to gear **410**. Increasing the speed of rotation of wave generator **416A** advances the phasing of camshaft **402**. Decreasing the speed of rotation of wave generator **416A** retards the phasing of camshaft **402**.

[0061] For example, in case in which there are fewer teeth **426A** than teeth **420A** in a same circumferential span of gears **418A** and **411**, camshaft **402** is retarded with respect to gear **410**. Increasing the speed of rotation of wave generator **416A** further retards the phasing of camshaft **402**. Decreasing the speed of rotation of wave generator **416A** advances the phasing of camshaft **402**.

[0062] The discussion of Figures 6A and 6B is applicable to harmonic drive **415B**. For example, in case in which there are more teeth **426B** than teeth **420B** in a same circumferential span of gears **418B** and **412**, camshaft **404** is advanced with respect to gear **411**. Increasing the speed of rotation of wave generator **416B** advances the phasing of camshaft **404**. Decreasing the speed of rotation of wave generator **416B** retards the phasing of camshaft **404**.

[0063] For example, in case in which there are fewer teeth **426B** than teeth **420B** in a same circumferential span of gears **418B** and **412**, camshaft **404** is retarded with respect to gear **411**. Increasing the speed of rotation of wave generator **416B** further retards the phasing of camshaft **404**. Decreasing the speed of rotation of wave generator **416B** advances the phasing of camshaft **404**. The above discussion regarding Figures 6A and 6B is applicable to the case in which there are a different number of teeth for input gear **411** than teeth **422A** or **422B** in a same circumferential span of respective portions of input gear **411** and gears **418A** or **418B**.

[0064] In an example embodiment the components described below are included in assembly **100**. Wave generator **118** includes rotor **118A** and a plurality of balls **118B** disposed between the rotor and outer race **126**. The balls facilitate rotation of the rotor with respect to the outer race. In an example embodiment, shaft **132** is connected to interface **146**, which is connected to the rotor by fasteners **148**. Bridge piece **150** is non-rotatably connected to gear **108** and teeth **136** are on bridge piece **150**. Gear **108** and bridge piece **150** can be made of a single piece of material. Bridge piece **152** is non-rotatably connected to gear **110** and camshaft **106**. Gear **110** and bridge piece **152** can be made of a single piece of material.

[0065] In an example embodiment the components described below are included in assembly **200**. Wave generator **216A** includes rotor **228A** and a plurality of balls **230A** disposed between rotor **228A** and outer race **232A**. The balls facilitate rotation of rotor **228A** with respect to outer race **232A**. In an example embodiment, shaft **222A** is connected to interface **234A**, which is connected to rotor **228A** by fasteners **236A**. Bridge piece **238A** is non-rotatably connected to gear **210A** and teeth **224A** are on bridge piece **238**. Gear **210A** and bridge piece **238A** can be made of a single piece of material. Bridge piece **240A** is non-rotatably connected to gear **212A** and camshaft **204**. Gear **212A** and bridge piece **240A** can be made of a single piece of material. Wave generator **216B** includes rotor **228B** and a plurality of balls **230B** disposed between rotor **228B** and outer race **232B**. The balls facilitate rotation of rotor **228A** with respect to outer race **232B**. In an example embodiment, shaft **222B** is connected to interface **234B**, which is connected to rotor **228B** by fasteners **236B**. Bridge piece **238B** is non-rotatably connected to gear **210B** and teeth **224B** are on bridge piece **238B**. Gear **210B** and bridge piece **238B** can be made of a single piece of material. Bridge piece **240B** is non-rotatably connected to gear **212B** and camshaft **202**. Gear **212B** and bridge piece **240B** can be made of a single piece of material.

[0066] The following provides further detail regarding assemblies **100**, **200**, and **300**. Advantageously, assemblies **100**, **200**, and **300** enable more flexibility for engine design by enabling greater control of and variation of camshaft phasing (and valve opening and closing events). Specifically, the phasing can be dynamically tailored to specific operating conditions such as engine speed and load. In comparison to hydraulic phasing system, assemblies **100**, **200**, and **300** have reduced space requirements, provide increased shift velocity over a wider range of operating conditions, are not subject to degraded operation by conditions such a cold oil temperatures, have faster response times, have unlimited shift authority, and are independent of oil pressure from an engine oil pump. Since the oil pump is not needed to control phasing, the oil pump can be sized smaller to increase efficiency and reduce losses.

[0067] It will be appreciated that various of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations, or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims.

What is Claimed is:

1. A concentric cam shaft assembly, comprising:

an electric motor;

a first camshaft;

a second camshaft including at least a portion disposed radially within the first camshaft;

an input gear non-rotatably connected to the first camshaft and arranged to rotate at a first speed, with respect to an axis of rotation for the first and second camshafts, in response to receiving rotational torque from a crankshaft of an engine;

an output gear non-rotatably connected to the second camshaft; and,

a harmonic drive including:

a wave generator; and,

a flexible gear radially disposed about the wave generator and including a radially inner circumference in contact with the wave generator, and a radially outer circumference with a plurality of drive teeth, wherein:

the input gear is arranged to rotate the first and second camshafts at the first speed;

the electric motor is arranged to rotate the wave generator, with respect to the flexible gear, about an axis of rotation for the wave generator:

to change respective radial distances of a plurality of points on the outer circumference of the flexible gear with respect to an axis of rotation for the flexible gear;

to urge only a respective portion of the plurality of drive teeth, and not all of the drive teeth, into contact with the one of the input or output gears; and,

to circumferentially off-set, using an engagement of the respective portion of the plurality of drive teeth with the one of the input or output gears, the second camshaft with respect to the first camshaft.

2. The concentric cam shaft assembly of claim 1, wherein:

the respective portions of the plurality of drive teeth include:

a first portion; and,

a second portion aligned with the first portion via a first straight line passing through the first axis of rotation.

3. The concentric cam shaft assembly of claim 2, wherein:

the plurality of drive teeth include third and fourth portions not in contact with the input or output gears when the first and second portions are in contact with the input and output gears; and,

the third and fourth portions are radially closer to the axis of rotation for the wave generator than the first and second portions.

4. The concentric cam shaft assembly of claim 1, wherein:

the flexible gear is arranged to rotate at the first speed.

5. The concentric cam shaft assembly of claim 1, wherein:

the one of the input or output gears includes a first plurality of teeth having a first number of teeth in a first circumferential span of a portion of the one of the input or output gears including the first plurality of teeth;

the flexible gear includes a second plurality of teeth having a second number of teeth in a second circumferential span, equal to the first circumferential span, of a portion of the flexible gear including the second plurality of teeth; and,

the first number is less than or greater than the second number.

6. The concentric cam shaft assembly of claim 5, wherein:

the first number is greater than the second number;

increasing a speed of rotation for the wave generator increases a circumferential off-set between the first and second camshafts; and,

decreasing the speed of rotation for the wave generator decreases the circumferential off-set.

7. The concentric cam shaft assembly of claim 5, wherein:

the first number is less than the second number;

increasing a speed of rotation for the wave generator decreases a circumferential off-set between the first and second camshafts; and,

decreasing the speed of rotation for the wave generator increases the circumferential off-set.

8. A concentric cam shaft assembly, comprising:

a first camshaft;

a second camshaft including at least a portion disposed radially within the first camshaft; and,

at least one phasing assembly including:

first and second electric motors;

a first input gear arranged to rotate at a first speed in response to receiving rotational torque from a crankshaft of an engine, wherein:

the rotational torque is arranged to rotate the first and second camshafts;

the first electric motor is arranged to circumferentially off-set one of the first or second camshafts with respect to the first input gear; and,

the second electric motor is arranged to circumferentially off-set an other of the first or second camshafts with respect to the first input gear.

9. The concentric cam shaft of claim 8, wherein:

the at least one phasing assembly includes:

a first output gear non-rotatably connected to a first axial end of the second camshaft; and,

a second input gear non-rotatably connected to a second axial end, opposite the first end, of the second camshaft; and,

axial is defined with respect to an axis of rotation for the first and second camshafts.

10. The concentric cam shaft of claim 9, wherein:

the at least one phasing assembly includes:

a first phasing assembly with:

the first electric motor;

the first input gear; and,

the first output gear; and,

a second phasing assembly including:

the second electric motor;

the second input gear; and,

a second output gear non-rotatably connected to the first camshaft.

11. The concentric cam shaft of claim 10, wherein:

the first phasing assembly includes a first harmonic drive with:

a first wave generator; and,

a first flexible gear radially disposed about the first wave generator and including a first radially inner circumference in contact with the first wave generator, and a first radially outer circumference with a first plurality of drive teeth;

the second phasing assembly includes a second harmonic drive with:

a second wave generator; and,

a second flexible gear radially disposed about the second wave generator and including a second radially inner circumference in contact with the second wave generator, and a second radially outer circumference with a second plurality of drive teeth;

the first electric motor is arranged to rotate the first wave generator, with respect to the first flexible gear to engage a portion of the first plurality of drive teeth with the first input or output gear;

an engagement of the first plurality of drive teeth with the first input or output gear is arranged to circumferentially off-set the second camshaft with respect to the first input gear;

the second electric motor is arranged to rotate the second wave generator, with respect to the second flexible gear to engage a portion of the second plurality of drive teeth with the second input or output gear; and,

an engagement of the second plurality of drive teeth with the second input or output gear is arranged to circumferentially off-set the first camshaft with respect to the first input gear.

12. The concentric cam shaft of claim 11, wherein:

the first electric motor is arranged to rotate the first wave generator, with respect to the first flexible gear, about an axis of rotation for the first wave generator:

to change respective radial distances of a plurality of points on the first outer circumference of the first flexible gear with respect to an axis of rotation for the first flexible gear; and,

to urge only respective portions of the first plurality of drive teeth, and not all of the first drive teeth, into contact with the first input and output gears;

the second electric motor is arranged to rotate the second wave generator, with respect to the second flexible gear, about an axis of rotation for the second wave generator:

to change respective radial distances of a plurality of points on the second outer circumference of the second flexible gear with respect to an axis of rotation for the second flexible gear; and,

to urge only respective portions of the second plurality of drive teeth, and not all of the second drive teeth, into contact with the second input and output gears.

13. The concentric cam shaft of claim 8, wherein:

the first camshaft includes first and second opposite ends;

the second camshaft includes third and fourth opposite ends;

a first axial direction is defined as being parallel to an axis of rotation for the first and second camshafts and extending from the first end to the second end and from the third end to the fourth end; and,

the first and second output gears are connected to the first and third ends, respectively.

14. The concentric cam shaft of claim 13, wherein:

the at least one phasing assembly includes:

a first phasing assembly with:

the first electric motor;

the first input gear; and,

a first output gear non-rotatably connected to the first camshaft; and, a second phasing assembly including:

the second electric motor;

the first input gear; and,

a second output gear non-rotatably connected to the second camshaft.

15. The concentric cam shaft of claim 14, wherein:

the first phasing assembly includes a first harmonic drive with:

a first wave generator; and,

a first flexible gear radially disposed about the first wave generator and including a first radially inner circumference in contact with the first wave generator, and a first radially outer circumference with a first plurality of drive teeth; and,

the second phasing assembly includes a second harmonic drive with:

a second wave generator; and,

a second flexible gear radially disposed about the second wave generator and including a second radially inner circumference in contact with the second wave generator, and a second radially outer circumference with a second plurality of drive teeth;

the first electric motor is arranged to rotate the first wave generator, with respect to the first flexible gear to engage a portion of the first plurality of drive teeth with the first input or output gear;

an engagement of the first plurality of drive teeth with the first input or output gear is arranged to circumferentially off-set the first camshaft with respect to the first input gear;

the second electric motor is arranged to rotate the second wave generator, with respect to the second flexible gear to engage a portion of the second plurality of drive teeth with the first input gear or the second output gear; and,

an engagement of the second plurality of drive teeth with the first input gear or the second output gear is arranged to circumferentially off-set the second camshaft with respect to the first input gear.

16. The concentric cam shaft of claim 15, wherein:

the first electric motor is arranged to rotate the first wave generator, with respect to the first flexible gear, about an axis of rotation for the first wave generator:

to change respective radial distances of a plurality of points on the first outer circumference of the first flexible gear with respect to an axis of rotation for the first flexible gear; and,

to urge only respective portions of the first plurality of drive teeth, and not all of the first drive teeth, into contact with the first input and output gears;

the second electric motor is arranged to rotate the second wave generator, with respect to the second flexible gear, about an axis of rotation for the second wave generator:

to change respective radial distances of a plurality of points on the second outer circumference of the second flexible gear with respect to an axis of rotation for the second flexible gear; and,

to urge only respective portions of the second plurality of drive teeth, and not all of the second drive teeth, into contact with the second input and output gears.

17. The concentric cam shaft of claim 13, wherein:

the at least one phasing assembly includes:

a first phasing assembly with:

the first electric motor;

the first input gear; and,

an input/output gear non-rotatably connected to the first camshaft; and,

a second phasing assembly including:

the second electric motor;

the input/output gear; and,

a second output gear non-rotatably connected to the second camshaft.

18. The concentric cam shaft of claim 17, wherein:

the first phasing assembly includes a first harmonic drive with:

a first wave generator; and,

a first flexible gear radially disposed about the first wave generator and including a first radially inner circumference in contact with the first wave generator, and a first radially outer circumference with a first plurality of drive teeth;

the second phasing assembly includes a second harmonic drive with:

a second wave generator; and,

a second flexible gear radially disposed about the second wave generator and including a second radially inner circumference in contact with the second wave generator, and a second radially outer circumference with a second plurality of drive teeth;

the first electric motor is arranged to rotate the first wave generator, with respect to the first flexible gear to engage a portion of the first plurality of drive teeth with the first input gear or the input/output gear;

an engagement of the first plurality of drive teeth the first input gear or the input/output gear is arranged to circumferentially off-set the first camshaft with respect to the first input gear;

the second electric motor is arranged to rotate the second wave generator, with respect to the second flexible gear to engage a portion of the second plurality of drive teeth with the input/output gear or the second output gear; and,

an engagement of the second plurality of drive teeth with the input/output gear or the second output gear is arranged to circumferentially off-set the second camshaft with respect to the first input gear.

19. The concentric cam shaft of claim 18, wherein:

the first electric motor is arranged to rotate the first wave generator, with respect to the first flexible gear, about an axis of rotation for the first wave generator:

to change respective radial distances of a plurality of points on the first outer circumference of the first flexible gear with respect to an axis of rotation for the first flexible gear; and,

to urge only respective portions of the first plurality of drive teeth, and not all of the first drive teeth, into contact with the first input gear or the input/output gear;

the second electric motor is arranged to rotate the second wave generator, with respect to the second flexible gear, about an axis of rotation for the second wave generator:

to change respective radial distances of a plurality of points on the second outer circumference of the second flexible gear with respect to an axis of rotation for the second flexible gear; and,

to urge only respective portions of the second plurality of drive teeth, and not all of the second drive teeth, into contact with the input/output gear or the second output gear.

20. A method of operating a concentric cam shaft assembly including an electric motor, a first camshaft, a second camshaft including at least a portion disposed radially within the first camshaft, an input gear non-rotatably connected to the first camshaft, an output gear non-rotatably connected to the second camshaft, and a harmonic drive including a wave generator and a flexible gear radially disposed about the wave generator and including a radially inner circumference in contact with the wave generator, and a radially outer circumference with a plurality of drive teeth, the method comprising:

receiving, with the input gear, rotational torque from a crankshaft of an engine;

rotating, with the input gear, the first and second camshafts;

rotating, with the electric motor, the wave generator, with respect to the flexible gear, about an axis of rotation for the wave generator;

changing, with the wave generator, respective radial distances of a plurality of points on the outer circumference of the flexible gear with respect to an axis of rotation for the flexible gear;

urging, with the wave generator, only respective portions of the plurality of drive teeth, and not all of the drive teeth, into contact with one of the input or output gears;

engaging the plurality of drive teeth with the one of the input or output gears; and,

circumferentially off-setting, using an engagement of the respective portion of the plurality of drive teeth with the one of the input or output gears, the second camshaft with respect to the first camshaft.

21. The method of claim 20, wherein:

engaging the plurality of drive teeth with the input and output gears includes aligning first and second portions from the respective portions of the drive teeth with a first straight line passing through the first axis of rotation.

22. The method of claim 21, wherein:

engaging the plurality of drive teeth with the input and output gears includes:

keeping third and fourth portions of the respective portions of the drive teeth out of contact with the input and output gears when the first and second portions are in contact with the input and output gears; and,

displacing the third and fourth portions radially closer to the axis of rotation for the wave generator than the first and second portions.

23. The method of claim 20, further comprising:

rotating the flexible gear at the first speed.

24. The method of claim 21, wherein:

the one of the input or output gears includes a first plurality of teeth having a first number of teeth in a first circumferential span of a portion of the one of the input or output gears including the first plurality of teeth;

the flexible gear includes a second plurality of teeth having a second number of teeth in a second circumferential span, equal to the first circumferential span, of a portion of the flexible gear including the second plurality of teeth; and,

the first number is less than or greater than the second number.

25. The method of claim 24, wherein:

the first number is greater than the second number, the method further comprising:

increasing a speed of rotation for the wave generator to increase a circumferential off-set between the first and second camshafts; and, decreasing the speed of rotation for the wave generator to decrease the circumferential off-set.

26. The method of claim 24, wherein:

the first number is less than the second number, the method further comprising:

increasing a speed of rotation for the wave generator to decrease a circumferential off-set between the first and second camshafts; and,

decreasing the speed of rotation for the wave generator to increase the circumferential off-set.

27. A method of phasing a concentric cam shaft assembly including a first camshaft; a second camshaft including at least a portion disposed radially within the first camshaft; and at least one phasing assembly including first and second electric motors and a first input gear, the method comprising:

receiving, with the input gear, rotational torque from a crankshaft of an engine;

rotating the input gear at a first speed, with respect to an axis of rotation for the first and second camshafts;

rotating, with the rotational torque, the first and second camshafts;

circumferentially off-setting, using the first electric motor, one of the first or second camshafts with respect to the first input gear; and,

circumferentially off-setting, using the second electric motor, an other of the first or second camshafts with respect to the first input gear.

28. The method of claim 27, wherein:

the at least one phasing assembly includes:

a first output gear non-rotatably connected to a first axial end of the second camshaft; and,

a second input gear non-rotatably connected to a second axial end, opposite the first end, of the second camshaft; and,

axial is defined with respect to an axis of rotation for the first and second camshafts.

29. The method of claim 28, wherein:

the at least one phasing assembly includes:

a first phasing assembly with:

the first electric motor;

the first input gear; and,

the first output gear; and,

a second phasing assembly including:

the second electric motor;

the second input gear; and,

a second output gear non-rotatably connected to the first camshaft;

the first phasing assembly includes a first harmonic drive with:

a first wave generator; and,

a first flexible gear radially disposed about the first wave generator and including a first radially inner circumference in contact with the first wave generator, and a first radially outer circumference with a plurality of first drive teeth; and,

the second phasing assembly includes a second harmonic drive with:

a second wave generator; and,

a second flexible gear radially disposed about the second wave generator and including a second radially inner circumference in contact with the second wave generator, and a second radially outer circumference with a second plurality of drive teeth, the method further comprising:

rotating, with the first electric motor, the first wave generator, with respect to the first flexible gear to engage a portion of the first plurality of drive teeth with the first input or output gear;

circumferentially off-setting, using an engagement of the portion of the first plurality of drive teeth with the first input or output gear, the second camshaft with respect to the first camshaft;

rotating, with the second electric motor, the second wave generator, with respect to the second flexible gear to engage a portion of the second plurality of drive teeth with the second input or output gear; and, circumferentially off-setting, using an engagement of the portion of the second plurality of drive teeth with the second input or output gear, the first camshaft with respect to the second camshaft.

30. The method of claim 29, further comprising:

rotating, with the first electric motor, the first wave generator, with respect to the first flexible gear, about an axis of rotation for the first wave generator;

changing, using the rotation of the first wave generator, respective radial distances of a plurality of points on the first outer circumference of the first flexible gear with respect to an axis of rotation for the first flexible gear;

urging, using the rotation of the first wave generator, only respective portions of the first plurality of drive teeth, and not all of the first drive teeth, into contact with the first input and output gears;

rotating, with the second electric motor, the second wave generator, with respect to the second flexible gear, about an axis of rotation for the second wave generator;

changing, using the rotation of the second wave generator, respective radial distances of a plurality of points on the second outer circumference of the second flexible gear with respect to an axis of rotation for the second flexible gear; and,

urging, using the rotation of the second wave generator, only respective portions of the second plurality of drive teeth, and not all of the second drive teeth, into contact with the second input and output gears.

31. The method of claim 27, wherein:

the first camshaft includes first and second opposite ends;

the second camshaft includes third and fourth opposite ends;

a first axial direction is defined as being parallel to an axis of rotation for the first and second camshafts and extending from the first end to the second end and from the third end to the fourth end; and,

the first and second output gears are connected to the first and third ends, respectively.

32. The method of claim 31, wherein:

the at least one phasing assembly includes:

a first phasing assembly with:

the first electric motor;

the first input gear; and,

a first output gear non-rotatably connected to the first camshaft;

a second phasing assembly including:

the second electric motor;

the first input gear; and,

a second output gear non-rotatably connected to the second camshaft.

the first phasing assembly includes a first harmonic drive with:

a first wave generator; and,

a first flexible gear radially disposed about the first wave generator and including a first radially inner circumference in contact with the first wave generator; and,

the second phasing assembly includes a second harmonic drive with:

a second wave generator; and,

a second flexible gear radially disposed about the second wave generator and including a second radially inner circumference in contact with the second wave generator, the method further comprising:

rotating, with the first electric motor, the first wave generator, with respect to the first flexible gear to engage a portion of the first plurality of drive teeth with the first input or output gear;

circumferentially off-setting, using an engagement of the portion of the first plurality of drive teeth with the first input or output gear, the first camshaft with respect to the second camshaft;

rotating, with the second electric motor, the second wave generator, with respect to the second flexible gear to engage a portion of the second plurality of drive teeth with the first input gear or the second output gear;

circumferentially off-setting, using an engagement of the portion of the second plurality of drive teeth with the first input gear or the second output gear, the second camshaft with respect to the first camshaft.

33. The method of claim 32, further comprising:

rotating, with the first electric motor, the first wave generator, with respect to the first flexible gear, about an axis of rotation for the first wave generator;

changing, with the first wave generator, respective radial distances of a plurality of points on the first outer circumference of the first flexible gear with respect to an axis of rotation for the first flexible gear;

urging, with the first wave generator, only respective portions of the first plurality of drive teeth, and not all of the first drive teeth, into contact with the first input and output gears;

rotating, with the second electric motor, the second wave generator, with respect to the second flexible gear, about an axis of rotation for the second wave generator;

changing, with the second wave generator, respective radial distances of a plurality of points on the second outer circumference of the second flexible gear with respect to an axis of rotation for the second flexible gear; and,

urging, with the second wave generator, only respective portions of the second plurality of drive teeth, and not all of the second drive teeth, into contact with the second input and output gears.

34. The method of claim 31, wherein:

the at least one phasing assembly includes:

a first phasing assembly with:

the first electric motor;

the first input gear; and,

an input/output gear non-rotatably connected to the first camshaft; and,

a second phasing assembly including:

the second electric motor;

the input/output gear; and,

a second output gear non-rotatably connected to the second camshaft;

the first phasing assembly includes a first harmonic drive with:

a first wave generator; and,

a first flexible gear radially disposed about the first wave generator and including a first radially inner circumference in contact with the first wave generator; and,

the second phasing assembly includes a second harmonic drive with:

a second wave generator; and,

a second flexible gear radially disposed about the second wave generator and including a second radially inner circumference in contact with the second wave generator, the method further comprising:

rotating, with the first electric motor, the first wave generator, with respect to the first flexible gear to engage a portion of the first plurality of drive teeth with the first input gear or the input/output gear;

circumferentially off-setting, using an engagement of the portion of the first plurality of drive teeth with the first input gear or the input/output gear, the first camshaft with respect to the second camshaft;

rotating, using the second electric motor, the second wave generator, with respect to the second flexible gear to engage a portion of the second plurality of drive teeth with the input/output gear or the second output gear; and,

circumferentially off-setting, using an engagement of the portion of the second plurality of drive teeth with the input/output gear or the second output gear, the second camshaft with respect to the first camshaft.

35. The method of claim 34, further comprising:

rotating, with the first electric motor, the first wave generator, with respect to the first flexible gear, about an axis of rotation for the first wave generator;

changing, with the first wave generator, respective radial distances of a plurality of points on the first outer circumference of the first flexible gear with respect to an axis of rotation for the first flexible gear;

urging, with the first wave generator, only respective portions of the first plurality of drive teeth, and not all of the first drive teeth, into contact with the first input gear and input/output gear;

rotating, with the second electric motor, the second wave generator, with respect to the second flexible gear, about an axis of rotation for the second wave generator;

changing, with the second wave generator, respective radial distances of a plurality of points on the second outer circumference of the second flexible gear with respect to an axis of rotation for the second flexible gear;

urging, with the second wave generator, only respective portions of the second plurality of drive teeth, and not all of the second drive teeth, into contact with the input/output gear and the second output gear.

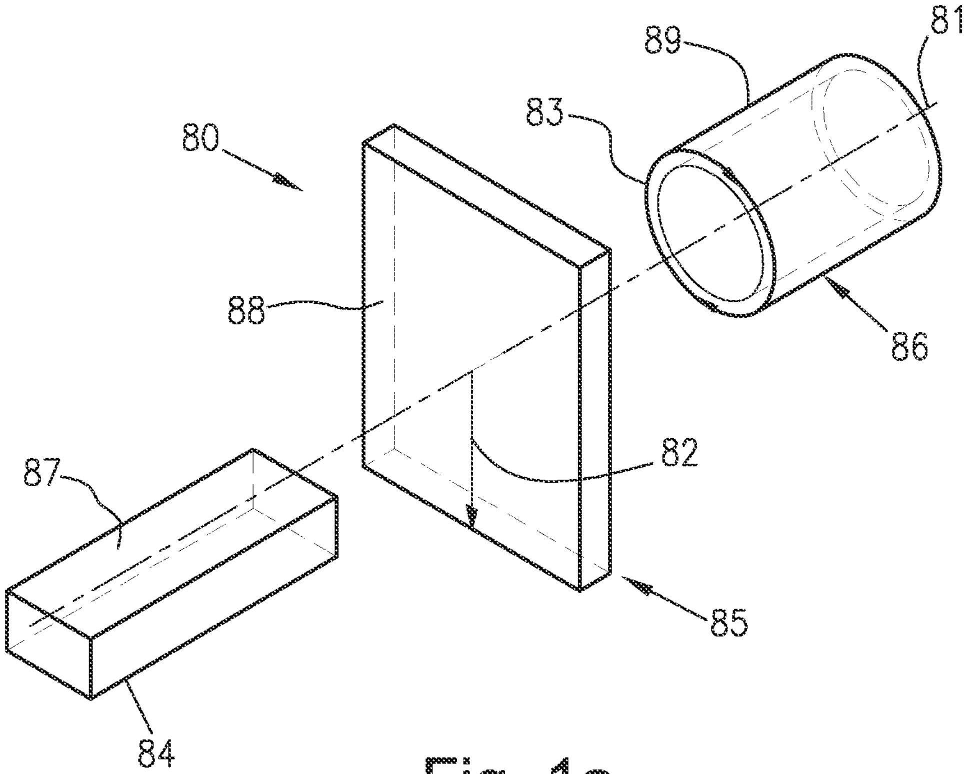


Fig. 1a

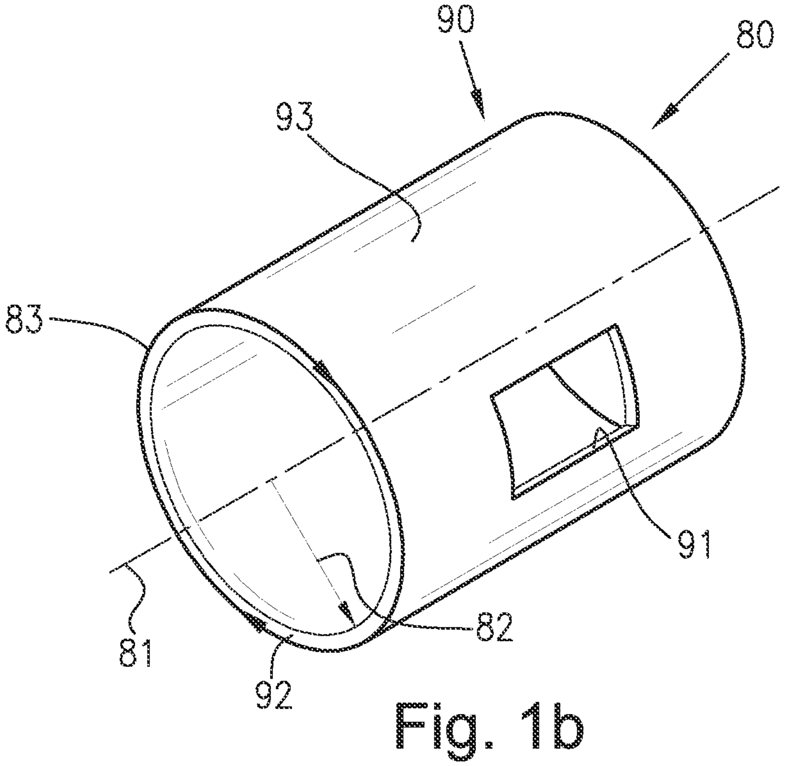


Fig. 1b

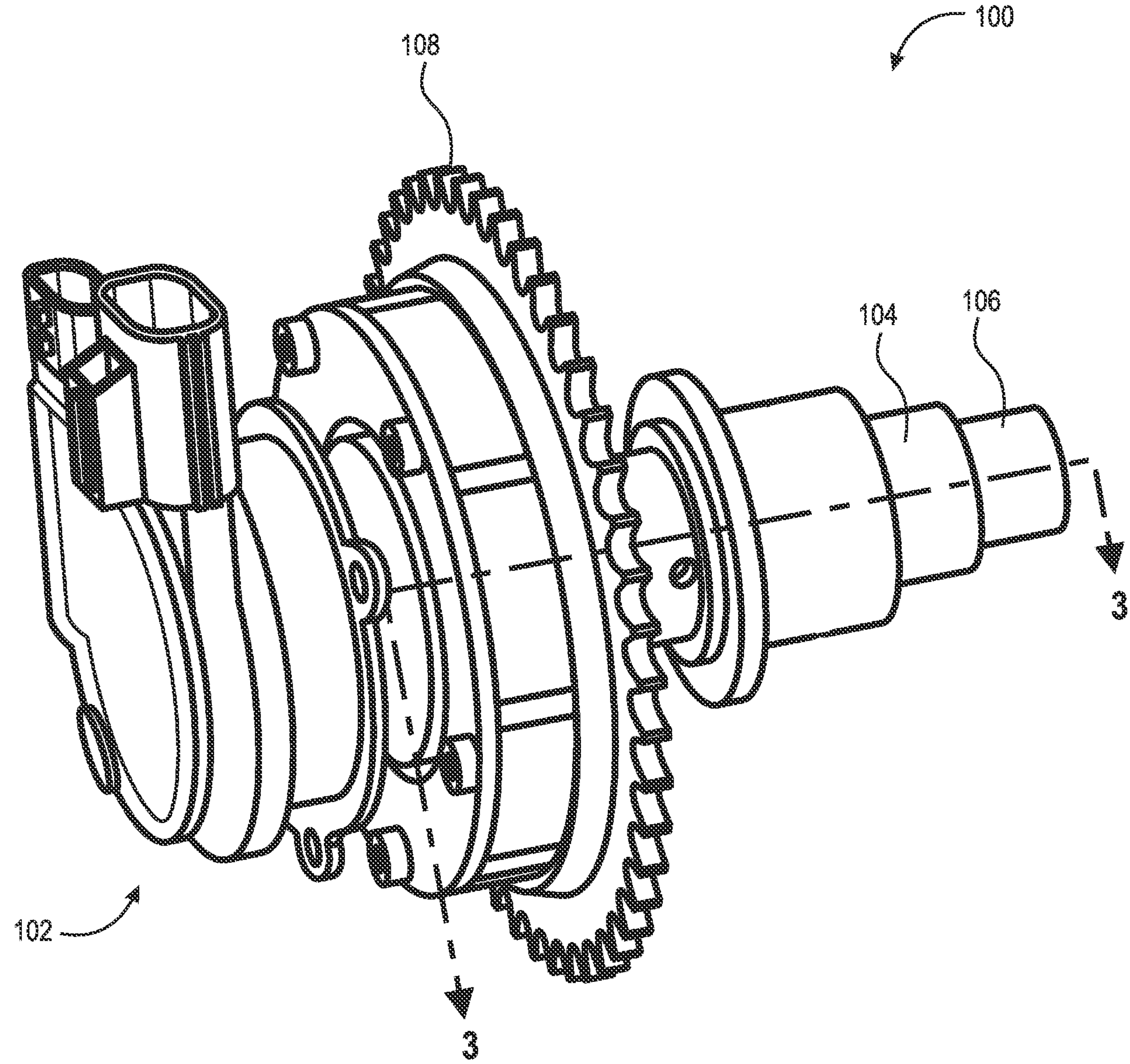
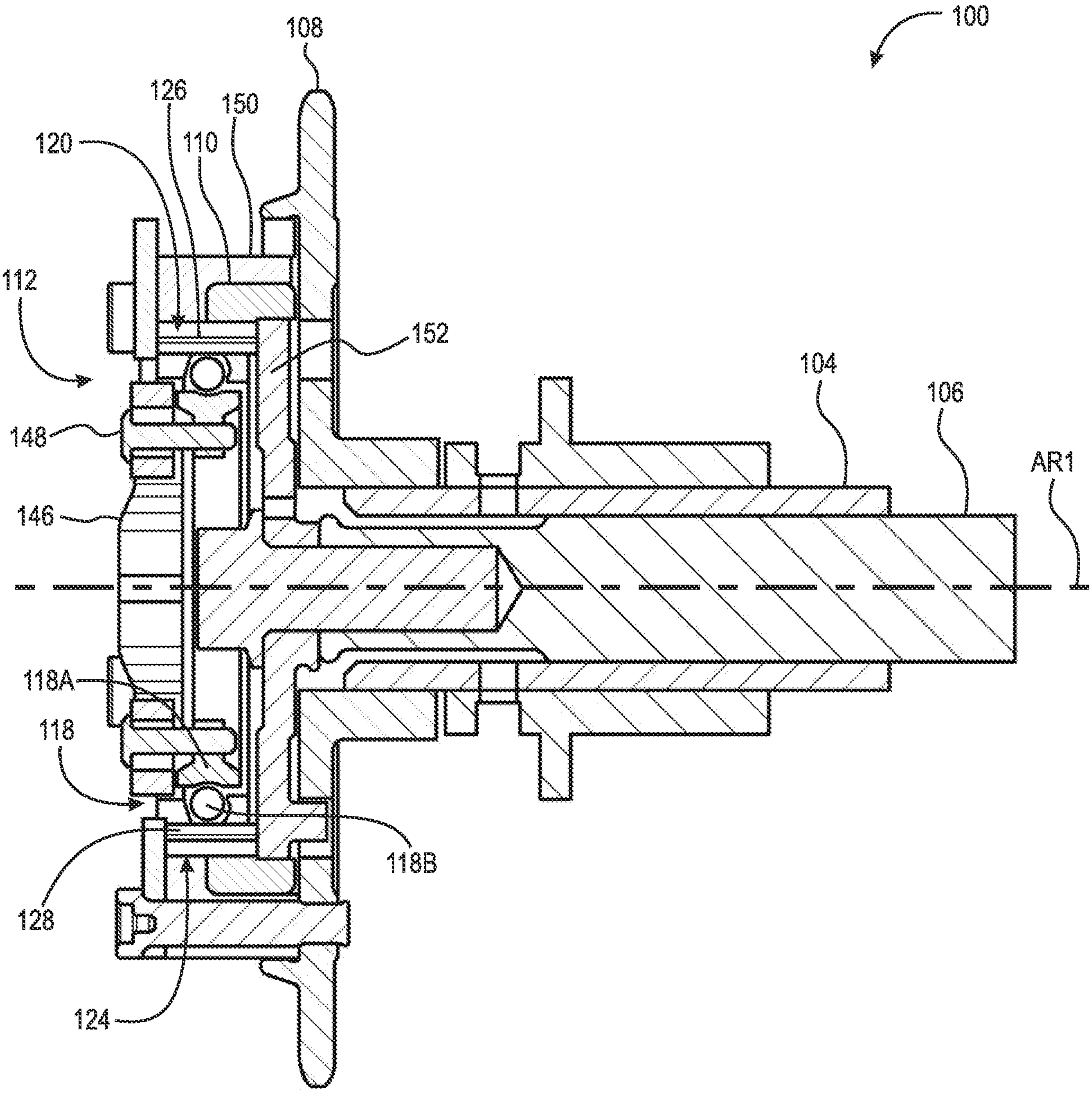


Fig. 2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112
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104
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148
AR1
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118B
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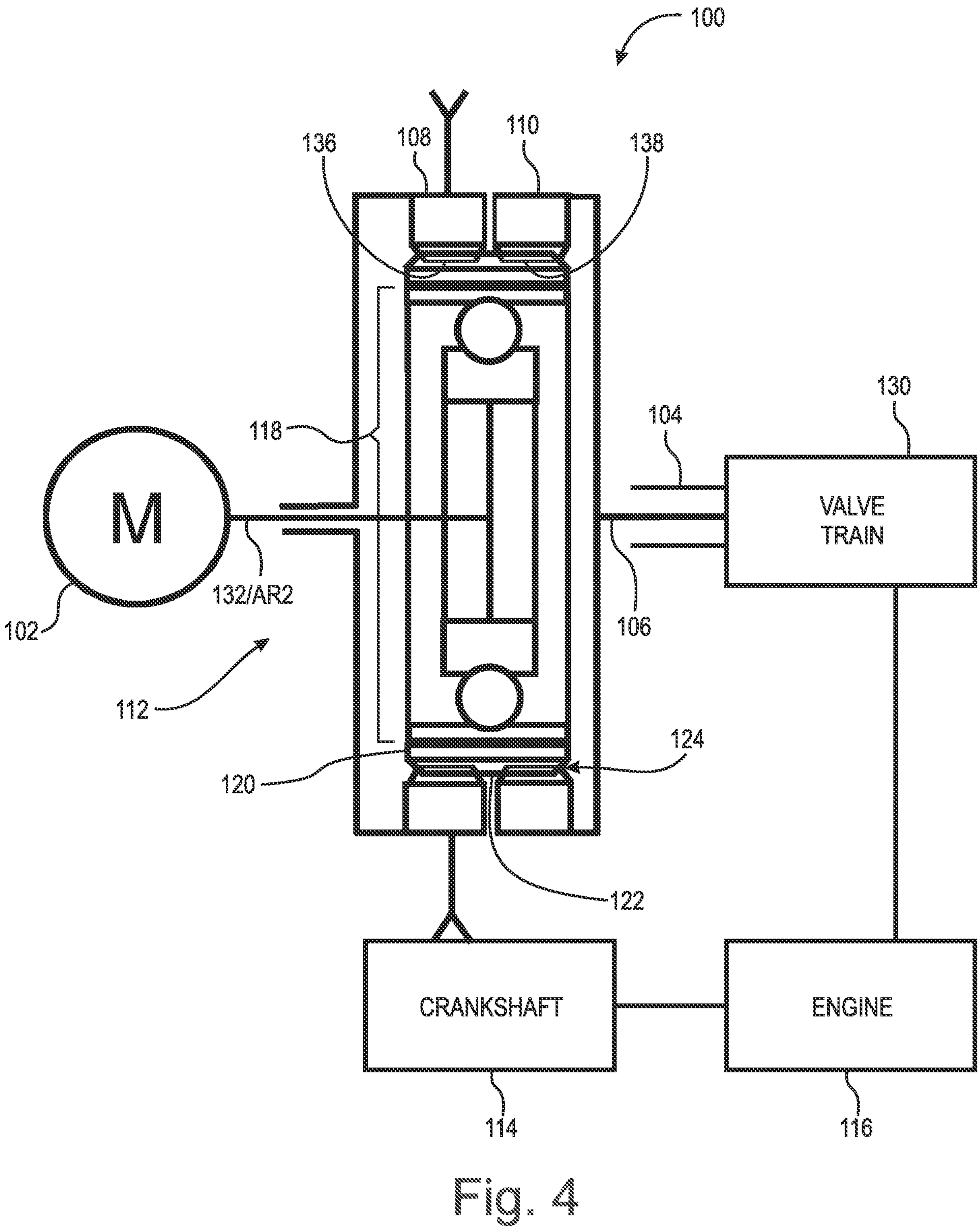
124

Fig. 3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120
122
CRANKSHAFT
ENGINE
114
116

Fig. 4

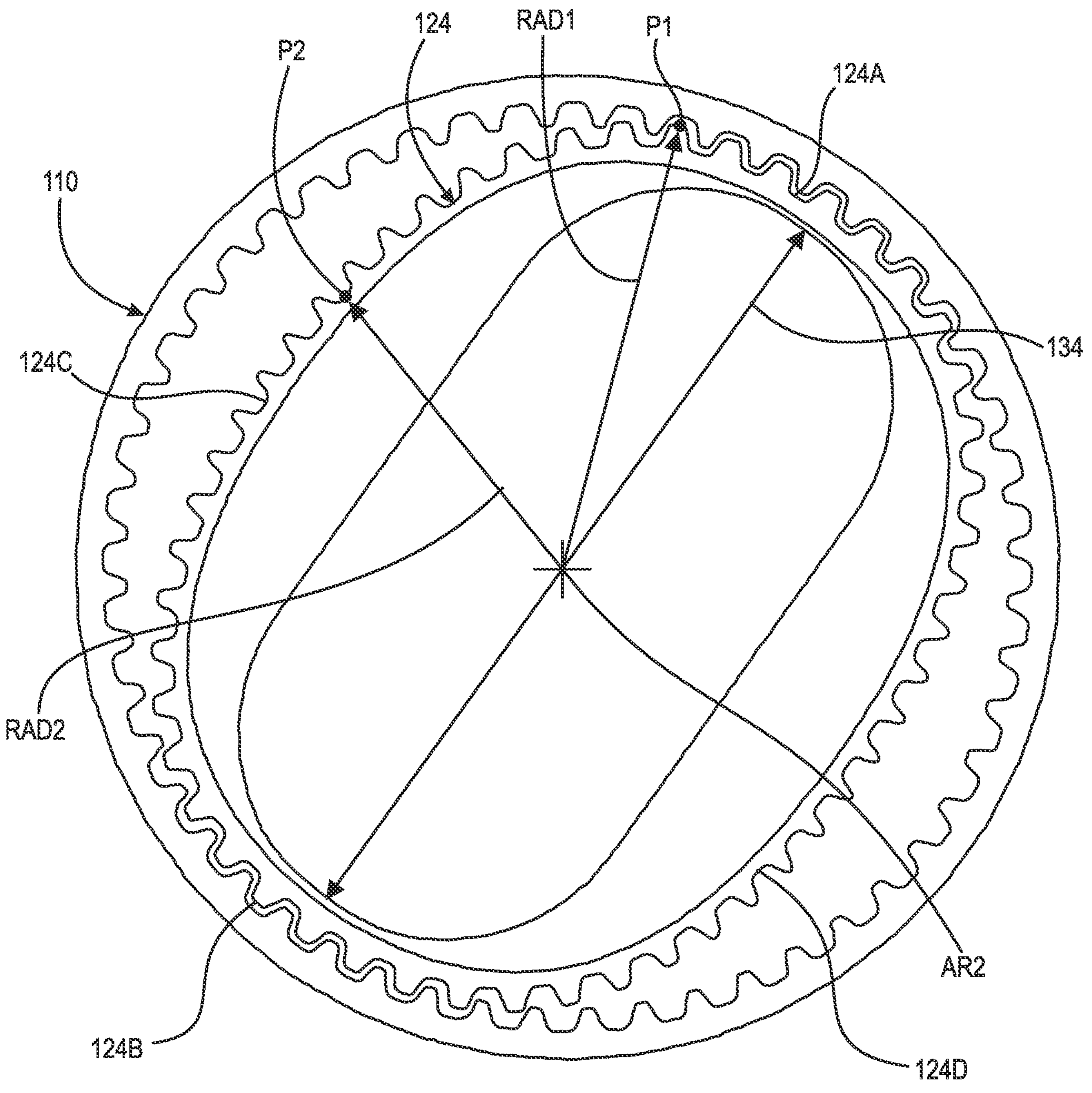


Fig. 5A

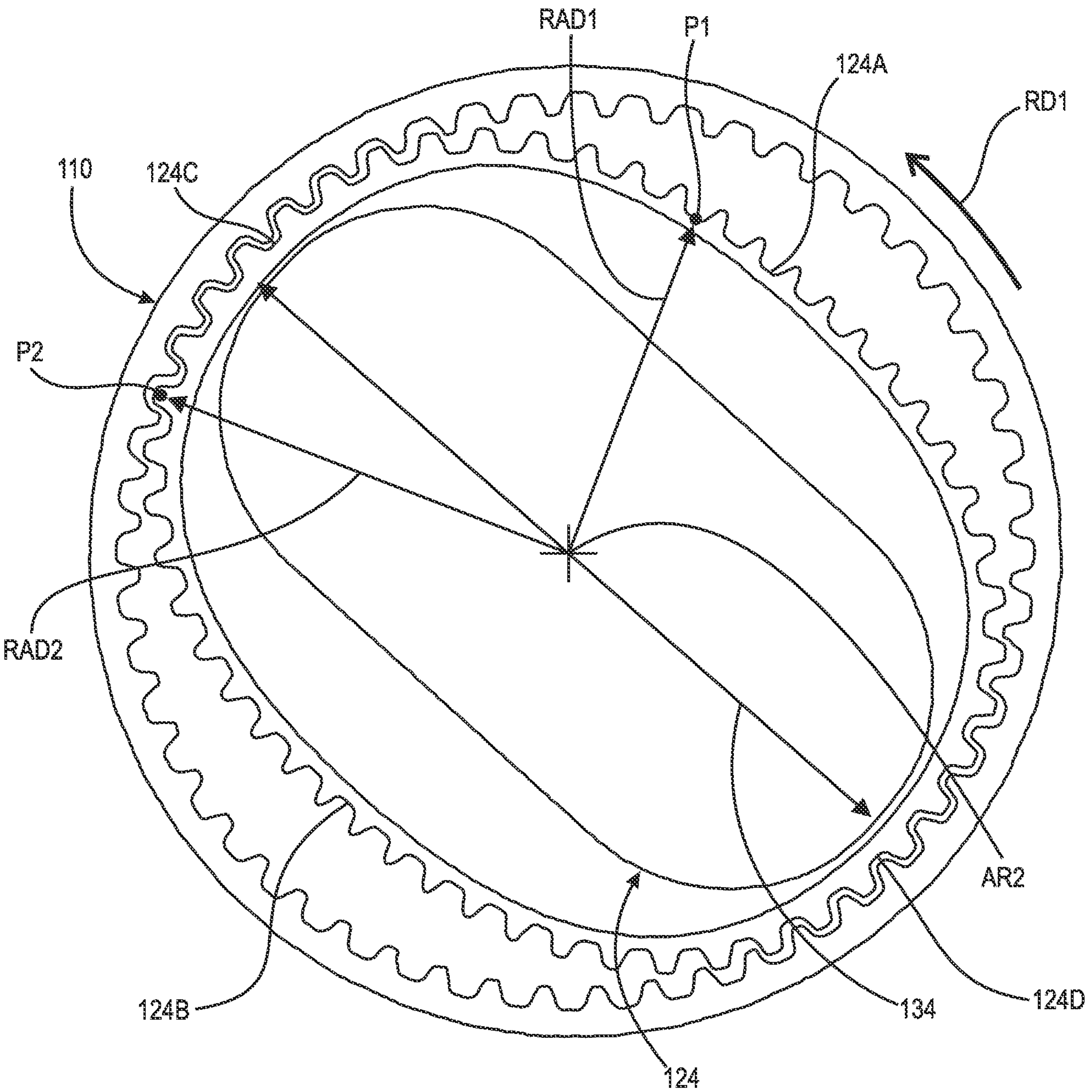
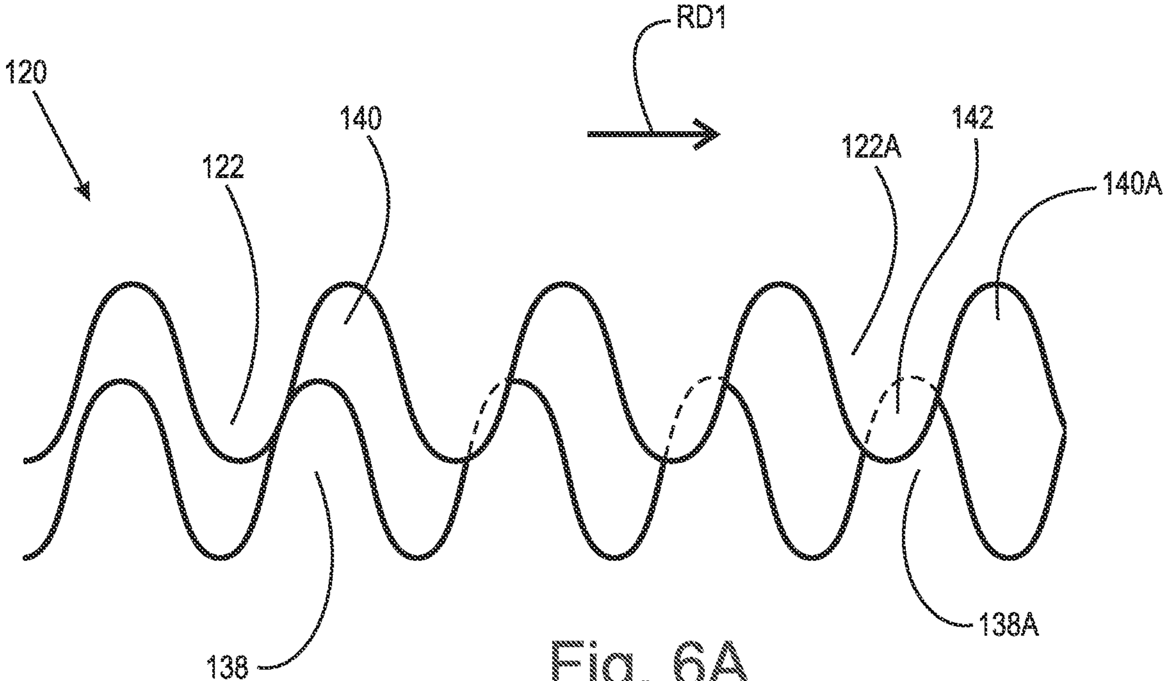


Fig. 5B


RD1
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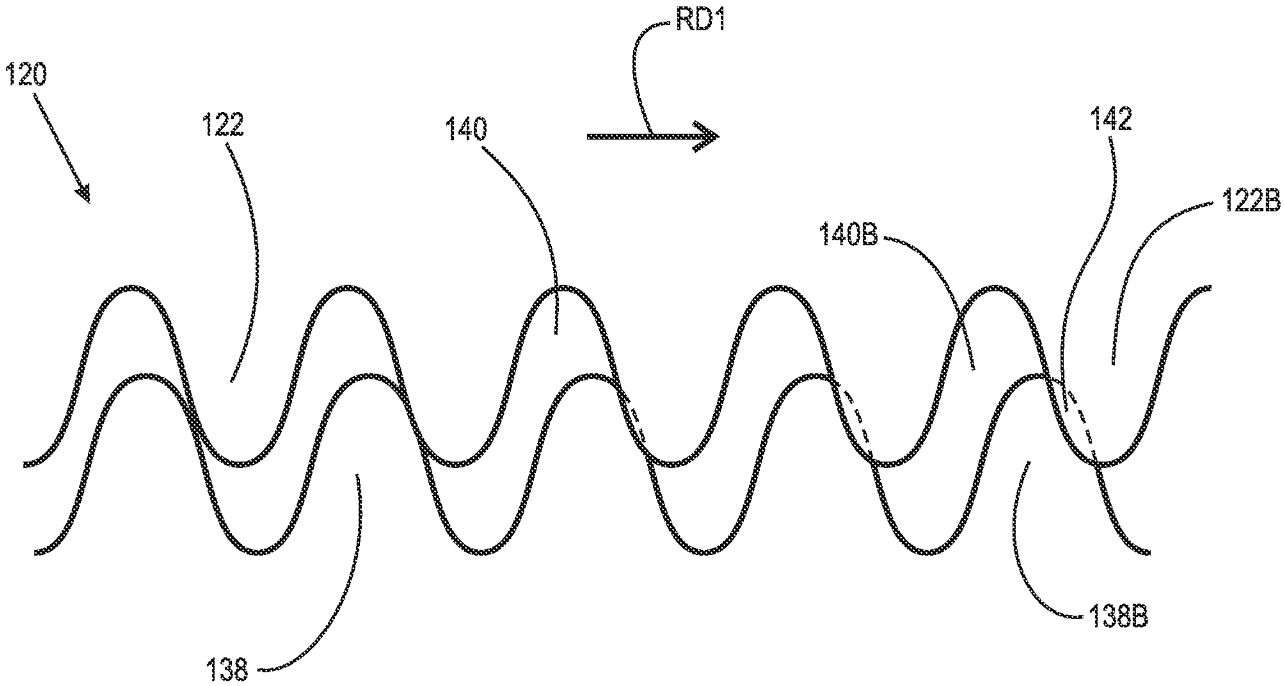
140
142
122A
122
140A
138
138A

Fig. 6A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122
140
142
122B
140B
138
138B

Fig. 6B

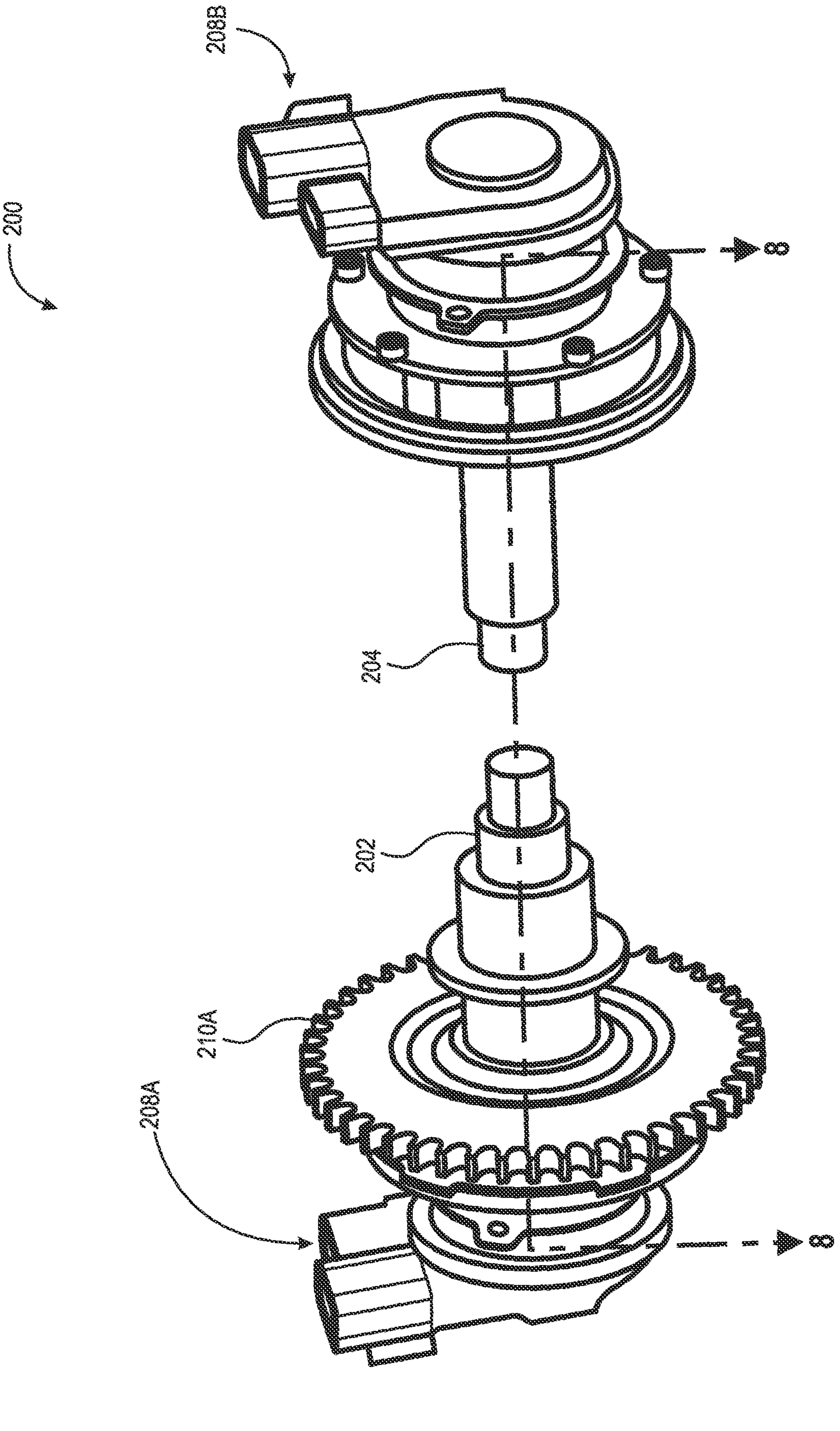
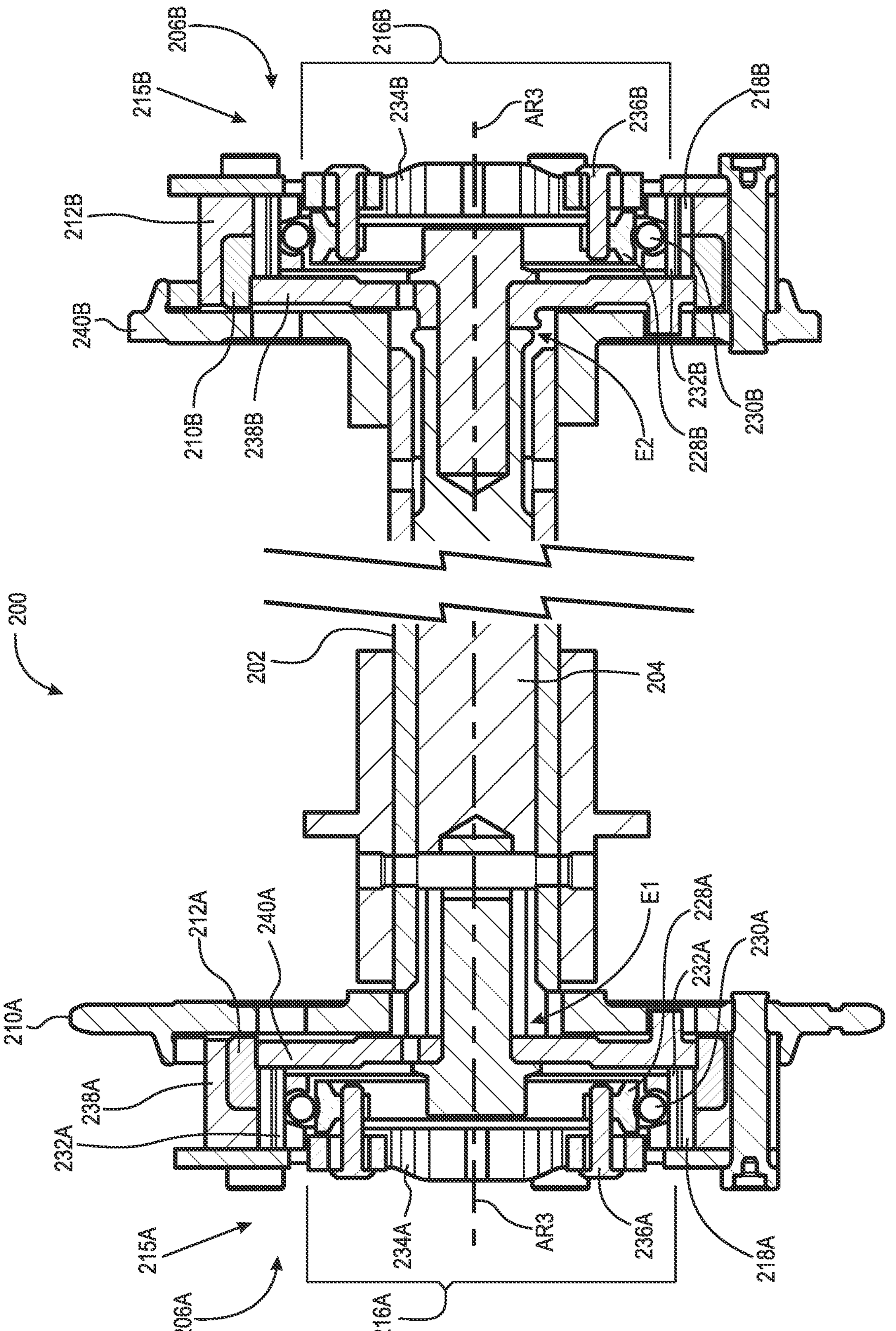


Fig. 7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202
204
210A
212A
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E1
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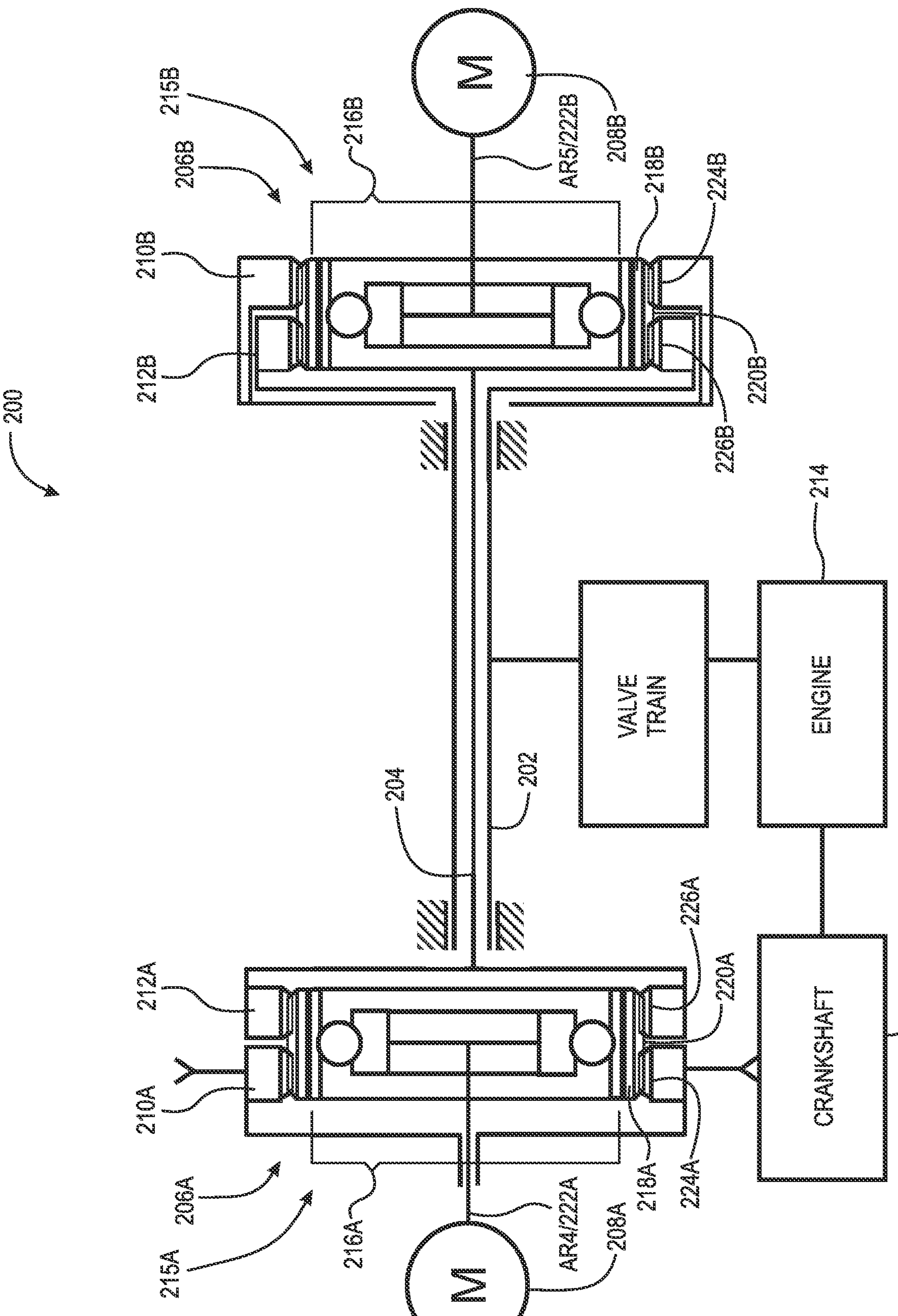
206A
234A
216A
AR3
236A
218A

Fig. 8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VALVE TRAIN
ENGINE
204
202
CRANKSHAFT
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AR4/222A
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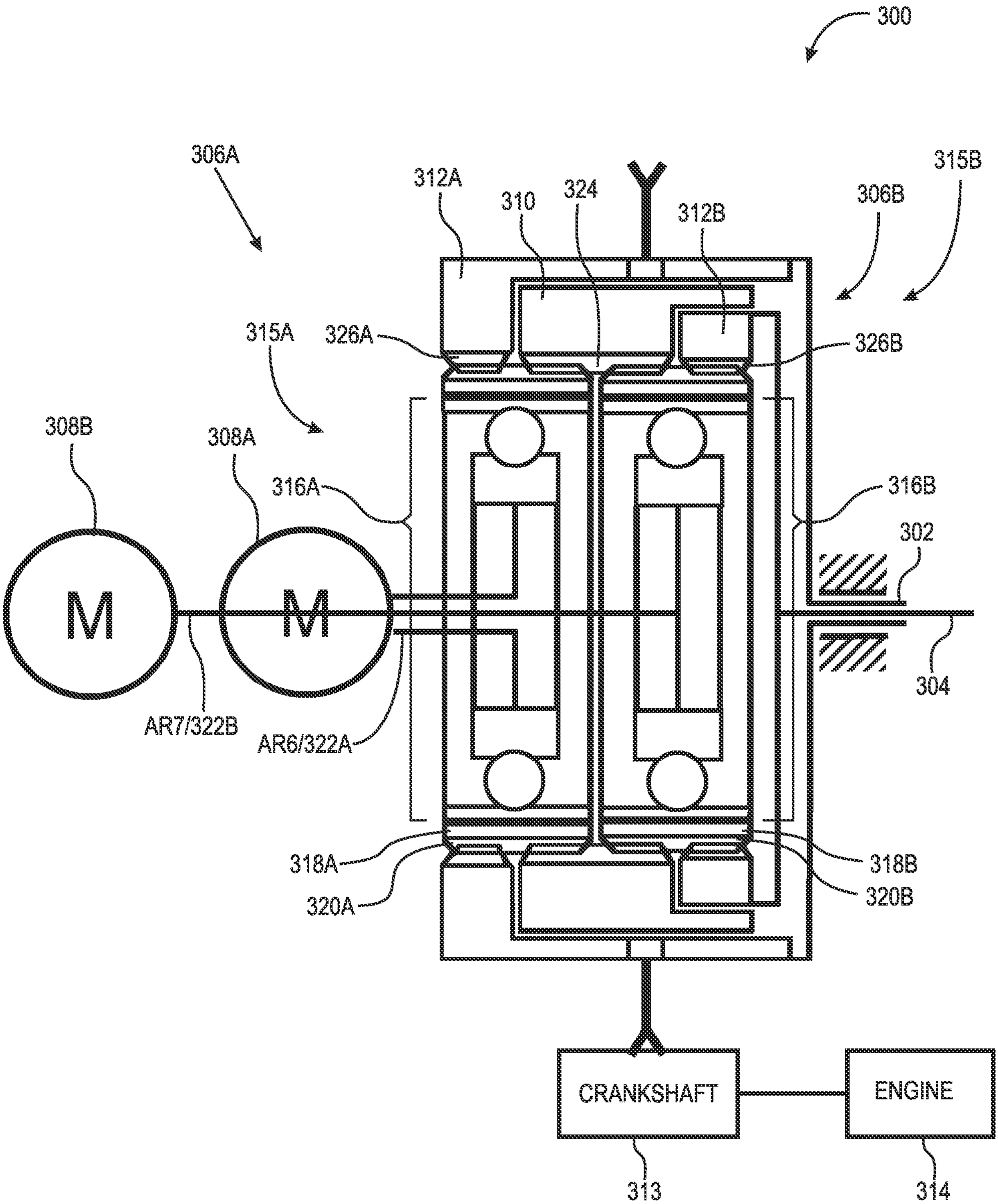
Fig. 9



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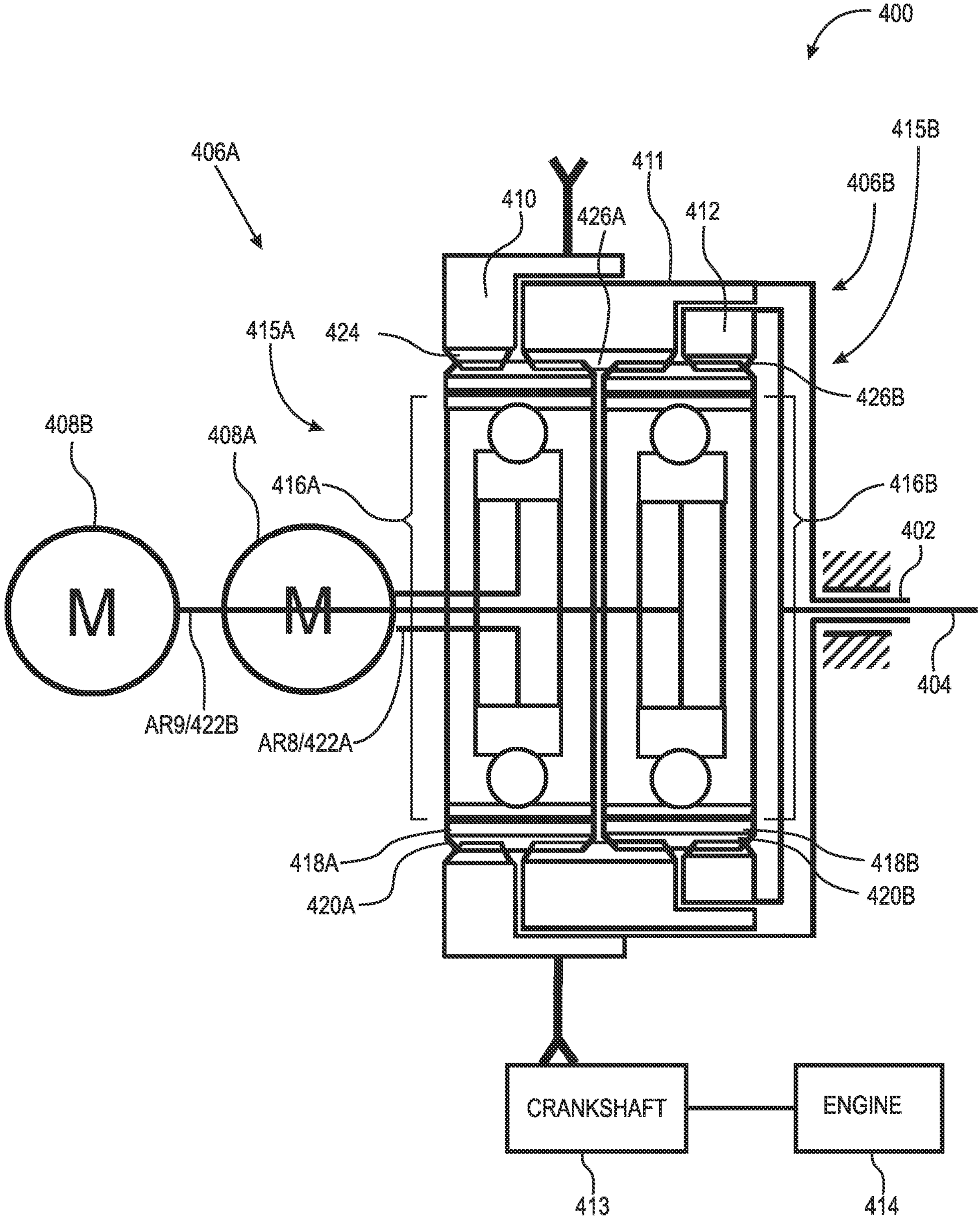
318B
320B
CRANKSHAFT
ENGINE
313
314

Fig. 10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404
AR9/422B
AR8/422A
418A
420A
418B
420B
CRANKSHAFT
ENGINE
413
414

Fig. 11