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(54) **CONCENTRIC CAMSHAFT AND ACTUATOR ASSEMBLY**

(57) An assembly is disclosed that includes a concentric camshaft and an actuator assembly. The concentric camshaft comprises an inner shaft (16), an outer tube (14) surrounding and rotatable relative to the inner shaft (16), and two groups of cam lobes (12a,12b) mounted on the outer tube (14), the first group of cam lobes (12a) being secured for rotation with the outer tube (14), the second group (12b) being rotatably mounted on the outer surface of the tube (14) and being connected for rotation with the inner shaft (16) by at least one connecting member (66) passing through at least one circumferentially elongated slot in the tube (14). The actuator (50) comprises a drive member (52; 156,154,158; 254; 352) and

at least one driven member (56,54,58; 152; 256,252,258; 354) that is rotatable relative to the drive member, each of the drive and driven members being connected for rotation with a respective one of the tube (14) and the inner shaft (16) of the concentric camshaft. The outer tube (14) of the camshaft is secured for rotation with a first actuator member (52; 152; 254; 352) and the inner shaft is connected for rotation with the second actuator member (56; 156; 256; 354) via a connecting pin (66) that passes through at least one circumferentially extending slot in the tube (14), whereby both the relative angular positions and the relative axial positions of the camshaft outer tube and inner shaft are defined by the actuator.

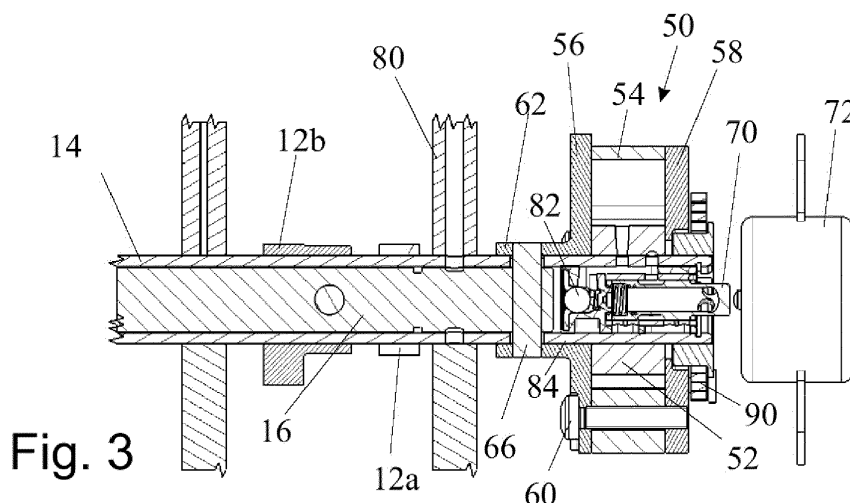


Fig. 3

Description

Field of the invention

[0001] The present invention relates a concentric camshaft and actuator assembly, the concentric camshaft comprising a camshaft tube with two groups of cam lobes on its outer surface, wherein the cam lobes of the first group are permanently fixed for rotation with the tube and the cam lobes of the second group are free to rotate on the outside of the tube and are connected for rotation with an inner drive shaft mounted within the inner bore of the tube, via connecting pins that pass through circumferentially extending slots in the tube. This assembled camshaft, which is referred to herein as a 'concentric camshaft' allows the timing of its two groups of cam lobes to be varied in relation to one another by relative rotation of the camshaft tube and the inner drive shaft. The assembly of the invention further includes an actuator for adjusting the relative timing of the two groups of cam lobes which is integrated with the concentric camshaft, so that the concentric camshaft and its actuator may be mounted to the engine as a single unit.

Background of the invention

[0002] Many different designs of concentric camshafts and associated actuators are known from the prior art. However, the connection of the actuator to the camshaft tube and inner drive shaft can be difficult to design, particularly if the actuator is assembled to the camshaft to form a single unit. This has hitherto called for an expensive solution requiring a large packaging space.

Object of the invention

[0003] The present invention aims to provide an actuator and concentric camshaft assembly of reduced complexity, to reduce manufacturing cost and packaging space.

Summary of the invention

[0004] According to the present invention, there is provided a concentric camshaft and actuator assembly as hereinafter set forth in Claim 1 of the appended claims.

[0005] In the proposed design, the actuator has a drive member and at least one driven member that is rotatable relative to the drive member. The camshaft tube is attached for rotation with a first of the actuator members using a firm jointing method, such as a shrink fit or welding, while the second actuator member is connected for rotation with the inner drive shaft via a connecting pin that passes through a clearance slot in the camshaft tube.

[0006] The actuator can be separate from the camshaft drive connection to the crankshaft and be used purely to adjust the relative timing of the two groups of cam lobes. Alternatively, the actuator may be integrated with a chain

sprocket or gear to provide a drive connection to the camshaft from the crankshaft. In either case, the design is compatible with either an electric or a hydraulic type of actuator.

[0007] In the prior art, a central fixing bolt is commonly used to create a drive connection between the actuator and the inner drive shaft. In the embodiments of the invention however, the bore of the camshaft tube need not be obstructed, neither by its connection to the first actuator member nor by the connection of the inner shaft to the second actuator member. Consequently, in the case where a hydraulic actuator is used, the central bore of the camshaft tube can accommodate an integrated control valve. The control valve may be supplied with oil via the clearance between the bore of the camshaft tube and the outer surface of the inner drive shaft.

[0008] Any concentric camshaft design needs to provide adequate control of the axial position of the inner drive shaft relative to the camshaft tube. In embodiments of the invention, the actuator may act to control the relative axial positions via its driving connections to the camshaft tube and inner drive shaft.

Brief description of the drawings

[0009] The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Figures 1A shows an isometric view of a first embodiment of an assembly comprising a concentric camshaft and actuator assembly, Figure 1B shows the first embodiment with the concentric camshaft separated from the actuator, Figure 2 shows the first embodiment with the hydraulic actuator exploded, Figure 3 is a section through the first embodiment when fully assembled, Figure 4 is an isometric view, similar to that of Figure 1 of a second embodiment of the invention, Figure 5 is a sectional view, similar to that of Figure 3, of the second embodiment of the invention, Figure 6 is an isometric view of the actuator only of the second embodiment of the invention, Figure 7 is an exploded view of a third embodiment of the invention, Figure 8 is a section similar to that of Figures 3 and 5 through the third embodiment of the invention, and Figure 9 is a section similar to that of Figure 8 through a fourth embodiment of the invention.

Detailed description of the drawings

[0010] Figures 1A, 1B, 2 and 3 show the construction of a first embodiment of an assembly of a concentric camshaft 10 and hydraulic actuator 50 configured to control the relative timing of the two sets of cam lobes 12a, 12b. In this embodiment the drive connection to the crankshaft

may be achieved by a sprocket or gear (not shown) mounted to the opposite end of the camshaft tube, either driving the tube directly, if the phase of the cam lobes of the first group is to be fixed in relation to the engine crankshaft, or via a conventional camshaft phasing system, if the phase of the cam lobes of the first group is to be variable in relation to the engine crankshaft.

[0011] The camshaft tube 14 drives the inner member 52, sometimes referred to as the rotor, of the actuator 50. The inner member 52 is rigidly attached to the camshaft tube 14 via a shrink fit, welding, adhesive or by mechanical deformation of the camshaft tube to generate an interference. The outer member of the actuator 50 is comprised of a central plate 54, defining, in conjunction with the inner member 52, a number of arcuate hydraulic cavities and two end plates 56, 58 that are clamped together around the inner member 52 via three fixing bolts 60 and thus limit the axial movement between the inner and outer members of the actuator 50. The end plate 56 on the camshaft side of the actuator 50 includes a sleeve 62 and has a close fitting bore 64 that rotatably engages on the outer surface of the camshaft tube 14. A radial connecting pin 66 engaged in the sleeve 62 passes through clearance slots in the tube 14 and connects the outer member 54, 56, 58 of the actuator 50 for rotation with the inner drive shaft 16. The driving connection between the outer member and the inner drive shaft is similar to the connection between the drive shaft and the second group of cam lobes. In this embodiment, the drive from the crankshaft would be at the other end of the cam and would incorporate the camshaft axial position control.

[0012] A hydraulic spool valve 70 is provided in the inner bore of the camshaft tube 14 in order to control the relative timing of the inner 52 and outer 54, 56, 58 actuator members in response to the force of a solenoid 72 mounted on a stationary part of the surrounding engine. Timing features 76 are also integrated onto the end plate 56 connected to the inner drive shaft 16 in order to provide actuator position feedback to the Engine Management System (EMS). It will be appreciated that timing features for this purpose may alternatively be provided on the central plate 54 or on the opposing end plate 58.

[0013] Oil is supplied to the control spool 70 from the adjacent camshaft support bearing 80 via a check valve 82 and an oil feed sleeve 84 located in the bore of the camshaft tube 14. It would additionally be possible to include a filter for preventing any particles in the oil supply from entering the spool valve.

[0014] The actuator also includes a lock pin 88 for fixing the relative timing of the two sets of cam lobes 12a, 12b when there is insufficient oil pressure to control the actuator position accurately. A torque spring 90 is also mounted to the actuator 50 to bias the relative angle of the inner and outer members of the actuator towards the locked position.

[0015] The outer member 54, 56, 58 of the actuator is adjustable to eliminate the effect of manufacturing and

assembly tolerances on the relative angular positions of the two sets of cam lobes. The central plate 54 has circumferentially elongated fixing bolt holes 92 to allow its rotational position to be adjusted before tightening the three fixing bolts 60.

[0016] The second embodiment of the invention, illustrated in Figures 4, 5 and 6, is generally similar to that of the first embodiment and the same reference numerals have been allocated to unchanged components. To avoid repetition, in the description of the three remaining embodiments shown in the drawings, modified components serving an analogous function have been allocated reference numerals with the same last two significant digits. In second embodiment, the actuator 150 has been adapted to provide the drive connection to the engine crankshaft, second camshaft or auxiliary system by the addition of a sprocket 151 (or a gear) to the end plate 156 of the outer member of the actuator 150. In this embodiment, it is advantageous to improve the support for the radial forces from the drive connection by using the outer surface of the sleeve 162 on the end plate 156 of the actuator 150 as a camshaft support bearing, as shown in the section of Figure 5. Advantageously, the axial position of the camshaft in the engine may also be controlled by one or more thrust features adjacent to the sleeve 162 on the end plate 156.

[0017] The second embodiment also shows how the design may be adapted to utilise an external hydraulic control valve by providing two separate oil feeds 181, 183 in the adjacent camshaft support bearing 180 that are communicated into the actuator 150 via the camshaft tube 14 and inner drive shaft 16.

[0018] In the second embodiment the feature 176 for generating a timing feedback signal is integrated into a support hub 175 for the bias spring 190 to provide feedback of the angular position of the tube 14 and thus the inner member 152 of actuator 150, rather than the outer member feedback used in the first embodiment.

[0019] The inner drive member 152 of the actuator, as best seen in Figure 6, has additional features 153 in its inner bore to form a more positive drive connection with the camshaft tube 14. In this embodiment the features are depicted as short splines, but other form locking features may alternatively be used.

[0020] Figures 7 and 8 show a third embodiment of the invention wherein the actuator 250 is controlled via an external oil control valve 273 mounted on a stationary part of the engine and supplying oil to the actuator 250 via two axially separated oil feeds located in the bore of the camshaft outer tube, the oil feed connections being sealed via rotatable sealing rings 275.

[0021] In this embodiment, the central plate 254 of the actuator has sprocket teeth 251 to enable it to be driven by the crankshaft and, unlike the first two described embodiments, it is the central plate 254 that is mounted for rotation with the outer tube 14 of the concentric camshaft. The end plates 256 and 258 are in this embodiment connected by the bolts 260 for rotation with radial vanes 252

that together with the end plates 256 and 258 constitute the inner member, or rotor, of the actuator 250.

[0022] Figure 9 illustrates a fourth embodiment of the invention in a diagrammatic form, and shows a concentric camshaft integrated with an electric actuator 350. The electric actuator 350 is controlled by a motor 373 mounted on a stationary part of the surrounding engine. The actuator 350 has a stator 354 connected for rotation with the inner shaft 16 of the concentric camshaft by a pin 366 passing through circumferentially elongated slots in the outer tube 14 and a rotor 352 coupled for rotation with the outer tube 14 of the concentric camshaft.

[0023] It should be made clear that the invention is not restricted to the specific embodiments described above, which have been given only by way of example, but various features may be combined in different ways. For example, the third embodiment serves to illustrate that in all embodiments the stator and rotor of the actuator may be interchanged and each of them can be connected either to the inner shaft or the outer tube of the concentric camshaft. Likewise, in any embodiment, it is possible to have a separate drive to the concentric camshaft or either one of the stator and rotor may serve as a sprocket or cog driven by the crankshaft, either directly or indirectly. If the phases of both sets of cams are to be variable, the actuator itself could be a twin hydraulic actuator, or a hybrid electric/hydraulic actuator.

[0024] The described embodiments of the invention offer the following advantages when compared to existing designs: -

- The concentric camshaft and its actuator can be supplied as a single-piece assembly.
- The design is applicable to both hydraulic and electric actuators.
- The actuator is directly connected to the camshaft tube rather than requiring additional drive components to be fitted to the tube.
- No threaded features or fasteners are required to attach the actuator to the Concentric Camshaft.
- Because the stator and rotor of the actuator are axially fixed relative to the outer tube and inner shaft of the concentric camshaft, the actuator is able to control the axial location of the inner drive shaft inside the camshaft tube.
- Hydraulic actuators can utilise an integrated spool valve located in the bore of the camshaft tube.
- The cost and complexity of the overall system is reduced.

Claims

1. A concentric camshaft and actuator assembly, wherein the concentric camshaft comprises an inner shaft (16), an outer tube (14) surrounding and rotatable relative to the inner shaft (16), and two groups of cam lobes (12a,12b) mounted on the outer tube

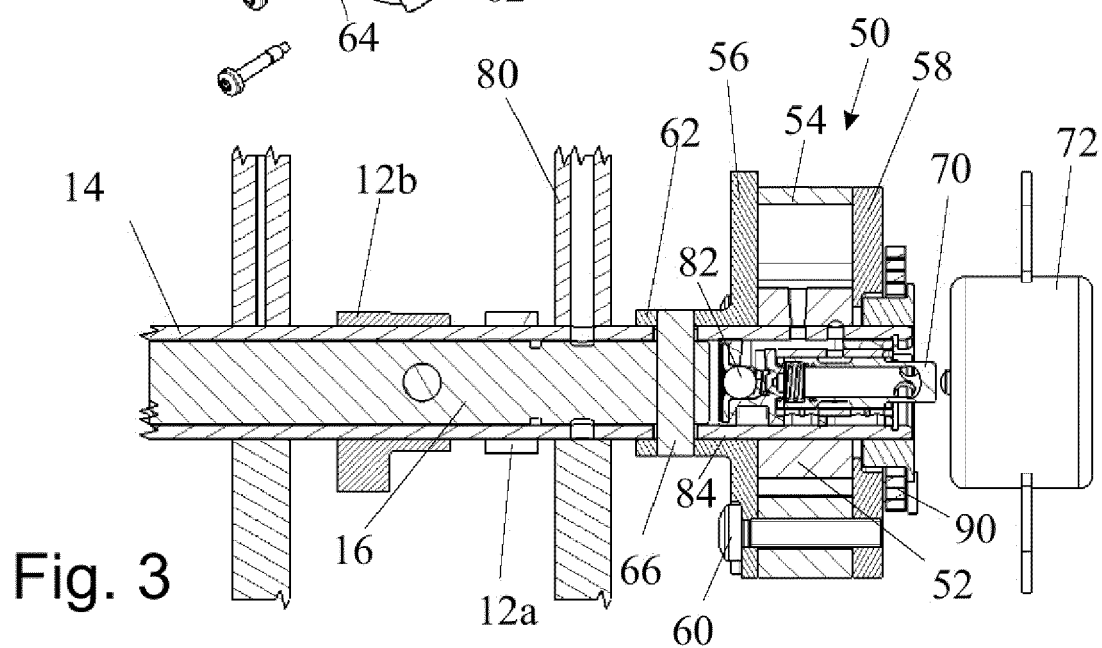
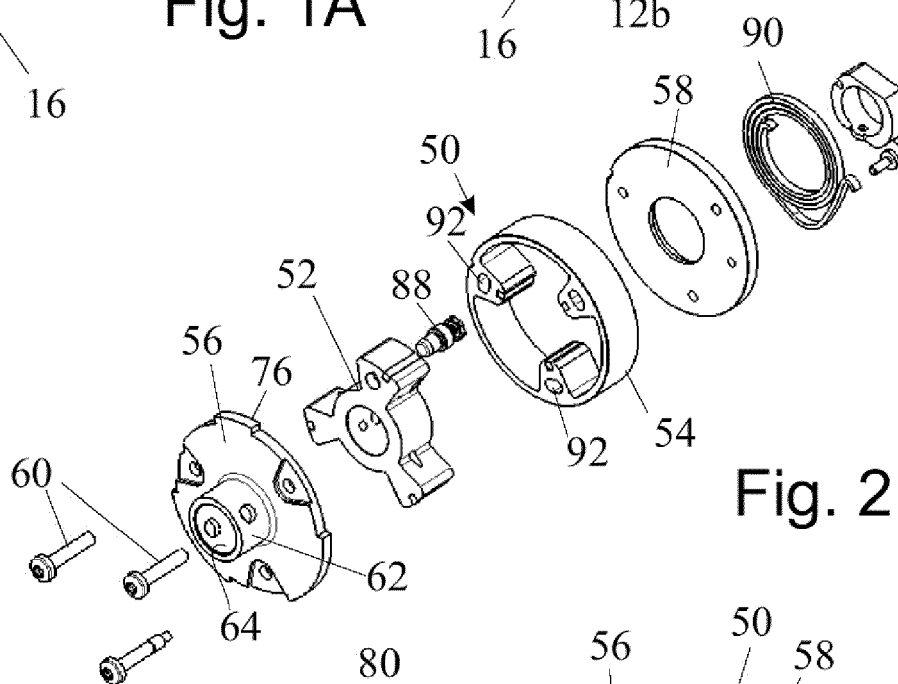
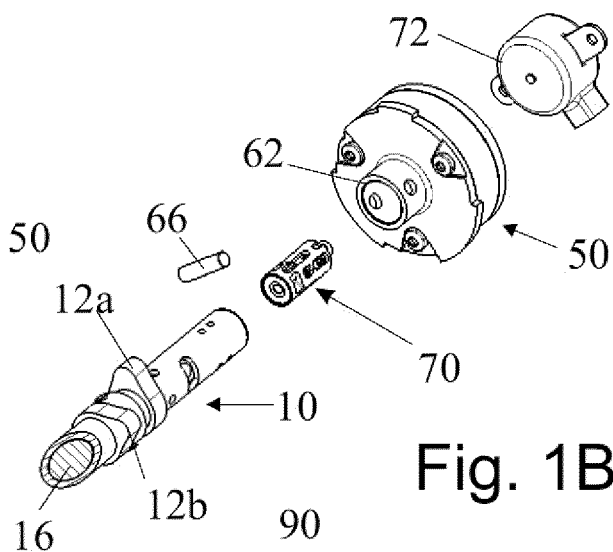
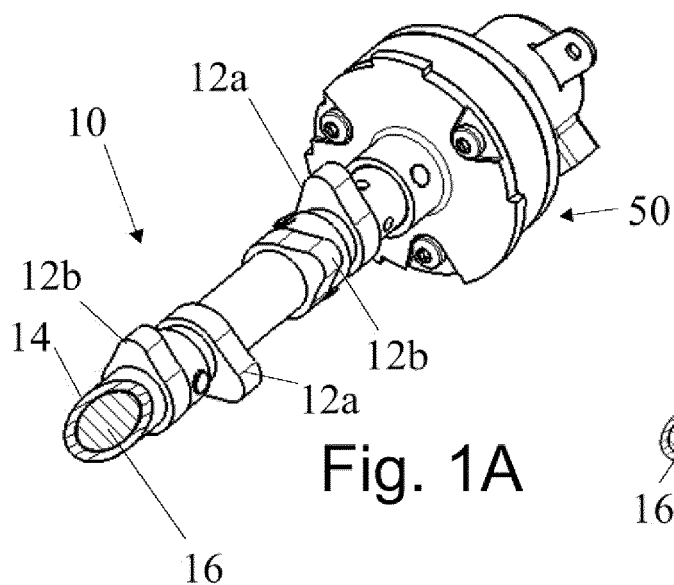
(14), the first group of cam lobes (12a) being secured for rotation with the outer tube (14), the second group (12b) being rotatably mounted on the outer surface of the tube (14) and being connected for rotation with the inner shaft (16) by at least one connecting member (66) passing through at least one circumferentially elongated slot in the tube (14), and wherein the actuator (50) comprises a drive member (52; 156,154,158; 254; 352) and at least one driven member (56,54,58; 152; 256,252,258; 354) that is rotatable relative to the drive member, each of the drive and driven members being connected for rotation with a respective one of the tube (14) and the inner shaft (16) of the concentric camshaft, **characterised in that** the outer tube (14) of the camshaft is secured for rotation with a first actuator member (52; 152; 254; 352) and the inner shaft is connected for rotation with the second actuator member (56; 156; 256; 354) via a connecting pin (66; 366) that passes through at least one circumferentially extending slot in the tube (14), whereby the relative angular positions of the camshaft outer tube and inner shaft are defined by the actuator.

2. An assembly as claimed in Claim 1, wherein the first actuator member (52; 152; 254; 352) is connected to the outer tube of the camshaft by one or more of the methods comprising welding, gluing, shrink fitting, and form locking.
3. An assembly as claimed in claim 1 or 2, wherein the actuator (50; 150) is a hydraulically operated actuator and wherein the second actuator member is comprised of a central plate (54; 154) defining a number of arcuate hydraulic cavities and two end plates (56,58; 156,158) clamped together via a plurality of fixing bolts (60; 160).
4. An assembly as claimed in 3, wherein the position of the central plate (54; 154) relative to the end plates (56,58; 156,158) has rotational clearance and is adjustable to eliminate angular tolerances before being clamped between the two end plates.
5. An assembly as claimed in Claim 1 or 2, having a hydraulically operated actuator wherein the first actuator member comprises a central plate (254) defining a number of arcuate hydraulic cavities and the second actuator member comprises a plurality of vanes (252), each separating an arcuate cavity of the first member into two volumes, and two end plates (256,258) clamped together via a plurality of fixing bolts (260).
6. An assembly as claimed in any one of claims 3 to 5, wherein the axial position of the camshaft in the engine is at least partially controlled by one or more thrust features on one of the end plates (156).

7. An assembly as claimed in any preceding claim, wherein the relative axial positions of the camshaft outer tube and inner shaft are additionally defined by the actuator. 5
8. An assembly as claimed in any preceding claim, wherein a spool valve (70) is located within an end of the inner bore of the outer tube (14) of the concentric camshaft to control the supply of oil to the actuator (50). 10
9. An assembly as claimed in claim 8, wherein the spool valve (70) is supported in a sleeve (84) located in the bore of the camshaft outer tube. 15
10. An assembly as claimed in claims 8 or 9, wherein the oil supply to the spool valve (170) passes through one or more holes in the second actuator member (156). 20
11. An assembly as claimed in any one of claims 1 to 8, wherein the actuator is controlled via two separate oil feeds connected to a hydraulic spool valve (273) connectible to an engine component that is stationary relative to the camshaft. 25
12. An assembly as claimed in claim 11, wherein the spool valve (273) is located substantially concentrically with the camshaft and communicates with the actuator (250) via two axially separated oil feeds located in the bore of the camshaft outer tube (14). 30
13. An assembly as claimed in claim 12 wherein rotatable seals (275) are provided to act between the stationary spool valve (273) and the bore of the camshaft tube (14). 35
14. An assembly as claimed in claim 1 or 2, wherein the actuator (350) is electrically operated. 40
15. An assembly as claimed in any one of the preceding claims wherein the actuator (150; 250) is adapted to support a drive connection (151 ;251) to the crankshaft, a second camshaft or an auxiliary system. 45

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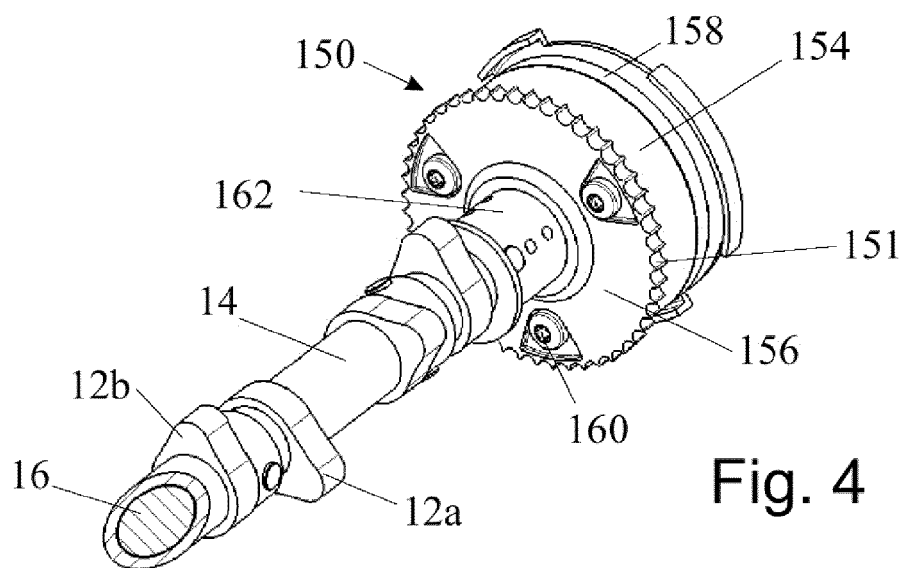


Fig. 4

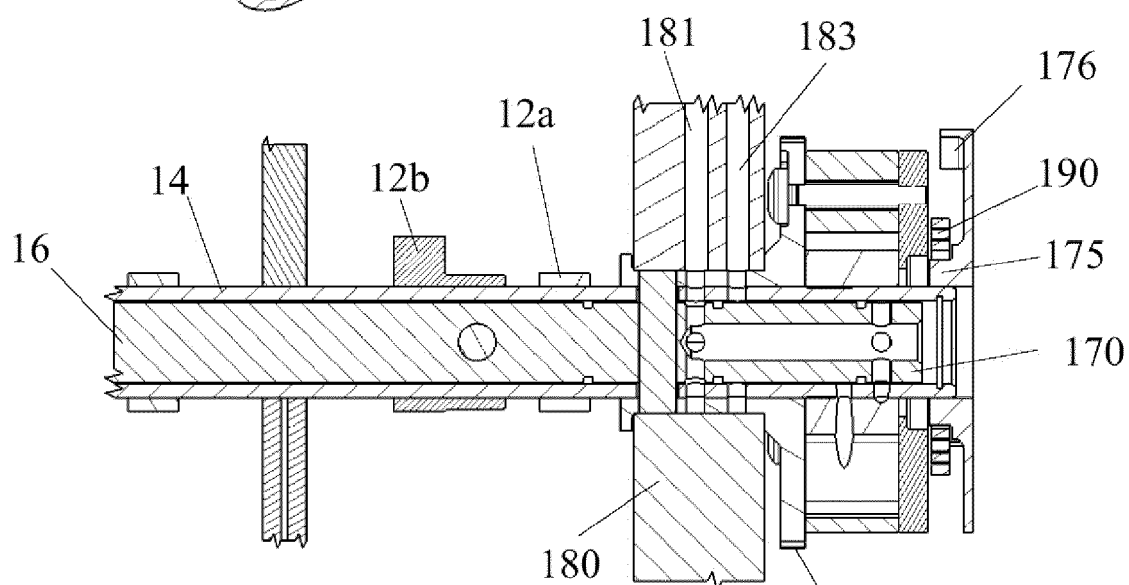


Fig. 5

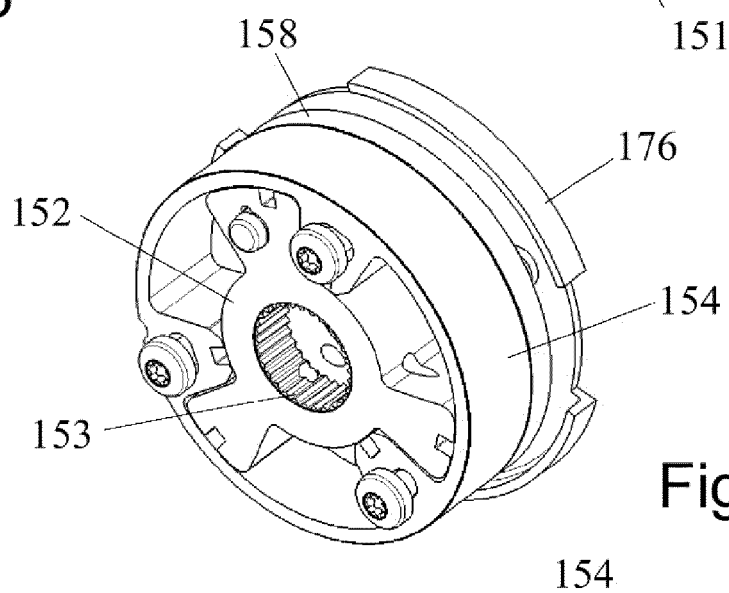
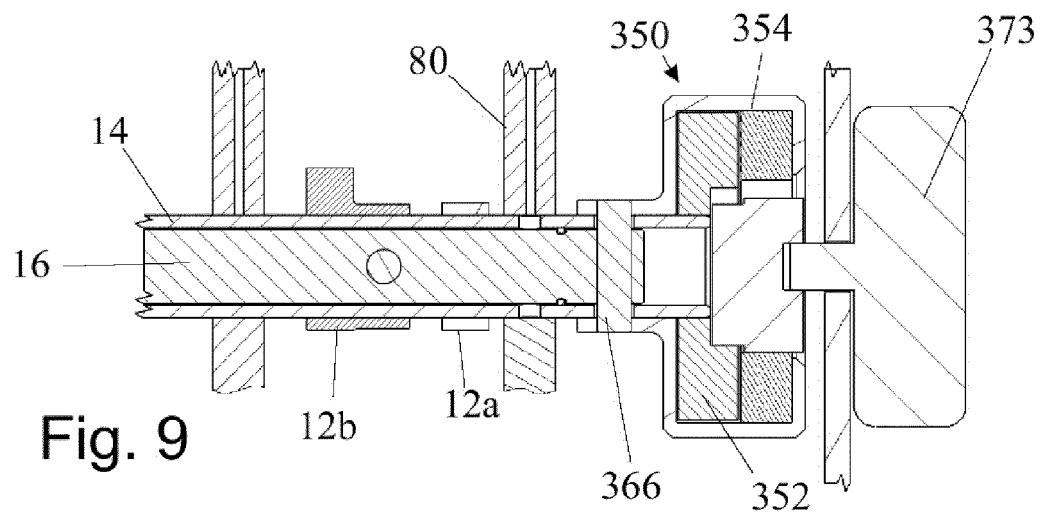
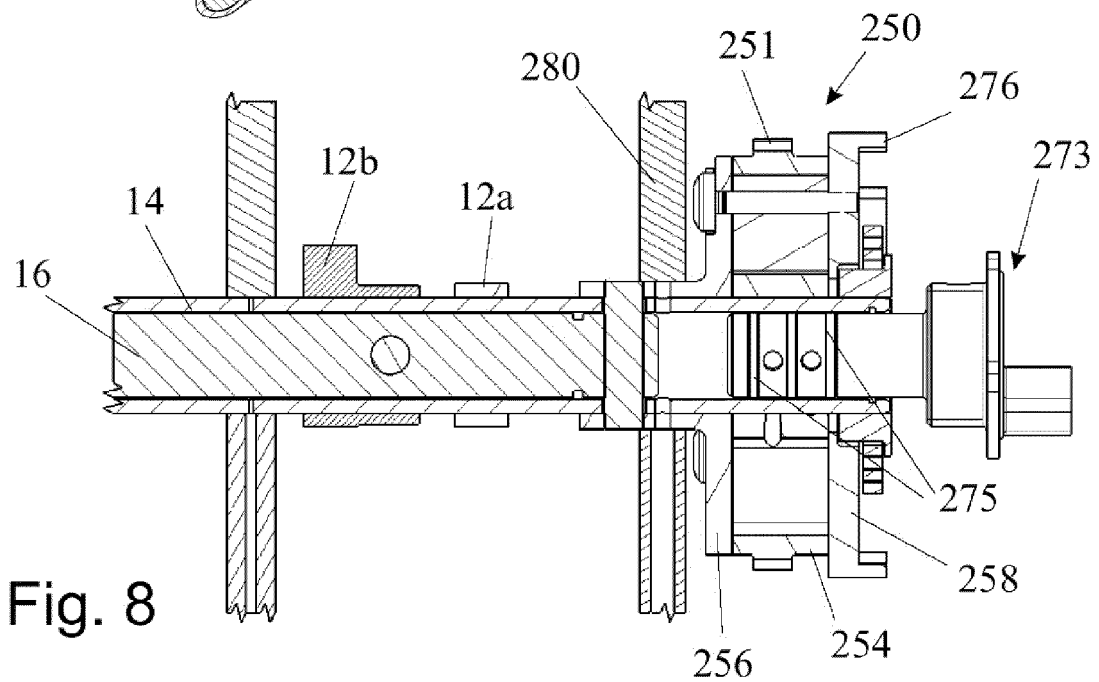
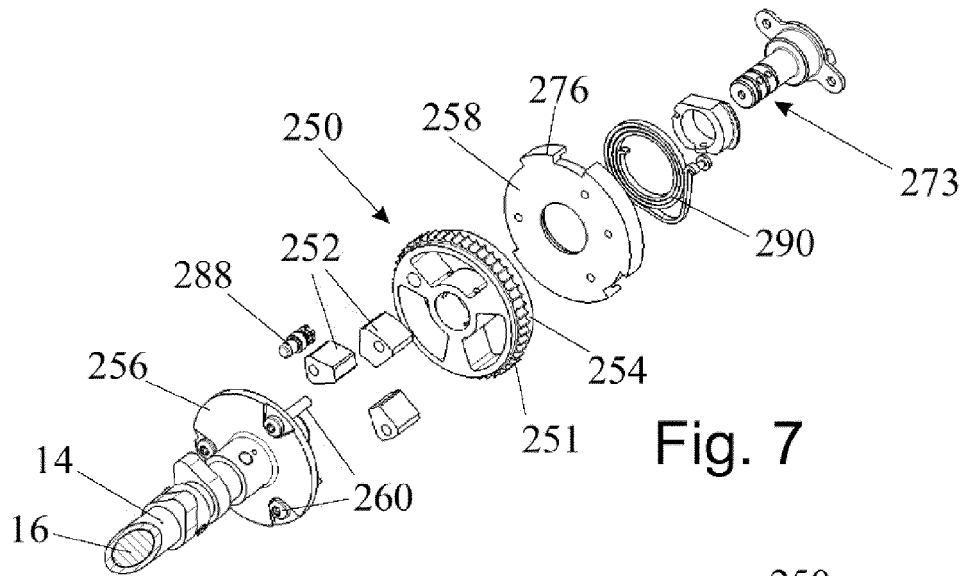


Fig. 6





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Application Number
EP 17 16 8117

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 9 October 2017	Examiner Klinger, Thierry
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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