(19) Europäisches Patentamt
European Patent Office
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(11) EP 3 683 412 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
22.07.2020 Bulletin 2020/30

(51) Int Cl.:
F01L 1/047 *(2006.01)* ***F01L 1/344*** *(2006.01)*

(21) Application number: **19152736.5**

(22) Date of filing: **21.01.2019**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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(54) **CONCENTRIC CAMSHAFT**

(57) A concentric camshaft is disclosed for an internal combustion engine. The camshaft comprises an outer tube, an inner shaft, and two groups of cam lobes. A first group of cam lobes is fixed for rotation with the outer tube, and the second group of cam lobes is for rotation with the inner shaft by use of at least one drive member, In the invention, the inner shaft is a formed as tube which has a region where both the inner and outer diameter are reduced, and the inner surface of the inner tube in the latter region features a threaded portion.

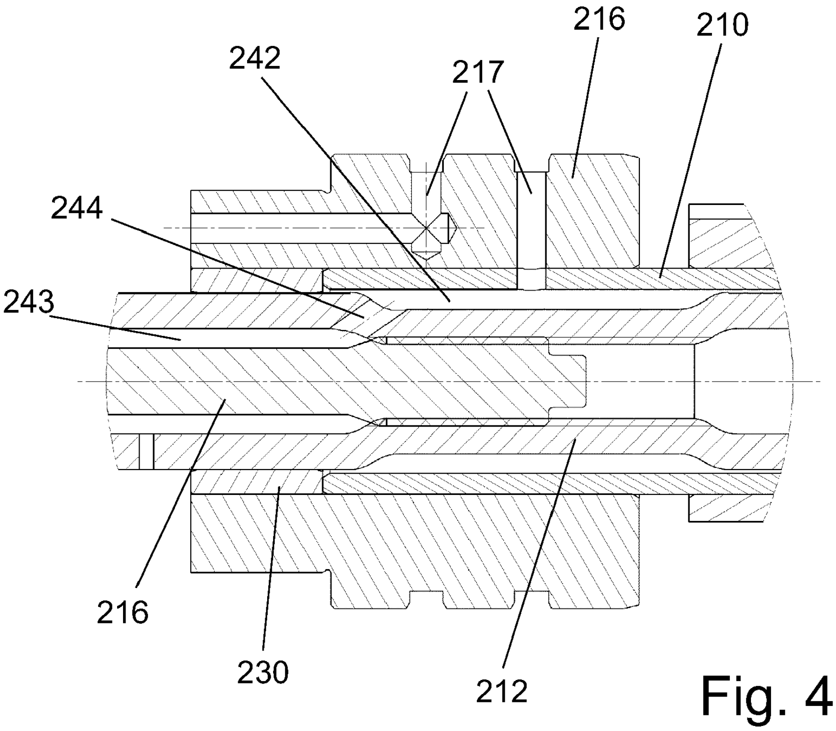

Fig. 4

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Description

Field of the invention

[0001] The invention relates to a valvetrain system for an internal combustion engine, and, in particular, to an adjustable camshaft, also known as a concentric camshaft, having two groups of cam lobes which can be phased relative to each other. When combined with a camshaft phasing system, known as a phaser, the concentric camshaft allows the phase of one. or both. of the two groups of lobes to be controlled independently relative to the phase of the engine crankshaft. In a single camshaft engine, this could allow independent control of intake and/or exhaust valve timing.

Background

[0002] Concentric camshafts are well known that allow the relative timing of two sets of cam lobes to be adjusted, and typically these are comprised of an outer tube having a first set of cam lobes fixed to its outer surface and a second set of cam lobes mounted for rotation about the outer surface of the tube. Each of the cam lobes of the second set is connected by a drive member, for rotation with an inner shaft passing through the bore of the outer tube. Each drive member passes with clearance through a circumferentially elongated slot in the wall of the outer tube, to allow rotation of the second set of cam lobes through a limited angle when the inner shaft is rotated relative to the outer tube.

[0003] There is an increased focus on reducing the mass of engine components to reduce vehicle fuel consumption/emissions, therefore it would be advantageous to form the inner shaft from a hollow tube, thereby saving mass with only a small reduction in stiffness. Furthermore, the use of an inner tube, in place of an inner shaft, opens the possibility of different constructions of the drive members for connecting the inner tube with the second set of cam lobes.

[0004] Replacing the inner shaft by a hollow tube does present some difficulty. The inner tube must be rigidly connectable to such elements as the phaser and a timing wheel, a task commonly performed by a threaded fastener. However, the requirement for an internal thread restricts the mass reductions that can be achieved by placing a limit on the maximum allowable inner tube internal diameter. The alternative of manufacturing a tube with multiple inner diameters would involve expensive machining.

Object of the invention

[0005] The invention therefore seeks to provide a practical and cost-effective method of manufacture and design of a concentric camshaft that employs an inner tube in place of an inner shaft.

Summary of the invention

[0006] According to a first aspect of the present invention, there is provided a concentric camshaft as set forth in claim 1 of the appended claims.

[0007] According to a second aspect of the present invention, there is provided a method of manufacturing a concentric camshaft as set forth in claim 13 of the appended claims.

Brief description of the drawings

[0008] The invention will now be described further, by way of example, with reference to the accompanying drawings, in which: -

Figure 1 is an isometric view of a first embodiment of a concentric camshaft,
Figure 2 is a section taken along the major axis of the first embodiment of the concentric camshaft,
Figure 3 is a section taken along the major axis of a second embodiment of the concentric camshaft,
Figure 4 is a sectional detail view of a third embodiment of the concentric camshaft,
Figure 5 is a sectional detail view of a fourth embodiment after deformation of a drive member connecting a cam lobe to the inner tube,
Figure 6 is a sectional detail view of a fifth embodiment before deformation of a drive member connecting a cam lobe to the inner tube,
Figure 7 is a sectional detail view of the fifth embodiment after a drive member deformation process,
Figure 8 is a sectional detail view of a sixth embodiment before a drive member deformation process,
Figure 9 is a detail view of the sixth embodiment after the drive member deformation process,
Figure 10 is a detail view of a seventh embodiment before a drive member deformation process,
Figure 11 is a detail view of the seventh embodiment after the drive member deformation process,
Figure 12 is a detail view of an eighth embodiment wherein ball bearings are disposed in a drive member,
Figure 13 is a detail view of the eight embodiment wherein additional ball bearings are disposed in the drive member,
Figure 14 is a detail view of a ninth embodiment wherein the drive member is a spring pin,
Figure 15 is a detail view of a tenth embodiment wherein drive members are engaged with a coupling piece, and
Figure 16 is a detail view of the tenth embodiment.

Detailed description of the drawings

[0009] Figures 1 and 2 illustrate the construction of a concentric camshaft of a first embodiment, the camshaft comprising an outer tube 10 and an inner tube 12. A first set of cam lobes 14, a front camshaft bearing 16, and additional camshaft bearings 18 for supporting the camshaft in an engine are fixed to the outer surface of the outer tube 10. A second set of cam lobes 20 and, optionally, a camshaft timing wheel 22 are attached for rotation with the inner tube 12. A camshaft phasing system 24 (shown in Figure 2 but not in Figure 1) is attached to the inner tube 12 via a fastener 26, the phasing system 24 being able to transfer torque through axial end of the inner tube 12. The inner tube 12 may protrude from the axial end of the outer tube 10 in order to engage the phasing system 24.

[0010] The second set of cam lobes 20, the outer tube 10 and the inner tube 12 each feature a corresponding radial through hole that, when the camshaft is assembled, line up with one another to allow a dowel-like drive member 40 to be inserted. The hole in the outer tube 10 is slotted around part of its circumference, enabling the inner tube 12, the second set of cam lobes 20 and the drive member 40 to rotate together relative to the outer tube 10.

[0011] The camshaft assembly may include a collar 30 fitted onto the outer surface of the inner tube 12 to contact an axial end of the outer tube 10, the collar 30 may serve to locate the inner tube 12 axially within the outer tube 10, or as a seal to prevent the egress of oil. The assembly may also include a plug 32 at the axial end of the outer tube 10 opposite to that of the phasing system 24, the plug 32 also serving as a seal to prevent egress of oil. The plug 32 may be push fit or may be threaded to engage threads in the inner surface of the outer tube 10.

[0012] The formation 28 is just one way of transmitting torque to the inner tube and alternative possibilities include the use of one or more keyways, a splined connection or a friction drive.

[0013] In order to accept the fastener 26 whilst reducing mass by having a thin wall, a region of the inner tube 12, disposed within the circle B in Figure 2, is plastically deformed to reduce both its inner and outer diameter, allowing the inner surface of the inner tube 12 to be tapped to provide a thread to engage the fastener 26. Plastic deformation of the inner tube 12 may be accomplished by swaging, application of heat and radial compression, hydroforming or any other suitable method that relies on deformation, as opposed to removal of material, to reduce the outer diameter of the inner tube.

[0014] In the description of further embodiments of the invention, in order to avoid repetition, like parts have been allocated reference numerals with the same last two significant digits. Thus, the second embodiment will feature reference numerals in the one hundred series, i.e. preceded by a '1', the third embodiment will feature reference numerals in the two hundred series, i.e. preceded by a '2', and so on.

[0015] A second embodiment of the invention is shown in figure 3, wherein the camshaft comprises an inner tube 112 which is deformed at one axial end. As with the first embodiment, the inner tube 112 is threaded in the deformed region and another component is attached to the inner tube 112 through use of a fastener 134. The component fastened to the inner tube in this embodiment is an assembly comprising a camshaft bearing 118 and a timing wheel 122. The inner diameter of the camshaft bearing 118 is in tight clearance to the outer diameter of the outer tube 110, thereby having a bearing surface to the outer tube 110. The timing wheel 122 is supported concentrically to the outer tube 110 via its connection to the camshaft bearing 118. An intermediary component in the form of an end plate may be used, the end plate being welded to the bearing 118 and fastened to the inner tube 112. The camshaft bearing 118 may contain oil vents as shown in figure 3 in the form of axial through holes, or similar, to avoid over-pressuring of a seal fitted in the bearing bore.

[0016] Figure 3 also shows an alternative arrangement for connecting the phaser (not shown) for rotation with the second set of cam lobes 120, wherein a drive coupling 138 features a threaded hole 139 for securing the phaser, through use of a fastener. The inner tube 112 and drive coupling 138 are connected by a drive member 140 in the form of a dowel pin, which also forms the drive connection for one lobe from the second set of cam lobes 120. Additionally, or alternatively, the drive coupling 138 may be connected to the bore of the inner tube 112 through an interference fit.

[0017] Figure 4 shows a third embodiment in which the front camshaft bearing 216 features channels 217 for fluid communication to the phaser. A hole in the outer tube 210 is arranged such that pressurized oil can enter a cavity 242 between the inner surface of the outer tube 210 and the outer surface of the deformed portion of the inner tube 212. Advantageously, the oil enters the cavity 242 between the inner shaft 212 and the outer shaft 210 such that there is no flow restriction. A hole 244 is provided in the inner tube 212 to allow oil to flow between two cavities 242, 243, one between the inner tube 212 and outer tube 210, and another between the fastener 216 and the inner tube 212. The hole 244 in the inner tube 212 allows the pressurized oil to flow through the cavity 243 between the inner tube 212 and the fastener 216 into the phaser.

[0018] Although the embodiments described above have all utilized a single solid pin as a drive member, it will be appreciated that this is not essential to the invention, and that a hollow drive member, or multiple drive members, may be used for each cam lobe.

[0019] Figure 5 to Figure 16 show different designs of the drive member connecting cam lobes for rotation with the inner tube. All these figures show different possible constructions of the detail shown with the circle C in Figure 2. Figure 5 illustrates a fourth embodiment comprising a hollow drive member 340. Before insertion into the hole in the inner tube 312 and its corresponding holes in the second set of cam lobes 320 and the outer tube 310, the inner and outer diameters of the drive member 340 are substantially constant along its length, the outer diameter of the drive member 340 being slightly smaller than the diameter of the hole. After insertion, the drive member 340 is plastically deformed such that it is in interference with the inner edge of the hole in the inner tube 312. Further, the central portion of the drive member 340 that lies between the holes in the inner tube 312 is of a greater diameter than the holes in the inner tube 312, thereby further securing the drive member 340 in the axial direction.

[0020] By way of example, one method of deforming the drive member 340 is hydroforming. Hydroforming comprises the steps of pumping a fluid, such as water or oil, into the bore of the drive member 340 at extreme pressures to force the material to plastically deform locally. The fluid is directed into the hollow cavity by punches 346 which contain sealing features to retain and direct the fluid into the required area. The length of the section of the punches that sit inside the drive member is chosen so that the fluid pressure cannot deform the drive member in the region of the outer tube and stop any relative rotation of the inner and outer tubes.

[0021] An alternative method to secure the drive member 440 is staking, as illustrated in Figures 6 and 7. The staking process involves passing a hardened tool through a radial pocket 448 in the drive member 440. The shape of the pocket 448 and the shape of the tool are designed such that when the tool passes through the pocket 448, the drive member 440 expands radially, thereby being secured inside the inner tube 412.

[0022] Figures 8 and 9 show a riveting process to cause an interference fit between the drive member 540 and the inner tube 512. The process includes forcing a mandrel 550 through the bore of the drive member 540, the mandrel 550 comprising a shaft of a smaller diameter than the bore of the drive member 540 and a spherical head of a greater diameter than the bore of the drive member 540. The mandrel 550 may be inserted into the drive member 540 before assembly into the inner tube 512. The hole in the drive member 540 may be a plain through hole or a counterbore hole, with the counterbore diameter being greater than the diameter of the spherical head of the mandrel 550, depending on whether an interference fit is desired between the drive member 540 and the cam lobe 520. The hole may feature a counterbore at both axial ends of the drive member 540.

[0023] It is possible to use more than one drive member to secure the second set of cam lobes for rotation with the inner tube. One such embodiment, as shown in Figures 10 and 11, uses the riveting technique already disclosed, but with two drive members 640a, 640b. The mandrels 650a, 650b are assembled to the individual drive members 640a, 640b before insertion into the inner tube 612 and may be passed through the holes of the drive members 640a, 640b individually or simultaneously. The holes in the drive members 640a, 640b may be counterbored as in the previous embodiment.

[0024] A further embodiment, as illustrated in Figure 12, uses the insertion of ball bearings 752a to plastically deform the drive member 740 in a precise location, such as where the drive member 740 is to contact the inner tube 712. If it is desired for the drive member 740 to also contact the cam lobe 720, then further ball bearings 752b may be used as shown in Figure 13. Although Figure 13 shows that all ball bearings 752a, 752b are the same diameter, the outer ball bearings 752b may be of a larger diameter to secure the drive member 740 to the cam lobe 720. If it is not desired for the drive member 740 to contact the cam lobe 720, then the drive member 740 may feature a counterbore hole and no outer ball bearings 752b, as shown in Figure 12. The ball bearings 752a, 752b may remain inside the drive member 740 after the assembly process, being retained by the interference generated by their insertion.

[0025] It is possible to utilize drive members that do not require plastic deformation to secure the second set of cam lobes to the inner tube. Figure 14 shows a drive member 840 consisting of a coiled sheet of material in the form of a spring, commonly known as a spring pin or a rolled pin. The spring pin 840 diameter in its relaxed state is greater than the hole in the inner shaft 812. Once coiled tightly, inserted into the hole in the inner tube 812 and its corresponding holes in the outer tube 810 and the second set of cam lobes 820, the energy stored in the spring pin is released to engage with the inner edge of the holes in the inner tube 812 and in the cam lobe 820.

[0026] Another embodiment featuring a removable drive member is illustrated in Figures 15 and 16, which show a drive connection method comprising a fastened assembly of two drive members 940a, 940b, each featuring a dowel-like portion and a threaded portion, and a coupling piece 954 with an axial hole, at least a portion of which is threaded. The coupling piece 954 may have features (not shown) which allow it to be correctly oriented both axially and rotationally in the inner tube 912 so that it can accept the drive members 940a, 940b during assembly. During the assembly process, the coupling piece 954 is inserted into the bore of the inner tube 912 and the two drive members 940a, 940b are inserted through the holes in the cam lobe 920 and inner tube 912 with a clearance or transition fit, and then fastened into the coupling piece 954 thereby securing them and the cam lobe 920 for rotation with the inner tube 912. The two drive members 940a, 940b may accept any means for tightening and loosening them, including Allen keys, sockets, or torx, flat-head, Philips and Posi drive drill bits and screwdrivers.

[0027] It will be appreciated that other methods known in the art may be used to secure the drive members to the inner tube or the cam lobe, one exemplary method involving shrink fitting.

[0028] Further, machining a counterbore into the axial end of a drive member may be carried out on any embodiment above in order to change the pressure distribution characteristics of the drive member acting on the outer tube and cam lobe.

[0029] Where the term counterbore has been used, a countersunk hole should be viewed as equivalent.

[0030] Some embodiments described and depicted as one drive member may instead feature a drive member assembly comprising two smaller drive members, each drive member disposed in a hole in the inner tube and a corresponding hole in the outer tube and second set of cam lobes.

Claims

1. A concentric camshaft for an internal combustion engine, comprising;
   an outer tube,
   an inner shaft, and
   two groups of cam lobes,
   the first group of cam lobes being fixed for rotation with the outer tube, and
   the second group of cam lobes being fixed for rotation with the inner shaft by use of at least one drive member,
   characterized in that,
   the inner shaft is hollow and is constructed as an inner tube having at least one region where both the inner and outer diameter are less than the inner and outer diameter of the remainder of the inner tube, and the inner surface of the inner tube in said region features a threaded portion.

2. A camshaft as claimed in claim 1, wherein a cavity lies between the inner surface of the outer tube, and the region of the outer surface of the inner tube where both the inner and outer diameter is less than the inner and outer diameter on at least one side of said region.

3. A camshaft as claimed in claim 1 or claim 2, wherein a camshaft timing wheel is fixed for rotation with the inner tube.

4. A camshaft as claimed in claim 3 wherein the axis of rotation of the camshaft timing wheel is located by a bearing surface in contact with the outer diameter of the outer tube.

5. A camshaft as claimed in claim 3 or claim 4, wherein the camshaft timing wheel is attached to a camshaft bearing, the camshaft bearing having a bearing surface in contact with outer diameter of the outer tube.

6. A camshaft as claimed in any preceding claim, wherein the at least one drive member is hollow and is secured to the inner tube by plastic or elastic deformation

7. A camshaft as claimed in claim 6, wherein the at least one drive member is a spring pin.

8. A camshaft as claimed in claim 6, wherein the at least one drive member features a radial pocket.

9. A camshaft as claimed in claim 6, wherein the at least one drive member contains one or more ball bearings serving to deform the drive member following insertion into the inner tube.

10. A camshaft as claimed in any of claims 6 to 9, wherein the at least one drive member features a counterbore or countersink in at least one axial end.

11. A camshaft as claimed in any of claims 1, 6, 7, 9 and 10, wherein each cam lobe of the second group is connected for rotation with the inner tube by means of two drive members, each disposed in a respective hole in the inner tube and a corresponding hole in the outer tube and the respective cam lobe.

12. A camshaft as claimed in claim 11, wherein each drive member has a dowel-like portion and a threaded portion, the threaded portion of each drive member engaged in a common threaded coupling piece disposed in the bore of the inner tube.

13. A method of manufacturing a concentric camshaft comprising:

    providing an outer tube,
    locating an inner tube within the outer tube,
    securing a first set of cam lobes to the outer tube for rotation therewith,
    rotatably mounting a second set of cam lobes on the outer tube, and
    securing the cam lobes of the second set for rotation with the inner tube by means of drive members passing through circumferentially elongated slots in the outer tube,
    characterized in that
    prior to locating the inner tube within the outer tube, a region of the inner tube is plastically deformed to reduce both the inner and outer diameters of the inner tube, and
    the inner surface of the reduced diameter region of the inner tube is provided with a screw-thread to receive a fastener for securing an output member of a phaser, a camshaft timing wheel, or other component to an axial end of the inner tube.

14. A method as claimed in claim 13, wherein plastically deforming a region of the inner tube is carried out by swaging or hydroforming.

15. A method as claimed in claim 13 or 14, wherein the step of securing the cam lobes of the second set for rotation with the inner tube comprises inserting hollow drive members into aligned radial holes in the

cam lobes of the second set and the inner tube and plastically or elastically deforming the drive members to retain the drive members within the inner tube.

None of the claims relating to hollow drive members mention that the drive member is deformed (elastically or plastically) after assembly to the camshaft. I'm not sure if this needs to be claimed, and if so, whether it fits best in the earlier claims (around claim 6) or following the method claim (claim 13).

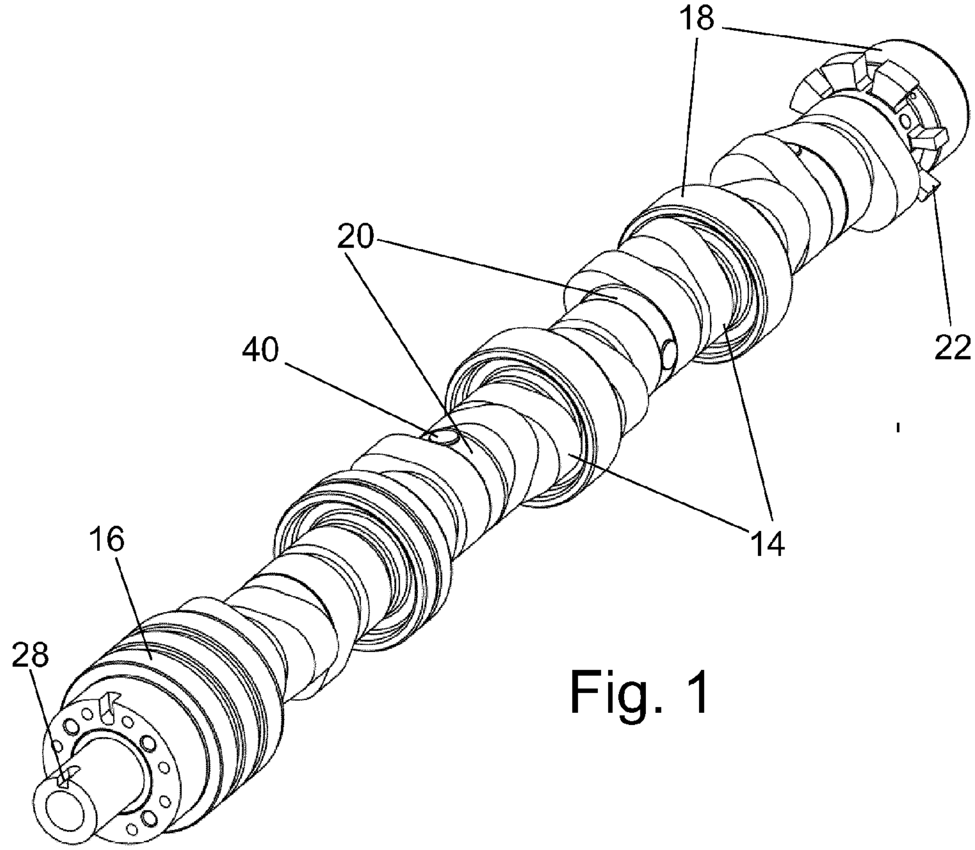

Fig. 1

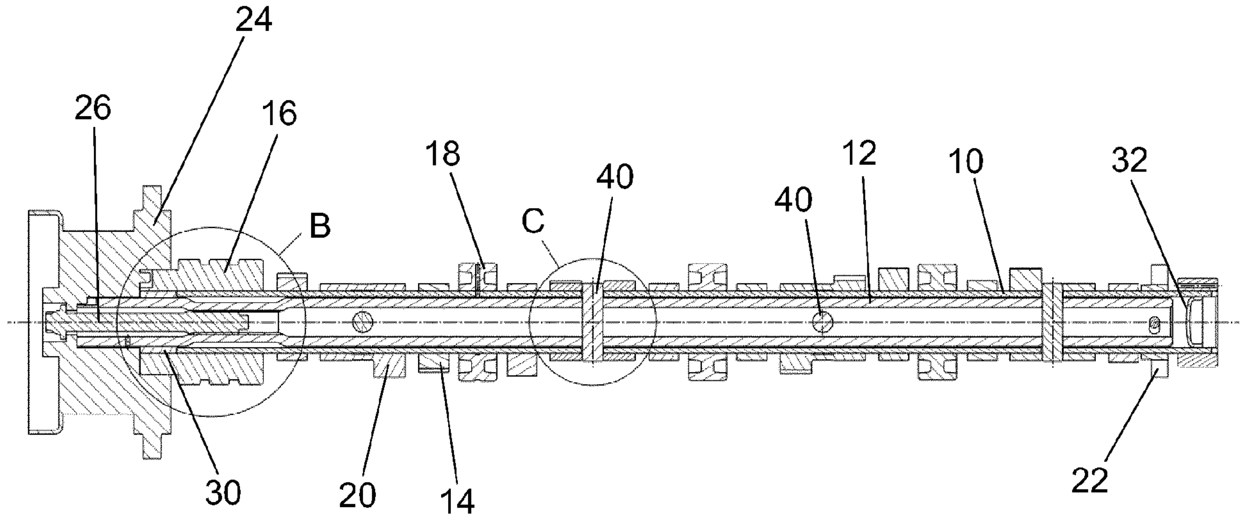

Fig. 2

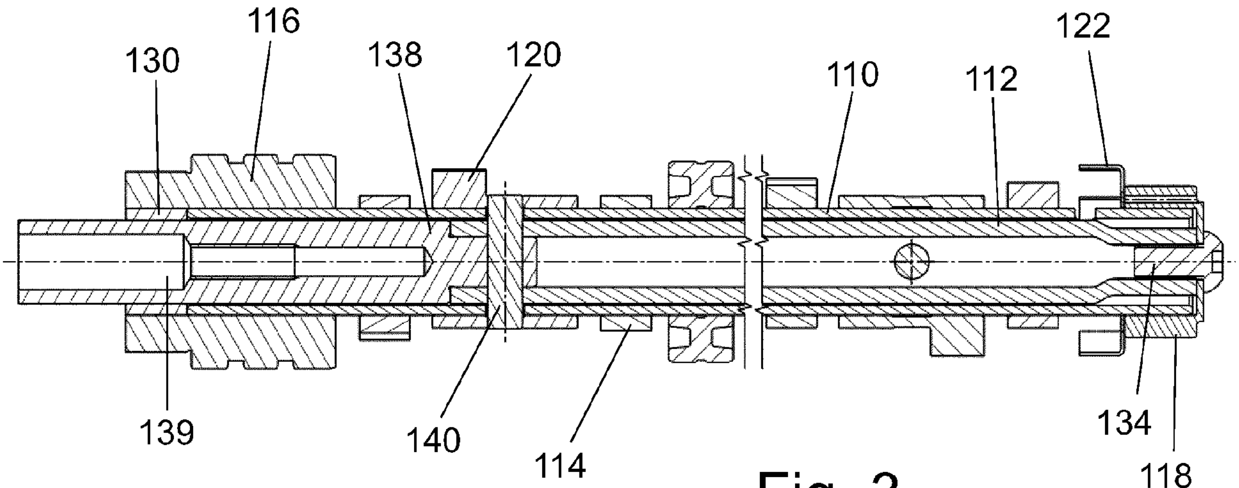
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Fig. 3

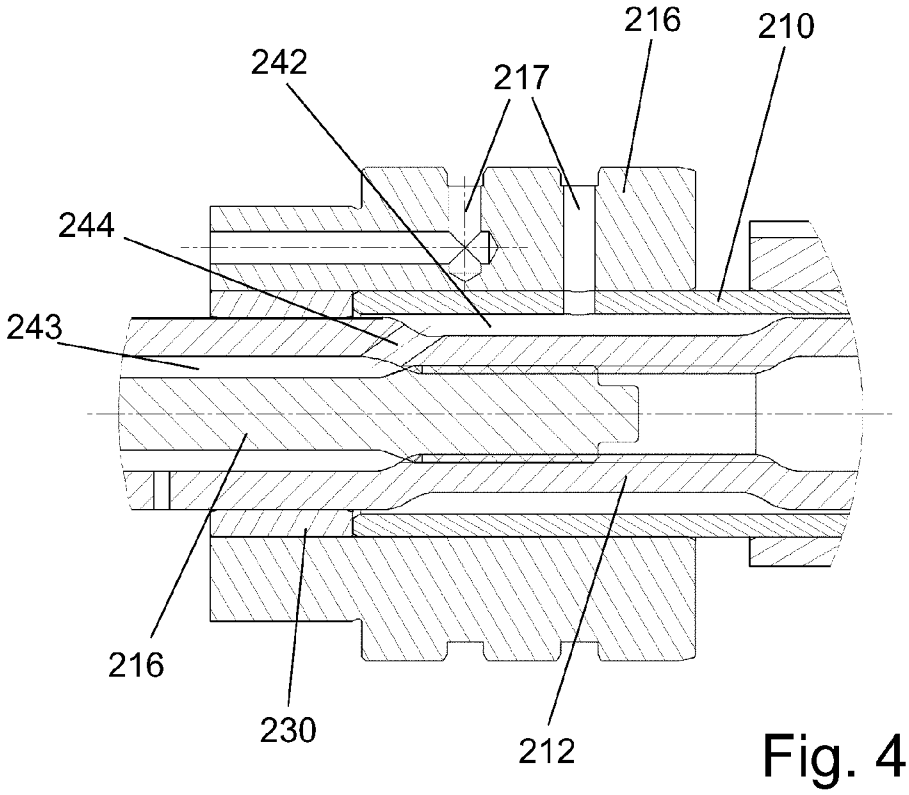
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Fig. 4

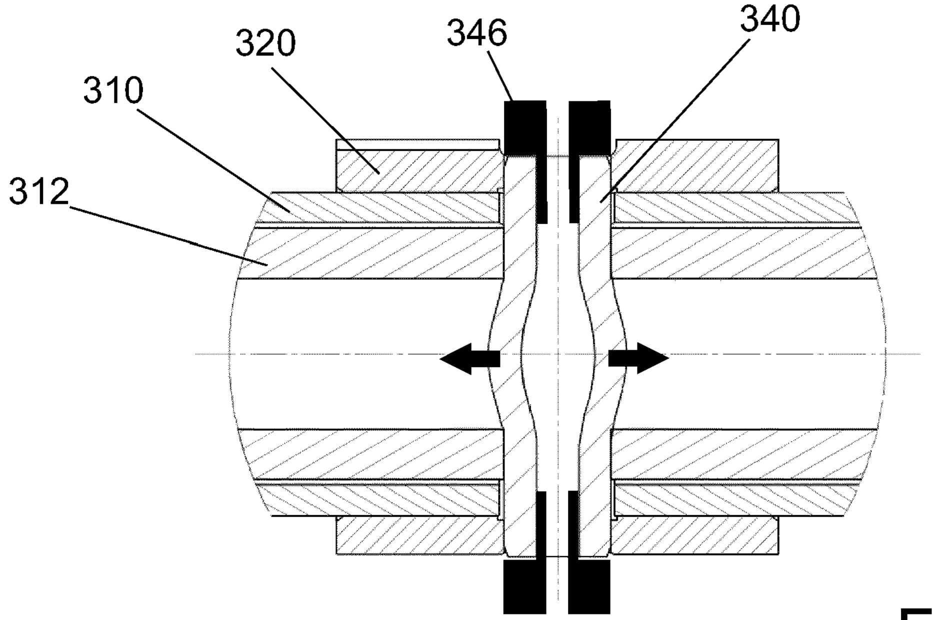

Fig. 5

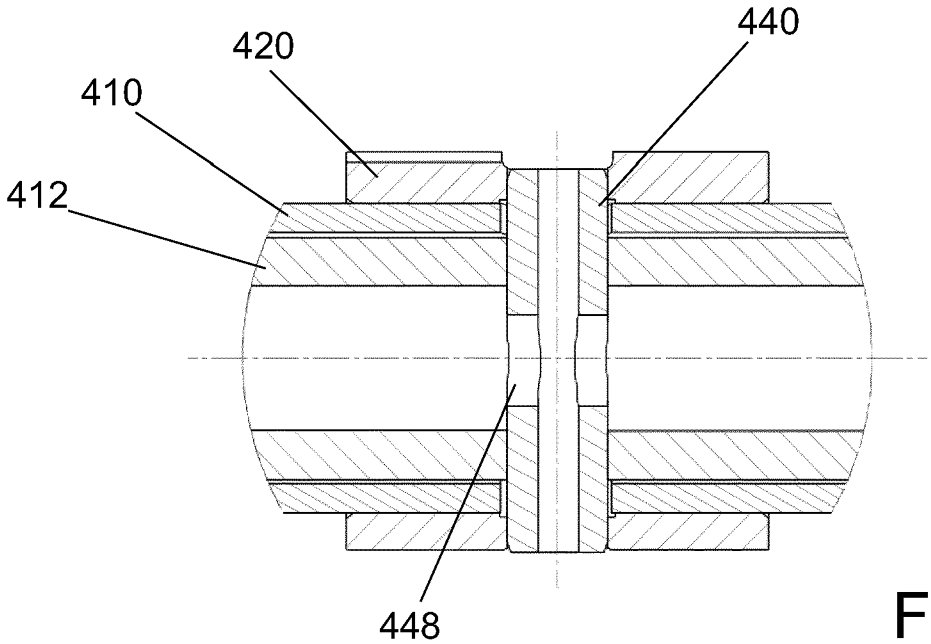

Fig. 6

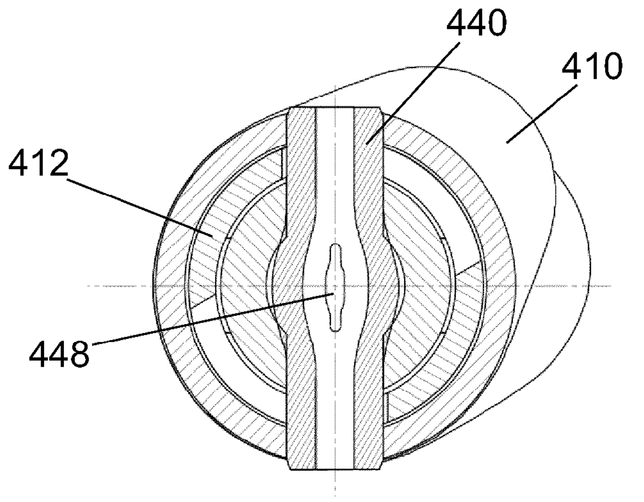

Fig. 7

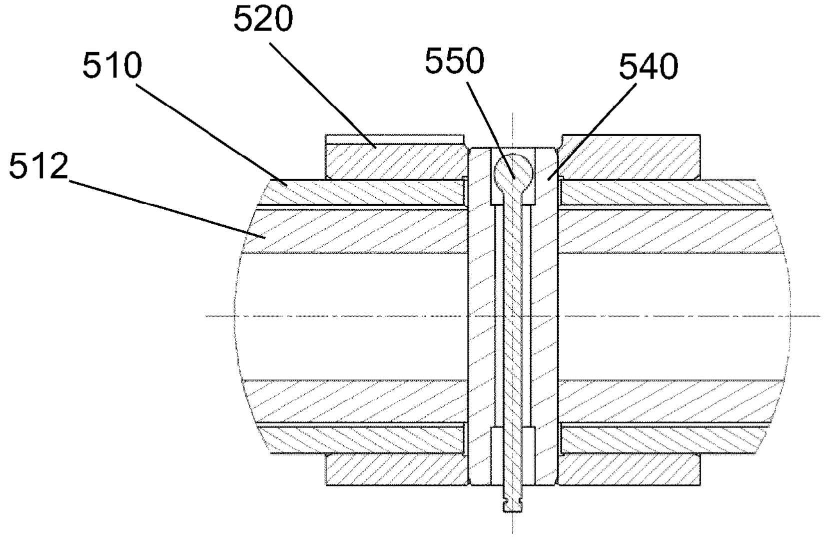

Fig. 8

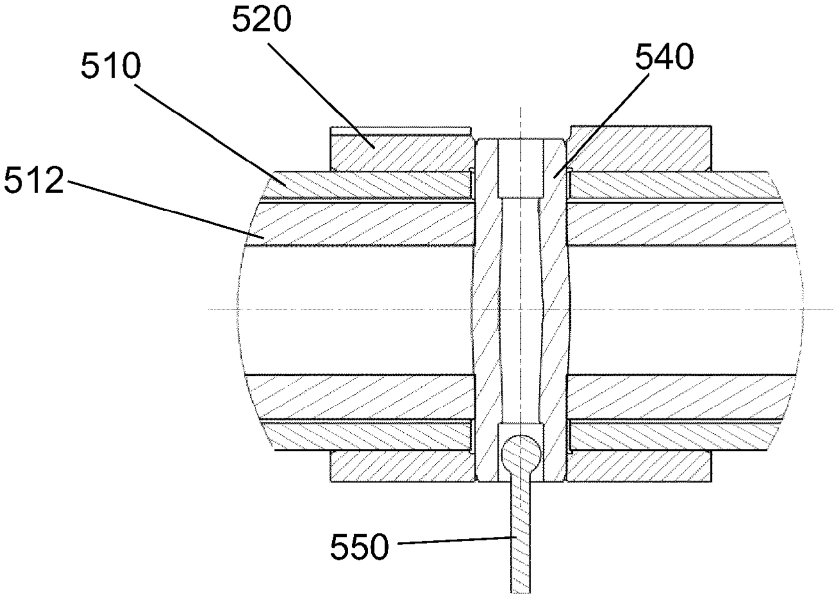

Fig. 9

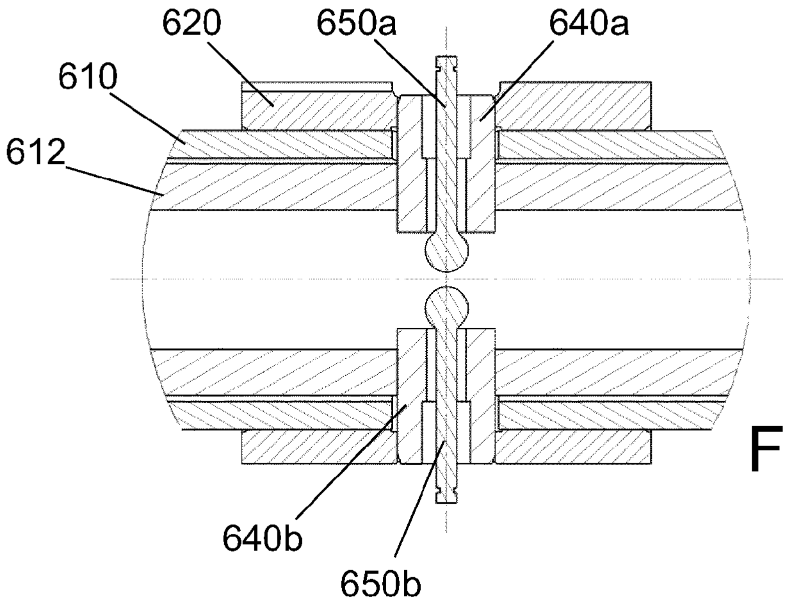

Fig. 10

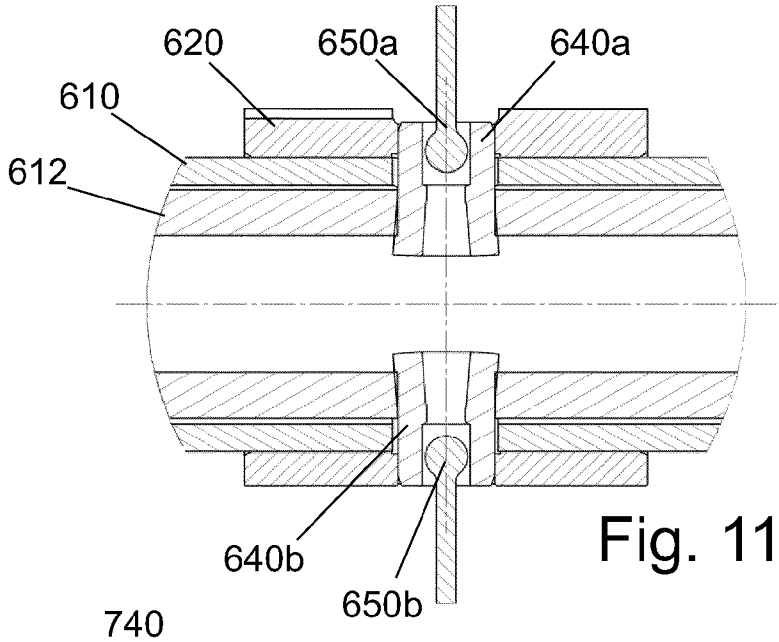

Fig. 11

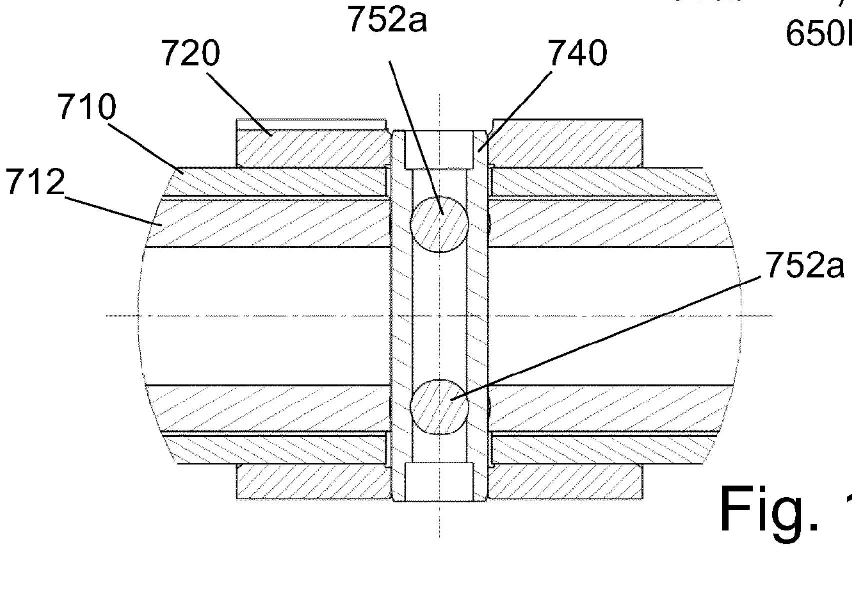

Fig. 12

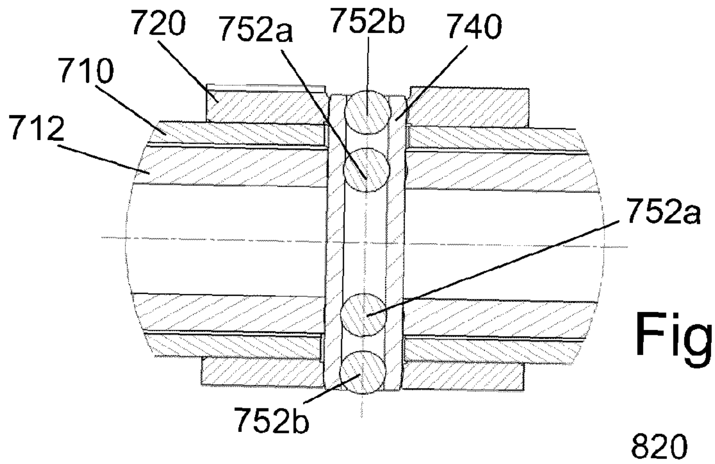

Fig. 13

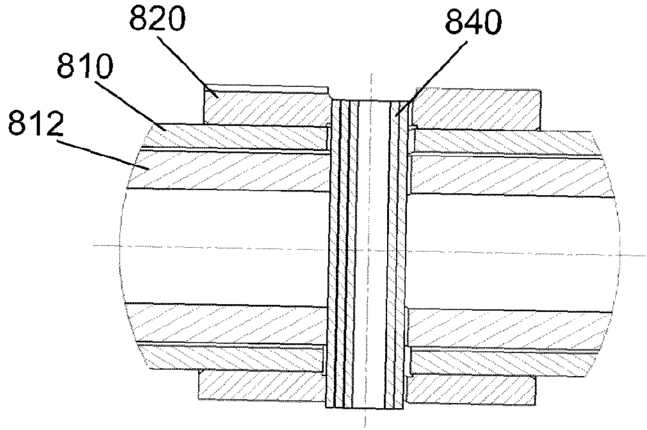

Fig. 14

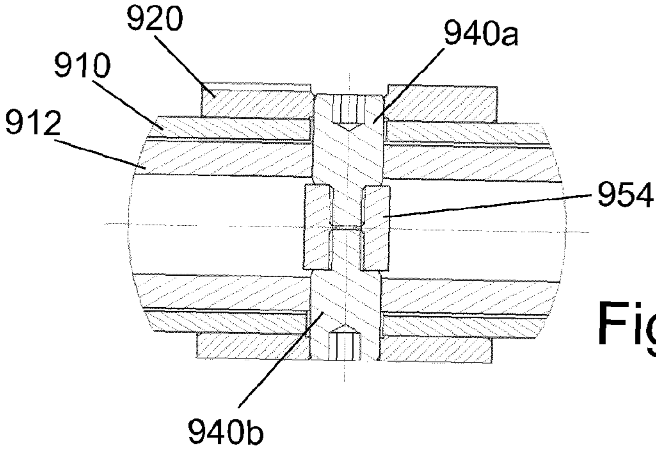

Fig. 15

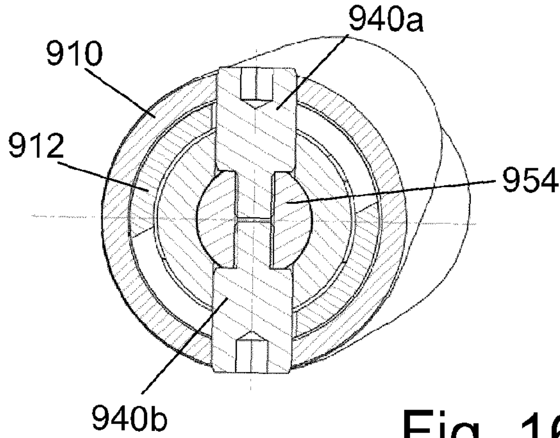

Fig. 16

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EUROPEAN SEARCH REPORT

Application Number
EP 19 15 2736

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 2014/283773 A1 (ELFERS UWE [DE]) 25 September 2014 (2014-09-25) * paragraphs [0020], [0021], [0025]; claim 7; figure 1 *	1,13 3-12,14, 15	INV. F01L1/047 F01L1/344
X	US 2017/183981 A1 (WEIDAUER MARCEL [DE] ET AL) 29 June 2017 (2017-06-29) * paragraphs [0030] - [0038]; figure 1 *	1,2	
Y	EP 3 000 995 A1 (MECHADYNE INTERNAT LTD [GB]) 30 March 2016 (2016-03-30) * paragraph [0020]; figures 5-8 *	3-5	
Y	US 2010/170458 A1 (PLUTA CHRISTOPHER J [US] ET AL) 8 July 2010 (2010-07-08) * paragraph [0039]; claims; figures *	6-8,12, 14,15	
Y	US 2010/223771 A1 (CLEVER GLENN E [US] ET AL) 9 September 2010 (2010-09-09) * paragraphs [0022] - [0024]; figure 5 *	9,10	TECHNICAL FIELDS SEARCHED (IPC)
Y	EP 3 176 390 A1 (MAHLE INT GMBH [DE]) 7 June 2017 (2017-06-07) * paragraph [0024]; figure 4 *	11	F01L
A	DE 10 2008 023066 A1 (HYDRAULIK RING GMBH [DE]; VOLKSWAGEN AG [DE]) 12 November 2009 (2009-11-12) * the whole document *	1	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	6 June 2019	Klinger, Thierry

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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E : earlier patent document, but published on, or after the filing date
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 19 15 2736

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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06-06-2019

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