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(54) Title: PISTON COOLING CONFIGURATIONS UTILIZING LUBRICATING OIL FROM A BEARING RESERVOIR IN AN OPPOSED-PISTON ENGINE

(57) Abstract: Pressurized lubricating oil is accumulated in the bearings of opposed pistons and accumulated oil is dispensed therefrom for bearing lubrication and also for cooling the under-crowns of the pistons by jets of oil emitted from the bearings.

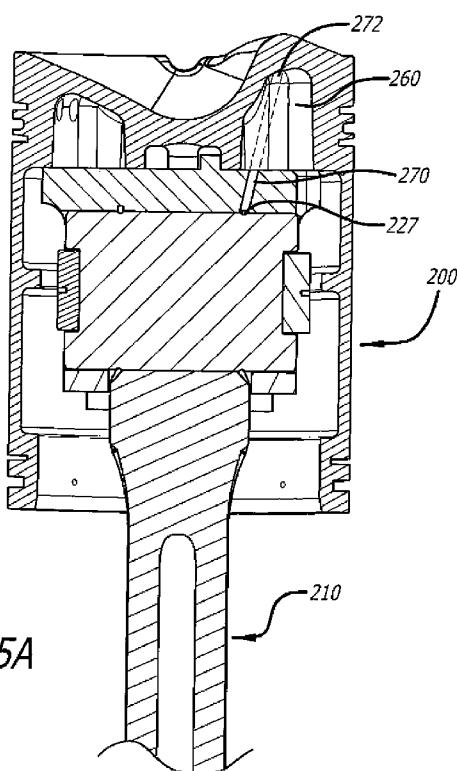


FIG. 5A



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## PISTON COOLING CONFIGURATIONS UTILIZING LUBRICATING OIL FROM A BEARING RESERVOIR IN AN OPPOSED-PISTON ENGINE

### PRIORITY

**[0001]** This application claims priority to, and is a continuation-in-part of, US 14/199,877 filed 06 March 2014.

### RELATED APPLICATIONS

**[0002]** This application contains subject matter related to the subject matter of US 2012/0073526 A1 and US publication 2014/0238360 A1.

### FIELD

**[0003]** The field is piston thermal management for internal combustion engines. More specifically the application relates to implementation of a piston cooling configuration for an opposed-piston engine in which the undercrown – that portion of the piston crown that is behind or underneath the crown end surface against which combustion acts – is cooled by use of one or more jets of lubricating oil fed from a reservoir in the piston's bearing mechanism.

### BACKGROUND

**[0004]** Piston thermal management presents continuing challenges to piston integrity due to increasing loads demanded for modern engines. In a typical piston, four areas are particularly susceptible to thermal damage: the piston crown, the ring grooves, the piston/wristpin interface, and the piston undercrown. If combustion temperatures felt by the crown end surface exceed the oxidation temperature of the crown materials, oxidation can result. The crown may be subject to mechanical failure caused by stress/fatigue at the oxidized sites. The piston's rings, ring grooves, and lands may exhibit carbon build-up due to lubricating oil being heated above its coking temperature. A hot wristpin bore can result in lower load-carrying capacity of the piston bearing. As with the ring grooves, the piston undercrown may also be subject to oil coking.

**[0005]** In some aspects of opposed-piston combustion chamber construction it is desirable to utilize pistons whose crowns include highly contoured end surfaces which produce complex, turbulent charge air motion that encourages uniform mixing of air and fuel. An example of a highly contoured piston end surface that forms a combustion chamber with an oppositely-disposed, similarly-contoured piston end surface is shown in

FIG. 11 of US 2011/0271932 A1. Combustion imposes a heavy thermal load on these pistons. Their highly contoured end surfaces create non-uniform thermal profiles with concentrations of heat ("hot spots") that can lead to asymmetrical thermal stress, wear, and piston fracture.

**[0006]** Typically, three approaches are taken to manage piston temperatures. In one, high thermal resistance of the piston crown reduces or blocks the passage of heat from the combustion chamber into the crown. A second approach relies on conduction of heat from the crown to the cylinder bore through the rings, ring grooves, lands, and skirt of the piston. The third approach uses a flow of liquid coolant to remove heat from the undercrown. Modern piston constructions typically include all three approaches.

**[0007]** Liquid coolant is typically applied to the undercrown by means of galleries and/or nozzles. For example, US 8430070 teaches a piston cooling construction including an outer gallery that receives and transports oil for cooling the piston undercrown. An oil outlet is provided on the bottom of the outer gallery. A nozzle mounted to the floor of the outer gallery, in fluid communication with the oil outlet is aimed toward the undercrown. Oil is inertially pumped from the gallery through the oil outlet in response to upward movement of the piston. The pumped oil is sprayed from the nozzle onto the undercrown in response to upward movement of the piston.

**[0008]** An example of undercrown cooling in an opposed-piston context is shown in FIG. 5 of the Applicant's US 2012/0073526 A1 wherein a piston with a contoured end surface includes an annular gallery 256 within the crown that follows the periphery of the crown, underneath the end surface. The annular gallery is in fluid communication with a central gallery 257 underneath the central portion of the end surface. A nozzle 262, separate from the piston, is aimed at an opening in the annular gallery 256. A high velocity jet of oil emitted by the nozzle 262 travels into the annular gallery, striking a specific portion of the crown underneath a ridge of the end surface that bears a heavy thermal burden during combustion. The jet cools the specific crown portion by impingement. The oil then flows through the annular and central galleries, thereby cooling additional portions of the undercrown. Oil flows out of the central gallery and exits the piston.

**[0009]** The cooling capability of the nozzle described in US 8430070 is limited by the inertial pumping operation which occurs only during upward movement of the piston. As a result, the undercrown is cooled by spraying oil through only one half of the piston's

operational cycle. Furthermore, because the sprayed oil is obtained from the cooling gallery, it is already heated, which limits its cooling capacity when emitted by the nozzle. The cooling construction of US 2012/0073526 A1 brings oil into the piston via a nozzle external to the piston. Separate transport channels are required to bring up pressurized oil to cool the undercrown and to lubricate the piston rod coupling mechanism. As a result, oil is provided throughout the operating cycle of the piston, but at the penalty of increased complexity and cost of the lubrication system.

**[0010]** Accordingly, there is a need for delivering lubricating oil to a piston for cooling the undercrown in a manner that maintains the flow of lubricating oil throughout the piston's cycle of operation without adding to the complexity and cost of the system that transports the oil to the piston for lubrication.

## SUMMARY

**[0011]** In order to cool the undercrown of a piston with pressurized lubricating oil throughout the piston's cycle of operation, without adding to the complexity and cost of the system that transports the oil to the piston for lubrication, oil is pumped to a reservoir in the piston's bearing for lubricating the bearing. From the reservoir, the pressurized oil is also provided to one or more cooling jet outlets provided in the bearing and aimed at the undercrown.

**[0012]** In some aspects, the reservoir is in the wristpin of the piston bearing. In some further aspects, the reservoir is in a piston bearing wristpin attached to the small end of a connecting rod.

**[0013]** In some aspects, a stationary cooling jet outlet in fluid communication with a bearing oil reservoir is positioned to emit a jet of oil targeted at a specific, large region of a piston undercrown. The stationary cooling jet outlet may be disposed in a bearing part that does not move relative to the undercrown. In some aspects, the bearing part supports the wristpin for oscillating movement with respect to the undercrown during engine operation.

**[0014]** In some aspects, a cooling jet outlet includes a movable nozzle in fluid communication with a bearing oil reservoir. The nozzle is positioned to emit a jet of oil targeted to a specific, large region of a piston undercrown. The nozzle may be mounted to a piston part that moves relative to the undercrown as the piston travels so as to sweep the region with the jet. In some other aspects, the part oscillates within the piston

skirt in response to piston movement so that the jet continuously sweeps the region with each cycle of piston movement. In yet other aspects, the nozzle is mounted to an element of the connecting rod that oscillates, or rocks, with respect to the undercrown during engine operation.

**[0015]** In further aspects, a cooling jet outlet includes a passage drilled or formed in a bearing support member that includes a bearing surface that receives and supports the wristpin for oscillating movement.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0016]** FIG. 1 schematic drawing of a prior art opposed-piston engine with a pump-supplied oil gallery.

**[0017]** FIG. 2 is a side view, in perspective, of a piston/connecting rod assembly for a two-stroke cycle, opposed-piston engine in which the piston has a first end surface construction.

**[0018]** FIG. 3 is a cross-sectional view of the piston crown and skirt taken along lines A-A of FIG. 2.

**[0019]** FIG. 4 is an exploded view of the piston/connecting rod assembly of FIG. 2 showing elements of a bearing configuration.

**[0020]** FIG. 5A is a cross-sectional view of the piston/connecting rod assembly taken along lines A-A of FIG. 2 showing a first cooling jet outlet construction.

**[0021]** FIG. 5B is a cross-sectional view of the piston/connecting rod assembly taken along lines B-B of FIG. 2 showing a second cooling jet outlet construction.

**[0022]** FIG. 6 is a cross-sectional view of the crown and skirt of a piston having a second end surface construction.

**[0023]** FIG. 7A is a cross-sectional view showing the piston of FIG. 6 assembled to a bearing with a first variation of the first cooling jet outlet construction.

**[0024]** FIG. 7B is a cross-sectional view showing the piston of FIG. 6 assembled to a bearing with a variation of the second cooling jet outlet construction.

**[0025]** FIG. 8 is a cross-sectional view of the piston/connecting rod assembly taken along lines A-A of FIG. 2 showing a cooling jet outlet construction for delivering one or more cooling jets to a central gallery of the piston.

## DETAILED DESCRIPTION

**[0026]** A two-stroke cycle engine is an internal combustion engine that completes a power cycle with a single complete rotation of a crankshaft and two strokes of a piston connected to the crankshaft. One example of a two-stroke cycle engine is an opposed-piston engine in which a pair of pistons is disposed in opposition in the bore of a cylinder. During engine operation, combustion takes place in a combustion chamber formed between the end surfaces of the pistons.

**[0027]** As seen in FIG. 1, an opposed-piston engine 49 has at least one ported cylinder 50. For example, the engine may have one ported cylinder, two ported cylinders, three ported cylinders, or four or more ported cylinders. For purposes of illustration, the engine 49 is presumed to have a plurality of ported cylinders. Each cylinder 50 has a bore 52. Exhaust and intake ports 54 and 56 are formed in respective ends of the cylinder such that the exhaust port 54 is longitudinally separated from the intake port 56. Each of the exhaust and intake ports 54 and 56 includes one or more circumferential arrays of openings. Exhaust and intake pistons 60 and 62 are slidably disposed in the bore 52 with their end surfaces 61 and 63 opposing one another. The exhaust pistons 60 are coupled to a crankshaft 71, and the intake pistons are coupled to a crankshaft 72. Each of the pistons is coupled to its associated crankshaft by a bearing 74 and a connecting rod 76.

**[0028]** A lubrication system that supplies oil to lubricate the moving parts of the engine 49 includes an oil reservoir 80 from which pressurized oil is pumped by a pump 82 to a main gallery 84. The main gallery supplies pressurized oil to the crankshafts 71 and 72, typically through drillings 86 to the main bearings (not seen). From grooves in the main bearings, pressurized oil is provided to grooves in the big end bearings of the connecting rods 76. From there, pressurized oil flows through drillings 77 in the connecting rods to the bearings 74.

**[0029]** In some aspects, which are not intended to be limiting, the engine 49 is equipped with an air management system 51 that includes a supercharger 110 and a turbocharger 120. The turbocharger has a turbine 121 and a compressor 122 rotating on a common shaft 123. The turbine 121 is coupled to the exhaust subsystem and the compressor 122 is coupled to the charge air subsystem. Exhaust gas emptied into the conduit 125 from the exhaust port 54 rotates the turbine 121. This rotates the compressor 122, causing it to generate charge air by compressing intake air. The charge air output

by the compressor 122 flows through a conduit 126, whence it is pumped by the supercharger 110 to the openings of the intake port 56.

**[0030]** The operational cycle of an opposed-piston engine is well understood. In response to combustion occurring between their end surfaces 61, 63, the opposed pistons 60, 62 move away from respective top center (TC) locations in the cylinder. While moving from TC, the pistons keep their associated ports closed until they approach respective bottom center (BC) positions. The pistons may move in phase so that the exhaust and intake ports 54, 56 open and close in unison; alternatively, one piston may lead the other in phase, in which case the intake and exhaust ports have different opening and closing times. As the pistons move through their BC locations exhaust products flowing out of the exhaust port 54 are replaced by charge air flowing into the cylinder through the intake port 56. After reaching BC, the pistons reverse direction and the ports are again closed by the pistons. While the pistons continue moving toward TC, the charge air in the cylinder 50 is compressed between the end surfaces 61 and 63. As the pistons advance to their respective TC locations in the cylinder bore, fuel is injected through the nozzles 100 into the charge air, and the mixture of charge air and fuel is compressed in the combustion chamber formed between the end surfaces 61 and 63 of the pistons 60 and 62. When the mixture reaches an ignition temperature, the fuel ignites. Combustion results, driving the pistons apart, toward their respective BC locations.

**[0031]** In some cases, the opposing end surfaces 61 and 63 are identically constructed and the pistons 60 and 62 are disposed in rotational opposition with reference to the axis of the cylinder in which they are disposed. See, for example, the piston end surface constructions described and illustrated in the Applicant's US publication 2011/0271932 A1 and US publication 2013/0213342 A1. In some other cases, the opposing end surfaces 61 and 63 have complementary constructions which do not require rotational opposition. See, for example, the piston end surface constructions described and illustrated in the Applicant's WO publication 2012/158756 A1 and related US application 14/026,931.

**[0032]** It is desirable to include undercrown cooling in the thermal design of the pistons of an opposed-piston engine such as the engine 49 shown in FIG. 1. Therefore, the undercrown cooling embodiments described and illustrated in this specification may be combined with other modes of piston thermal management in order to realize an

effective piston thermal performance. Undercrown cooling and other objectives are achieved by accumulating pressurized lubricating oil in the piston bearings of an opposed-piston engine and dispensing accumulated oil therefrom for bearing lubrication and also for cooling the undercrowns of the pistons by way of one or more jets.

First End Surface Construction:

**[0033]** FIG. 2 is a perspective view of a piston assembly used in an opposed-piston engine in which the pistons have identical end surfaces. In this case the description is directed to a single piston, with the understanding that it applies as well to its opposing counterpart. The piston assembly includes a piston 200 and its associated connecting rod 210. The piston 200 has a crown 203, and a skirt 205. An end surface 206 of the crown is configured to form a combustion chamber in cooperation with the end surface of an identically-configured, opposing piston. Lands and ring grooves 207 are provided in the crown's side wall. Referring to FIGS. 2, 3, and 4, the piston includes an undercrown 208, which is that portion of the piston crown 203 that is behind or underneath the end surface 206 against which combustion acts. The connecting rod 210 has a large end 211 for coupling to a crank throw of a crankshaft (not seen). An oil groove 212 is formed in the bearing surface of the large end 211. An oil delivery passage 213 (best seen in FIG. 5B) extends longitudinally in the connecting rod 210 from the oil groove 212 to the small end 215.

**[0034]** As per FIGS. 2 and 3, the contour of the end surface 206 includes a ridge 209 formed by complex curved surfaces including a bowl 214 that interact with bulk air motion components to enhance charge air turbulence in the combustion chamber. During combustion, one or more hot spots may occur in portions of the crown including the ridge 209 and/or the bowl 214.

Piston Bearing Construction and Lubrication:

**[0035]** With reference to FIGS. 4, 5A, and 5B, the piston 200 includes a bearing 217 fixed to the undercrown 208 and disposed in space encircled by the skirt 205. As per FIGS. 4 and 5B, a bearing structure includes bearing support members 219a and 219b. The bearing support member 219a includes a bearing surface 220 that receives a wristpin 221 (also called a "journal" or a "gudgeon pin") mounted to the small end 215 by threaded fasteners. In some instances, the bearing support members 219a and 219b are joined around the wristpin 221 and secured to the undercrown by fasteners 218 that are

threadably seated in interior structures of the undercrown 208. As seen in FIG. 4, an opening 223 in the bearing support member 219b receives the connecting rod 210. When assembled, the bearing support member 219a, 219b retains the wristpin 221 for oscillation on the bearing surface 220 caused by arcuate oscillation of the connecting rod 210 in the opening 223.

**[0036]** As per FIGS. 4 and 5B, the wristpin 221 includes an internal oil reservoir 222 in fluid communication with an oil inlet passage 224 drilled through the wristpin 221 and one or more oil outlet passages 225 drilled through the wristpin 221. Circumferential oiling grooves 227 are formed in the bearing surface 220 in alignment and fluid communication with the oil outlet passages 225. In some aspects, best seen in FIG. 4, the oil reservoir 222 can be configured as an annular recess with opposing ends and an axis that corresponds to the axis on which the wristpin 221 oscillates. In this case, a cylindrical shaft 250 is received in the cylindrical inner surface 228 of the wristpin 221. A flange 252 is fixed to one end of the shaft 250; the opposite end of the shaft is threaded to another flange 254 so as to retain the shaft 250 in coaxial alignment with the cylindrical inner surface 228 of the wristpin 221. As the views in FIGS. 4 and 5B show, the smaller diameter of the shaft 252 results in the formation of an annular space between itself and the inner surface 228. In other instances the oil reservoir may be formed by a capped or stoppered drilling in the wristpin 221.

**[0037]** With reference to FIG. 5B, pressurized oil is transported to the large end oil groove 212 in the manner illustrated by the transport path 80, 82, 84, 86 in FIG. 1. From the oil groove 212, pressurized oil is delivered to the oil reservoir 222 via the oil reservoir inlet passage 224. Pressurized oil received in the oil reservoir 222 is provided in multiple streams through the outlet passages 225 to the oiling grooves 227 whence it flows to lubricate the bearing interface between the bearing surface 220 and the wristpin 221.

**[0038]** In some aspects, but not necessarily, the bearing 217 may be constructed as a rocking journal bearing (also called a "biaxial" bearing). Such a bearing is described in the Applicant's US 13/776,656. In this case the bearing surface 220 comprises a plurality of axially-spaced, eccentrically-disposed surface segments and the wristpin 221 includes a corresponding plurality of axially-spaced, eccentrically-disposed wristpin segments. In such cases, the bearing surface 220 may have a semi-cylindrical configuration with two lateral surface segments sharing a first centerline and a central surface segment separating the two lateral surface segments and having a second centerline offset from

the first centerline. In such cases, the circumferential oiling grooves 227 are formed in the bearing surface 220 at the borders between the central surface segment and the lateral surface segments. In some instances, the outer surface of the wristpin 221 may have axially-spaced circumferential grooves 226 (best seen in FIG. 4) and one or more circumferentially-spaced axial oiling grooves (not seen) may also be formed in the bearing surface 220 to enhance the lubrication of the bearing interface.

Gallery Cooling:

**[0039]** As best seen in FIGS. 3, 4 and 5A, the undercrown 208 is cooled by flow of lubricating oil through one or more galleries internal to the crown 203. Preferably, the galleries comprise shaped spaces in the undercrown 208 with floors provided on the upper surface of the bearing support member 219a. For example, an annular gallery 256 follows the periphery of the crown 203 and girds a central gallery 257. The annular gallery 256 communicates with the central gallery 257 through holes 258. The annular gallery 256 has an asymmetric profile that rises as at 260 under the ridge 209. The central gallery 257 abuts the deepest part of the end surface 206. Lubricating oil for cooling the undercrown is provided to the galleries via a high velocity jet of pressurized oil. The jet strikes the interior surface of the annular gallery at its highest point 260, thereby cooling that portion of the undercrown 208 beneath the ridge 209 by impingement. The oil carried by the jet flows from there throughout the annular gallery 256. From the annular gallery 256, the lubricating oil flows into the central gallery 257 where it continuously irrigates the central portion of the undercrown along the inside of the ridge 209. Lubricating oil flowing throughout the annular gallery 256 washes and cools an annular portion of the undercrown 208 that abuts the lands and ring grooves 207. Reciprocation of the piston agitates the oil, which causes it to circulate in the annular gallery 256. In response to the agitation and piston motion, oil also flows from the annular gallery 256 into the central gallery 257. Piston reciprocation also agitates the oil collected or accumulated in the central gallery 257 so as to cool the undercrown 208 beneath the central portion of the end surface 206. The oil flows from the bottom of central gallery 257 via one or more passages in the bearing structure into the interior of the skirt 205. From there, the oil flows out the open end of the skirt 205.

**[0040]** In the prior art gallery cooling constructions described in the Applicant's US 2012/0073526 A1, the lubricating oil jets for cooling the undercrown are provided to the piston galleries from nozzles that are separate from, external to, and fixed with respect

to, the pistons. In the embodiments to be described, the oil jets are delivered from elements of the pistons themselves and are fed from oil reservoirs in the piston bearings.

Cooling Jet Constructions:

**[0041]** With regard to the piston lubrication constructions thus far described, the pressurized oil delivered to a bearing oil reservoir for lubrication may at the same time be used for undercrown cooling in an opposed-piston engine. In some aspects, pressurized oil obtained from a bearing oil reservoir is provided in the form of a high velocity stream or jet for cooling a piston undercrown. Hereinafter such a jet is referred to as a "cooling jet", for convenience and clarity. A cooling jet is provided from a cooling jet outlet that is in fluid communication with the bearing oil reservoir. At least one cooling jet constituted of received, pressurized lubricating oil is provided from each piston bearing so as to cool a portion of the undercrown by impingement. Jetted oil flows from the undercrown portion into the piston cooling galleries so as to provide a constant replenishment of coolant with which to cool the rest of the undercrown by irrigation. A cooling jet may be stationary, or it may be swept in an oscillating motion.

**[0042]** FIGS. 4, 5A, and 5B illustrate two cooling jet embodiments. Although both embodiments are shown together in one or more of the figures, this is for convenience and clarity. In fact the embodiments are proposed as alternatives. That is to say a piston may be equipped with one or the other, as required by design considerations and cost.

First Embodiment:

**[0043]** Continuing with the exemplary piston construction shown in FIGS. 4 and 5A, a first cooling jet outlet embodiment is constituted of a passage 270 drilled or formed in the bearing support member 219a. One end of the passage 270 is in fluid communication with the oil reservoir 222 via an oiling groove 227. When pressurized oil received in the reservoir enters the oiling grooves 227, a portion of it flows into the passage 270 whence it is emitted in the form of a coolant jet 272. The passage 270 is located and oriented so as to be aimed at the undercrown portion 260. As a result, the coolant jet 272 is directed toward the hot spot in the crown 203 that is associated with the ridge 209. As should be evident with regard to the figures, the bearing support member 219a is fixed to the undercrown. Lacking relative movement between the member 219a and the undercrown 208, the jet 272 is stationary with respect to the undercrown 208.

Second Embodiment:

**[0044]** An alternative coolant jet outlet is best seen in FIGS. 4 and 5B, where a nozzle 278 is mounted to the wristpin 221 so as to be in fluid communication with the reservoir 222 by way of an oil outlet 280. In the illustrated example, the oil outlet 280 is formed in the flange 252, and the nozzle 278 is mounted thereto by an elbow joint 281 received in the oil outlet. The nozzle 278 extends into the annular gallery 256, aimed toward the undercrown portion 260. Pressurized oil received in the reservoir 222 flows into the nozzle through the oil outlet 280 and the elbow joint 281. From the nozzle 278, the pressurized oil is emitted in the form of a coolant jet 284. As should be evident with regard to the figures, the wristpin 221 undergoes oscillatory movement relative to the undercrown 208. As a result, the coolant jet 284 is swept to and fro across the undercrown portion 260.

Second Piston Construction:

**[0045]** In some aspects, it may be desirable to provide more than one cooling jet to the undercrown of a piston with an end surface construction having a more complex contour than that of the piston of FIG. 2. For example, the first combustion chamber construction for an opposed-piston engine described and illustrated in the Applicant's WO2012/158756 includes a piston end surface with two opposing ridges, each with an associated hot spot. Such a piston is shown in FIG. 6, in which the piston 300 has a crown 303 with an end surface 306 and an undercrown 308. The end surface includes an elongated cleft 307 extending in a diametrical direction of the piston 300, defined between opposing ridges 309. As best seen in FIGS. 7A and 7B, the undercrown 308 includes annular and central cooling galleries and the piston includes a bearing structure identical to that of the bearing 217, except that the first and second cooling jet embodiments include two jet outlets each, with each cooling jet outlet aimed at a respective hot spot portion of the undercrown.

Central Gallery Cooling:

**[0046]** Referring to FIGS. 3 and 8, in some aspects, it may be desirable to cool the undercrown 208 of the piston 200 by flow of lubricating oil to and through the central gallery 257. In such cases, a cooling jet outlet embodiment is constituted of a passage 275 drilled or formed in the bearing support member 219a. One end of the passage 275 is in fluid communication with the oil reservoir via an oiling groove 227. When

pressurized oil received in the reservoir enters the oiling grooves 227, a portion of it flows into the passage 275 whence it is emitted in the form of a coolant jet. The passage 275 is located and oriented so as to be aimed at the central gallery 257. As a result, the coolant jet is directed toward a portion of the crown 203 that is associated with the deepest portion of the bowl 214. Lacking relative movement between the member 219a and the undercrown 208, the jet emitted from the passage is stationary with respect to the undercrown 208. In some aspects it may be desirable to direct more than one coolant jet into the central gallery 257; this is provided by the second passage 275 indicated by the dotted line in FIG. 8. With reference to FIGS. 6 and 7A, it should be evident that the same provisions may be made to the piston 300 so as to enable one or more cooling jets of lubricating oil to be injected into the central cooling gallery of the crown 303, which would deliver liquid coolant to the part of the undersurface that underlies the deepest portion of the cleft 307.

Method of Operating an Opposed-Piston Engine:

**[0047]** With reference to the figures, an opposed-piston engine such as the engine 49 includes at least one cylinder 50 and a pair of pistons 200 equipped with bearing constructions as described herein. The pistons are disposed in opposition to one another in a bore 52 of the cylinder, and each piston is connected to a respective connecting rod 210 by a bearing 217. The engine is operated by a method that includes providing a flow of pressurized oil to each bearing 217. The flow of pressurized oil to each bearing 217 is received in a wristpin 222 of the bearing. In response to pressurized oil in the wristpins, multiple streams of the received, pressurized oil from each wristpin are provided to lubricate a respective bearing interface, and at least one jet of the received, pressurized oil is provided from one of a fixed part and a moving part of each bearing, in which each jet is aimed at a respective piston undercrown portion. In the method, the flow of pressurized oil is received in an oil reservoir in the wristpin. In the method, providing a jet from a moving part of each bearing includes providing the jet from a wristpin. In the method, providing a jet from a moving part of each bearing includes sweeping the jet across the respective piston undercrown portion.

**[0048]** The cooling construction embodiments that are described herein, and the devices and methods with which they are implemented, are illustrative and are not intended to be limiting.

## CLAIMS

1. A piston cooling configuration for an opposed-piston engine, comprising:
  - a piston (200, 300) with crown (203, 303) having an end surface (206, 306) shaped to form a combustion chamber with an end surface of an opposing piston;
  - the crown including an undercrown (208, 308);
  - a bearing (217) mounted in the piston between the undercrown and a small end (215) of a connecting rod (210);
  - the bearing including a wristpin (221);
  - an oil reservoir (222) in the wristpin in fluid communication with one or more wristpin oil outlet passages (225) positioned to pass oil through the wristpin into a lubrication interface between the wristpin and a bearing surface;
  - a wristpin oil inlet passage (224) in fluid communication with the reservoir; and,
  - at least one cooling jet outlet (270, 275, 278) on one of a fixed part (219a) of the bearing and a moving part (221) of the bearing;
  - in which the cooling jet outlet is in fluid communication with the oil reservoir and is aimed toward an undercrown portion.
2. The piston cooling configuration of claim 1, in which the wristpin is received on the small end of the connecting rod.
3. The piston cooling configuration of claim 2, in which:
  - the fixed part of the bearing includes a bearing member supporting the wristpin for rotatable oscillation with respect to the undercrown in response to movement of the piston; and,
  - the cooling jet outlet includes an oil outlet passage in the bearing member.
4. The piston cooling configuration of claim 3, in which:
  - the connecting rod includes an oil passage in fluid communication with the wristpin oil inlet passage; and,
  - the oil outlet passage in the bearing member receives pressurized oil from the interface between the wristpin and the bearing surface
5. The piston cooling configuration of claim 4, in which the wristpin and the bearing surface form a rocking bearing.

6. The piston cooling configuration of claim 4, in which the wristpin and the bearing surface form a biaxial bearing.
7. The piston cooling configuration of claim 2, in which:
  - the moving part of the bearing includes the wristpin, which rotatably oscillates with respect to the undercrown in response to movement of the piston; and,
  - the cooling jet outlet includes a nozzle mounted to the wristpin.
8. The piston cooling configuration of claim 7, in which the connecting rod includes an oil passage in fluid communication with the wristpin oil inlet passage.
9. The piston cooling configuration of claim 8, in which the wristpin and the bearing surface form a rocking bearing or a biaxial bearing.
10. An opposed-piston engine including at least one cylinder with longitudinally-separated exhaust and intake ports, a pair of pistons disposed in opposition to one another in a bore of the cylinder, and a pair of connecting rods, in which each piston is coupled to a respective connecting rod by a bearing, and at least one piston includes a piston cooling configuration according to any one of claims 1-9.
11. A method for operating an opposed-piston engine according to claim 11, including:
  - providing a flow of pressurized oil to a wristpin of a bearing;
  - receiving the flow of pressurized oil in the wristpin;
  - providing multiple streams of the received, pressurized oil from the wristpin to lubricate a bearing interface; and,
  - providing at least one jet of the received, pressurized oil from one of a fixed part and a moving part of the bearing, the jet being aimed at a respective piston undercrown portion.
12. The method of claim 11, wherein receiving includes receiving the flow of pressurized oil in an oil reservoir in the wristpin.

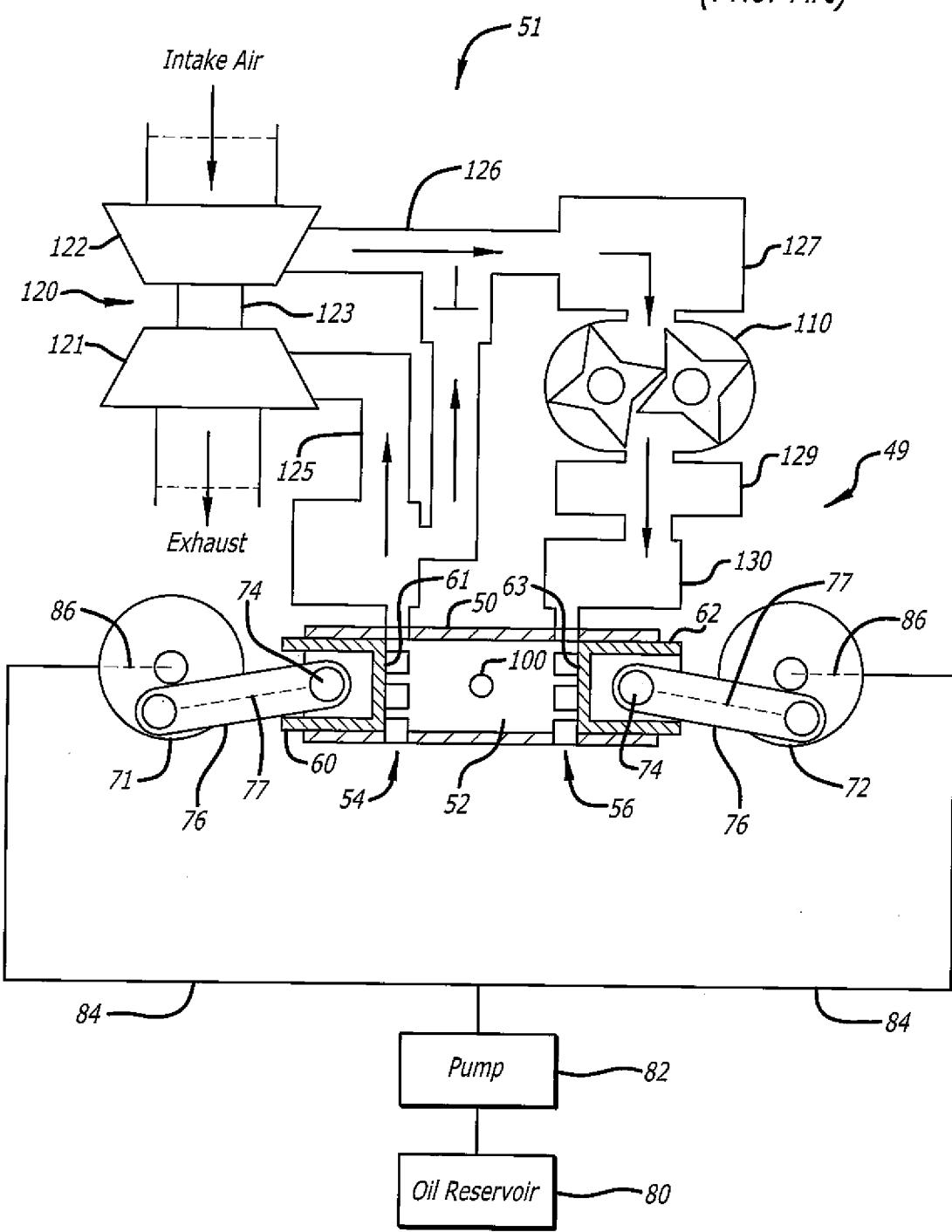
13. The method of claim 12, wherein providing a jet from a moving part of the bearing includes providing the jet from the wristpin.

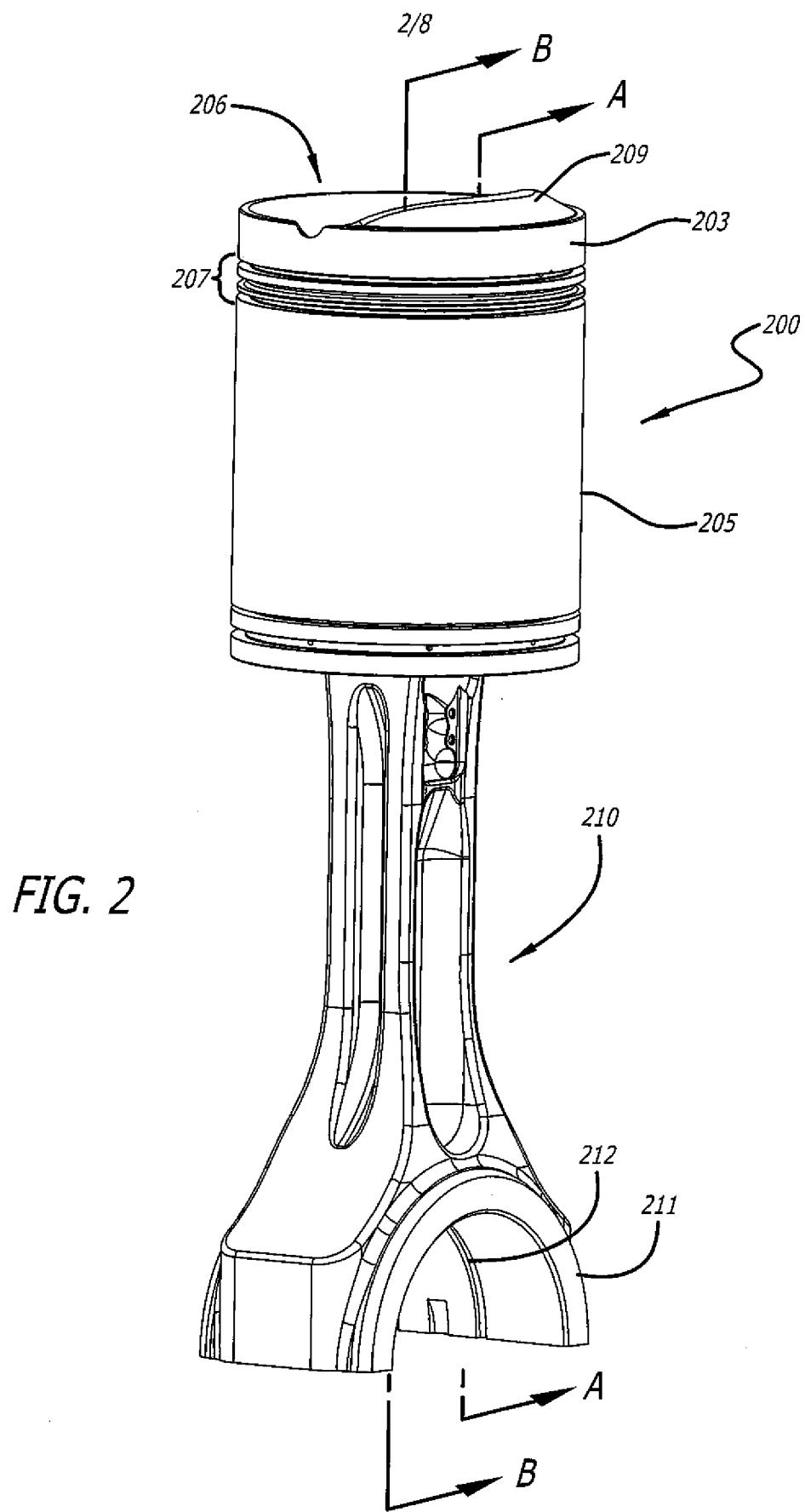
14. The method of claim 12, wherein providing a jet from a moving part of the bearing includes sweeping the jet across the respective piston undercrown portion.

15. The method of claim 12, wherein providing a jet from a fixed part of the bearing includes providing the jet from a passageway formed in the fixed part.

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*FIG. 1*  
(Prior Art)





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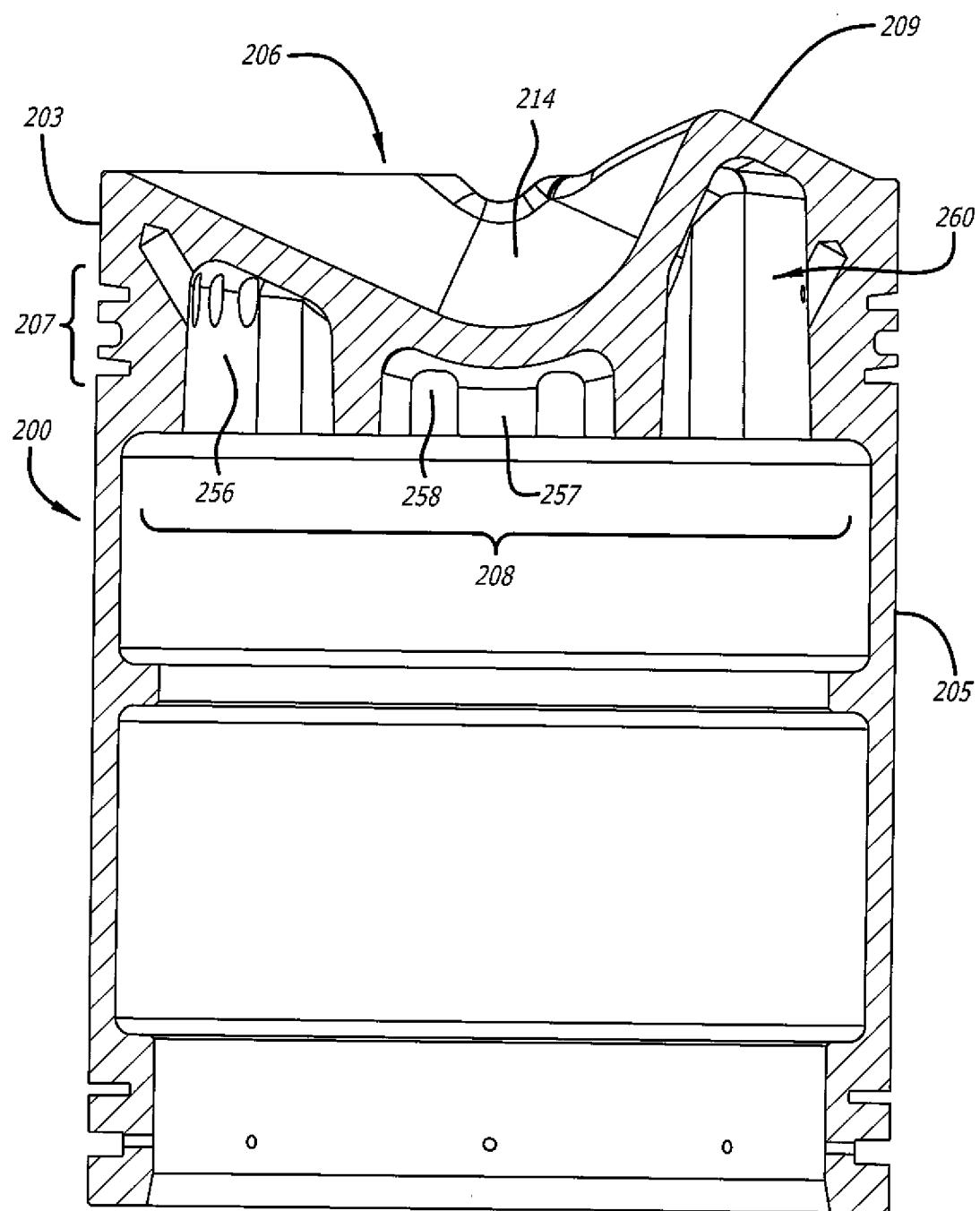
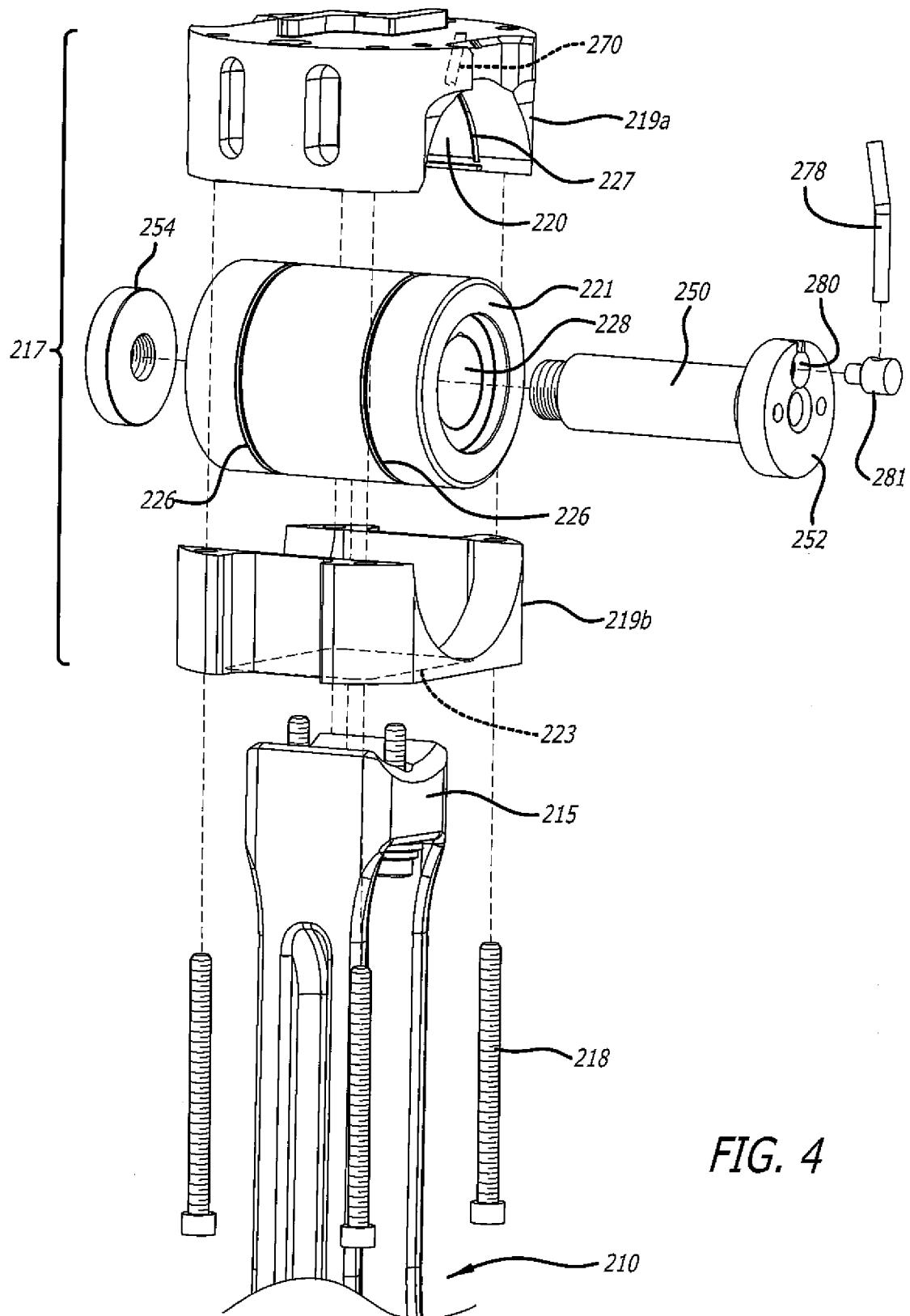
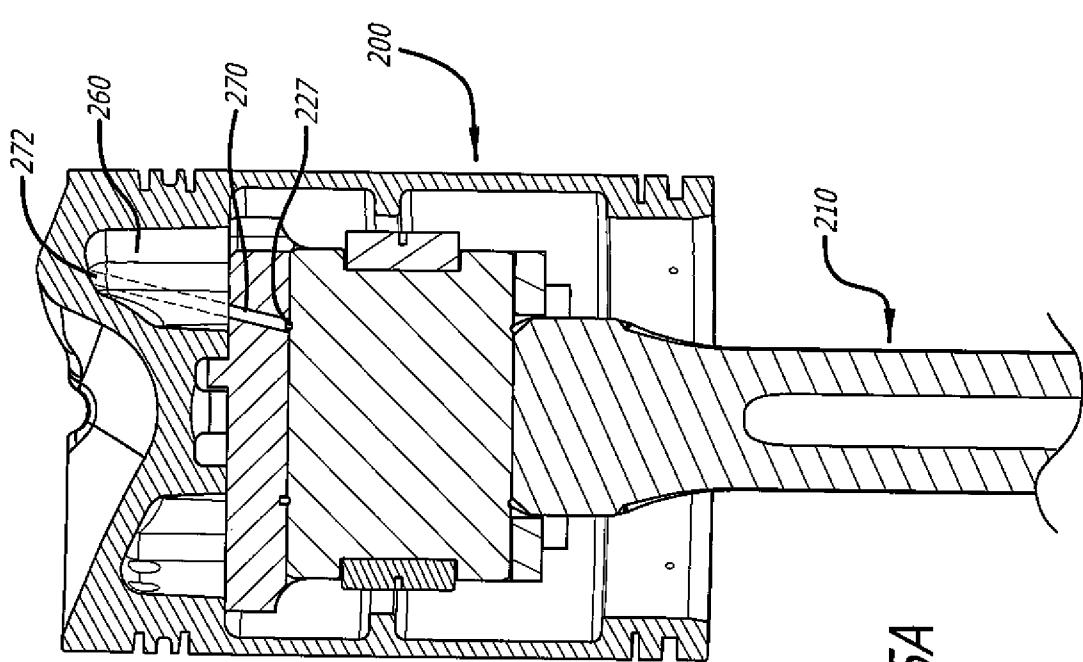
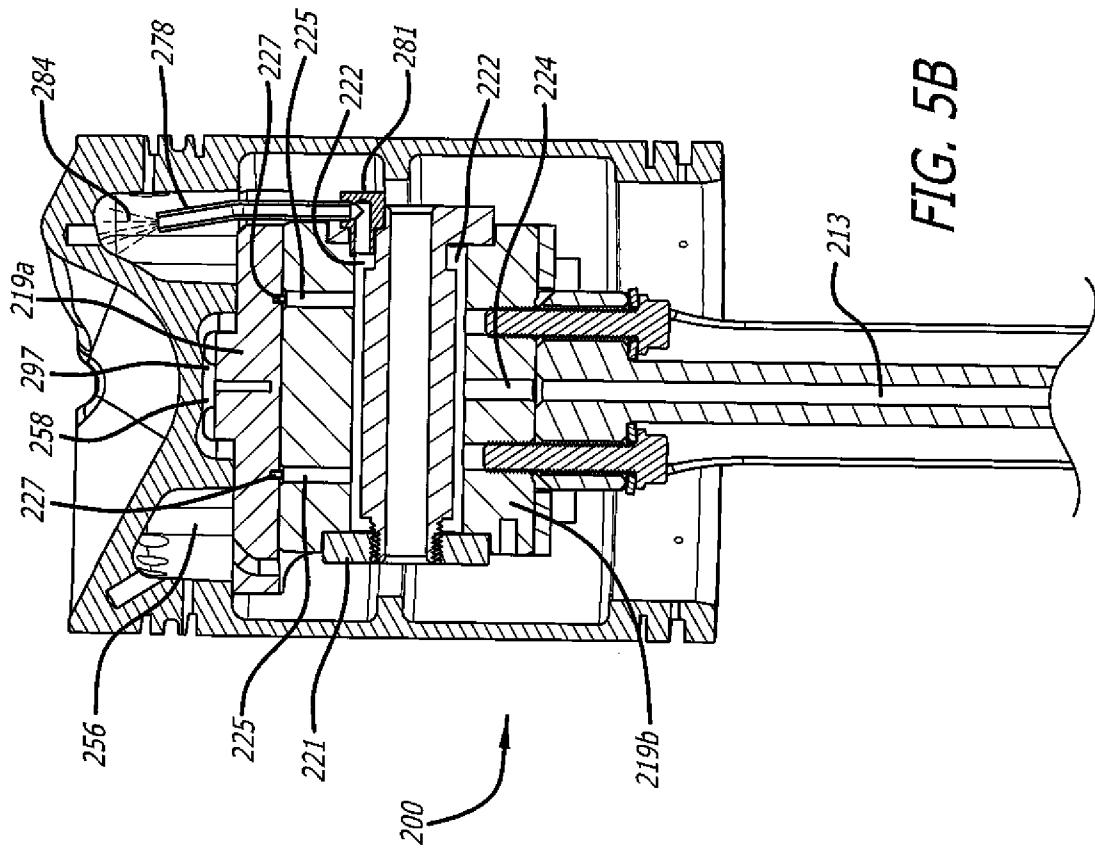


FIG. 3

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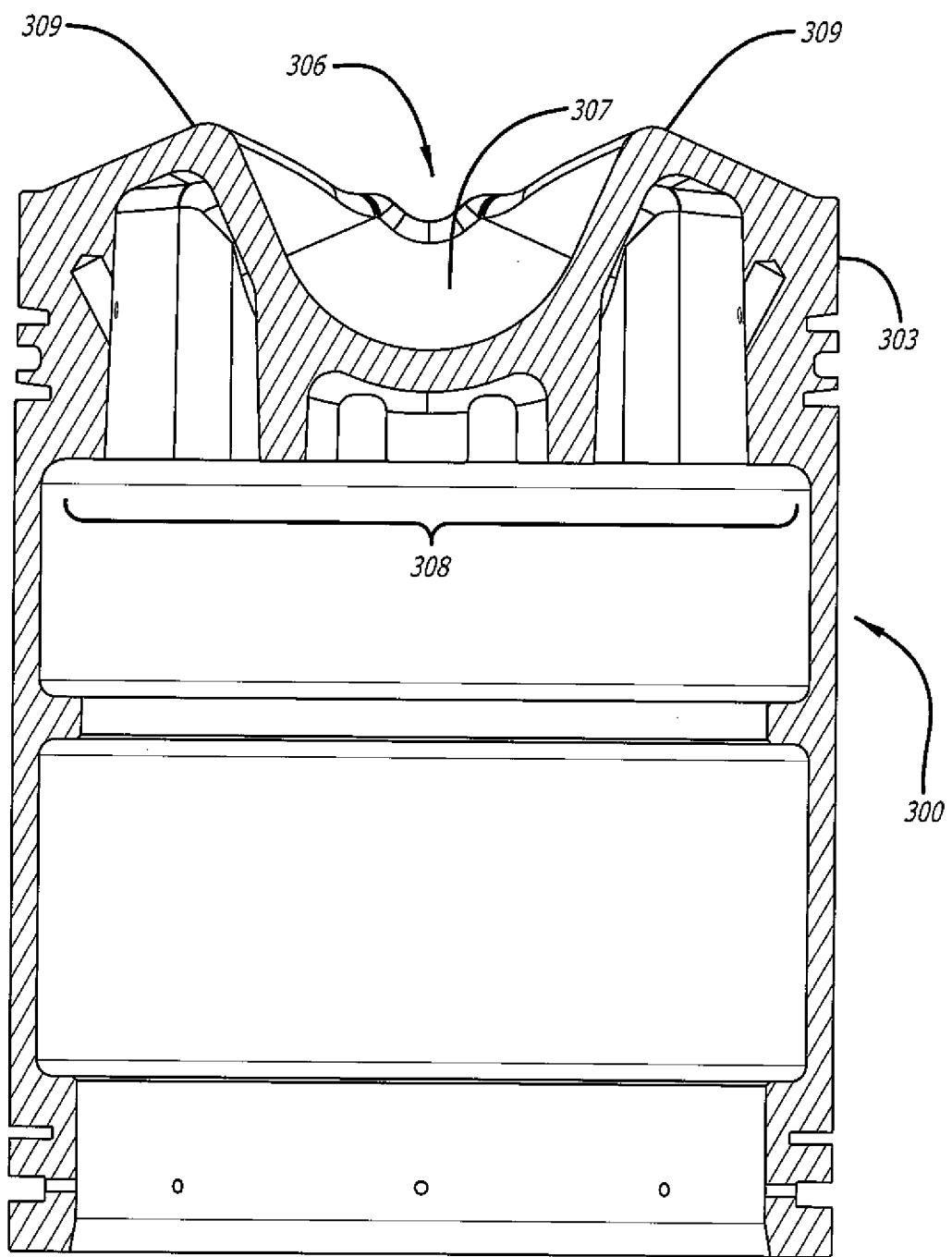


FIG. 6

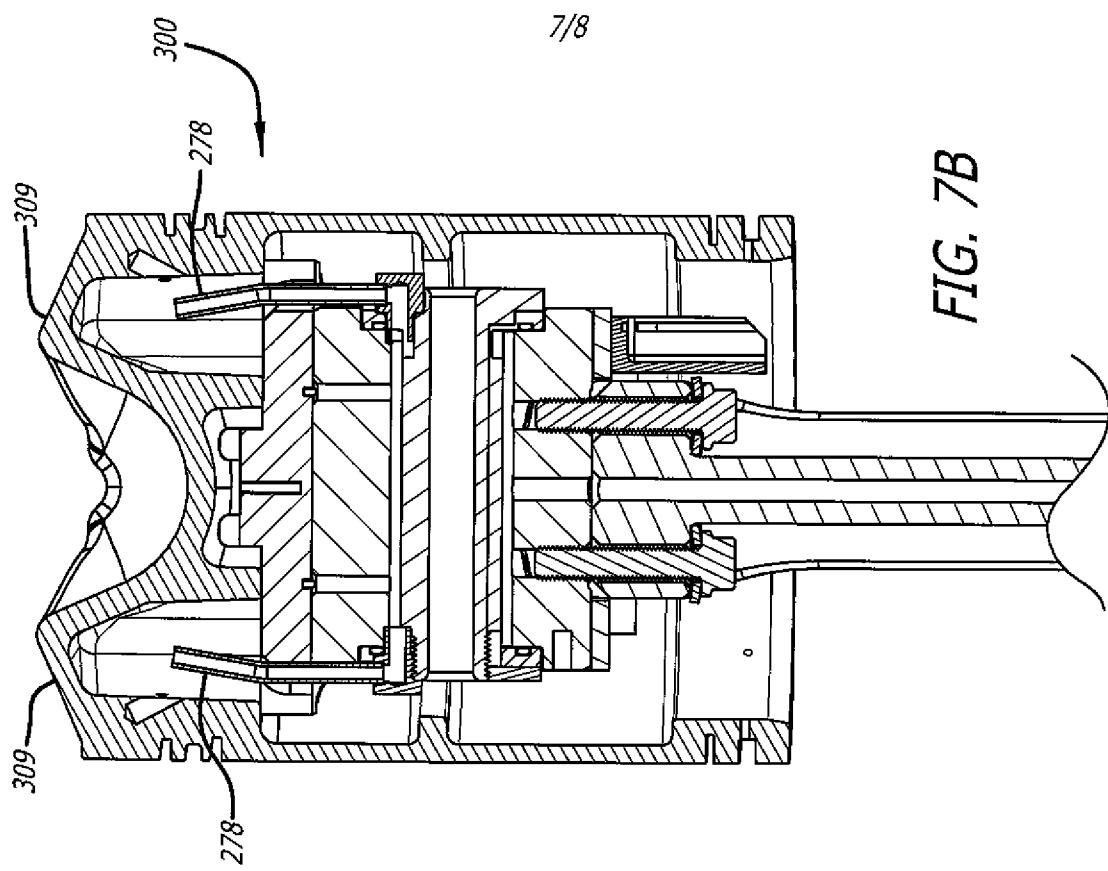


FIG. 7B

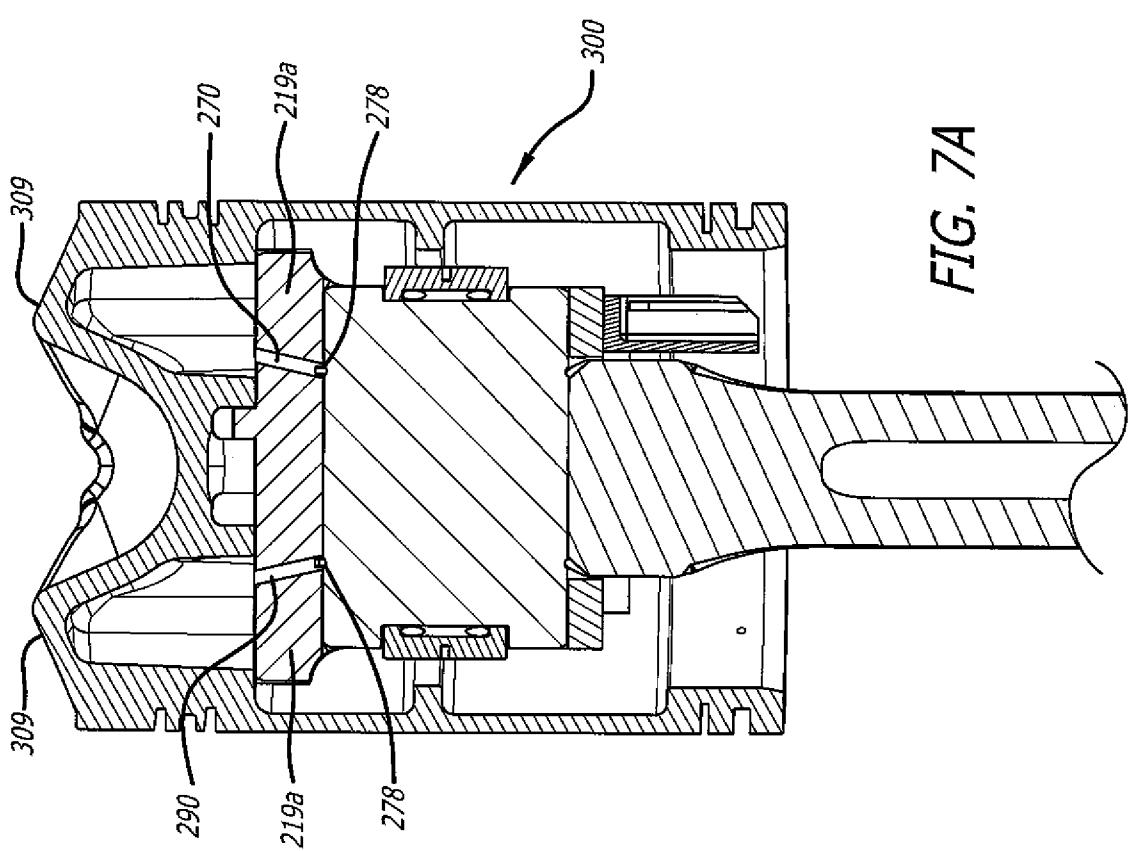


FIG. 7A

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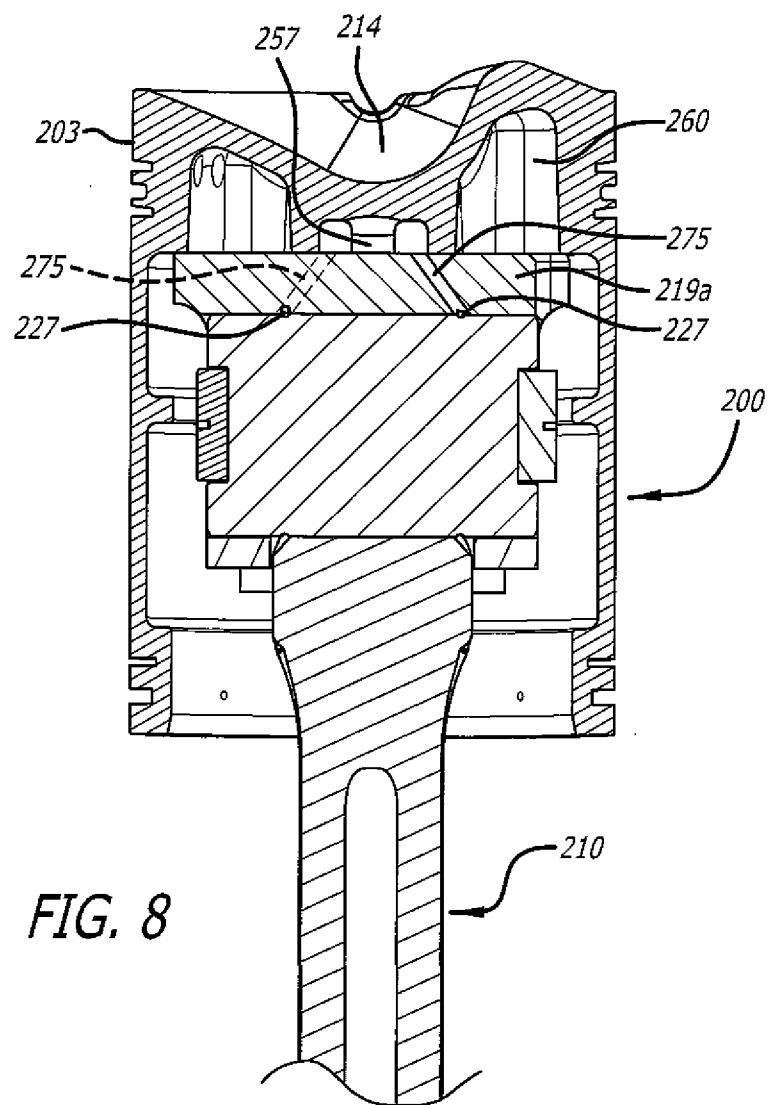


FIG. 8

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2015/019028

**A. CLASSIFICATION OF SUBJECT MATTER**  
INV. F02F3/22 F01M1/06 F01M1/08 F16J1/16  
ADD.

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
F02F F01M F16J F02B

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

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

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2 236 401 A (GEHRES HEWITT A) 25 March 1941 (1941-03-25)	1-6
Y	page 2, column 1, lines 50-58 -----	10-12,15
Y	US 3 023 743 A (SCHAUER JR GEORGE A) 6 March 1962 (1962-03-06)	10-15
A	abstract figures -----	1
X	JP H03 77052 U (-) 1 August 1991 (1991-08-01)	1,2,7-9
Y	figure 7 -----	10-14
X	US 2008/295683 A1 (WAGNER JAY T [US]) 4 December 2008 (2008-12-04)	1-6
Y	figures ----- -/-	10-12,15

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See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 May 2015	13/05/2015
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Matray, J

**INTERNATIONAL SEARCH REPORT**

International application No
PCT/US2015/019028

**C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 363 293 A (MUNOZ BERNARD ET AL) 14 December 1982 (1982-12-14) abstract figures -----	1-6
Y		10-12,15

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/US2015/019028
---

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2236401	A 25-03-1941	NONE	
US 3023743	A 06-03-1962	NONE	
JP H0377052	U 01-08-1991	NONE	
US 2008295683	A1 04-12-2008	NONE	
US 4363293	A 14-12-1982	AU 6991081 A 03-12-1981 BR 8103244 A 16-02-1982 CS 244413 B2 17-07-1986 DD 159190 A5 23-02-1983 DE 3164126 D1 19-07-1984 DK 237881 A 01-12-1981 EP 0041416 A1 09-12-1981 ES 8202913 A1 16-05-1982 FI 811624 A 01-12-1981 FR 2483521 A1 04-12-1981 IN 155862 A1 16-03-1985 JP S5720536 A 03-02-1982 NO 811816 A 01-12-1981 PL 231374 A1 23-12-1981 SU 1102490 A3 07-07-1984 US 4363293 A 14-12-1982 YU 137681 A 31-10-1983	