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Arumugam

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(54) LUBRICATION SYSTEM FOR A PIN JOINT OF AN ENGINE PISTON, AN ENGINE PISTON, AND A METHOD OF LUBRICATING A PIN JOINT OF AN ENGINE PISTON

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F01M 1/08 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F02F 3/22*** (2013.01); ***F01M 1/08*** (2013.01); ***F01M 1/16*** (2013.01); ***F01P 3/10*** (2013.01); *F01M 2001/086* (2013.01)

(58) **Field of Classification Search**
CPC F02F 3/22; F01P 3/10; F16J 1/08; F16J 1/16; F01M 1/08; F01M 2001/086; F01M 2011/025
See application file for complete search history.

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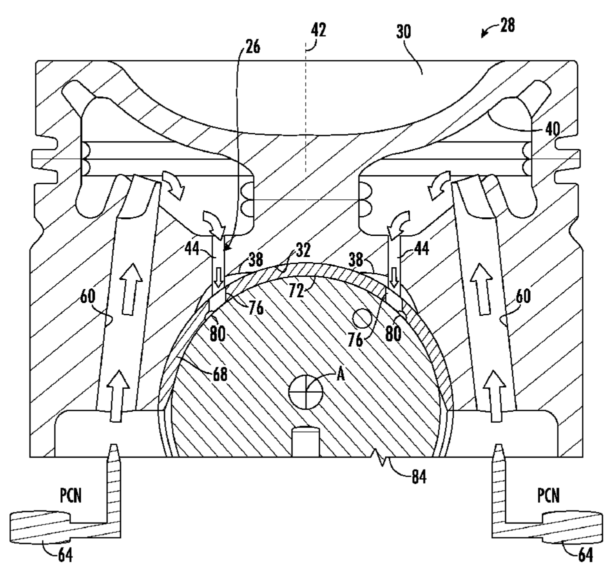
(57) **ABSTRACT**

Systems and apparatuses include a lubrication system having an engine piston defining a gudgeon pin aperture, a piston pooling cavity extending radially outward from the gudgeon pin aperture, a piston cooling gallery, and a piston lubrication passage. The piston lubrication passage is in fluid communication with the piston cooling gallery and the piston pooling cavity. The piston further includes a pin journal received in the gudgeon pin aperture of the engine piston and defining a journal aperture in fluid communication with the piston pooling cavity and a journal pooling cavity in fluid communication with the journal aperture. A gudgeon pin is received within the gudgeon pin aperture adjacent the pin journal, which provides fluid communication between the journal pooling cavity and the gudgeon pin.

19 Claims, 13 Drawing Sheets



(51) **Int. Cl.**
F01M 1/16 (2006.01)
F01P 3/10 (2006.01)

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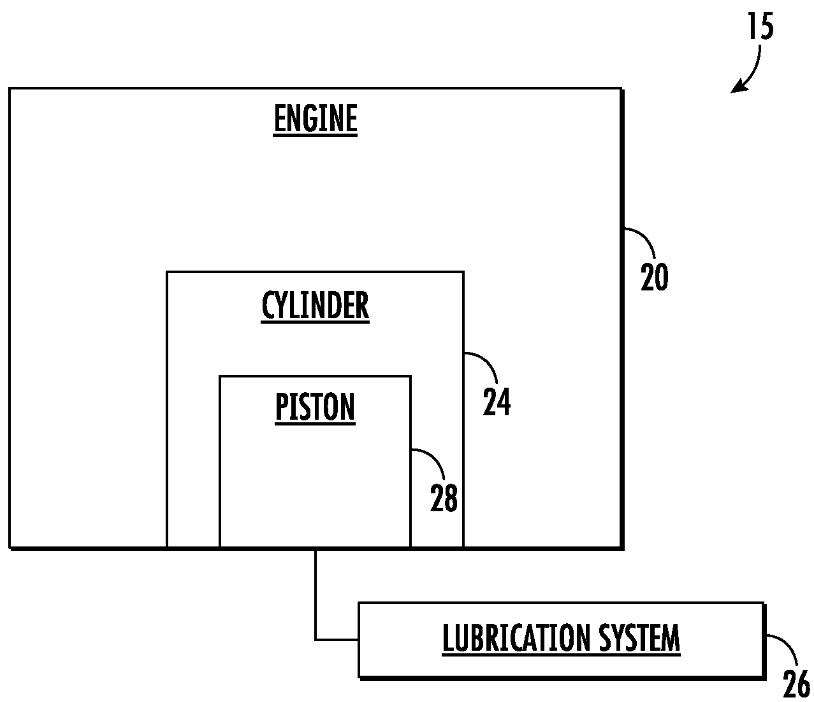

FIG. 1

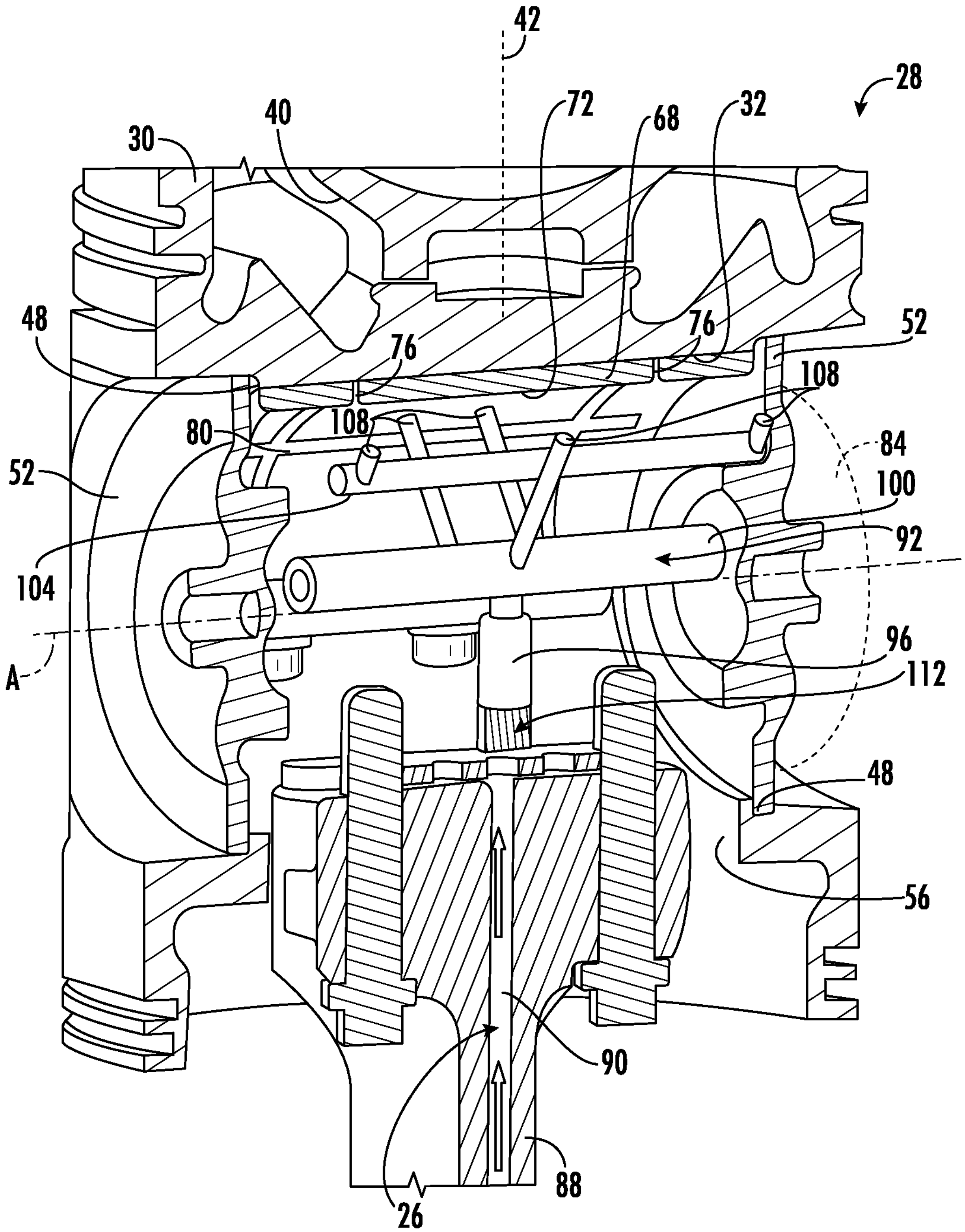
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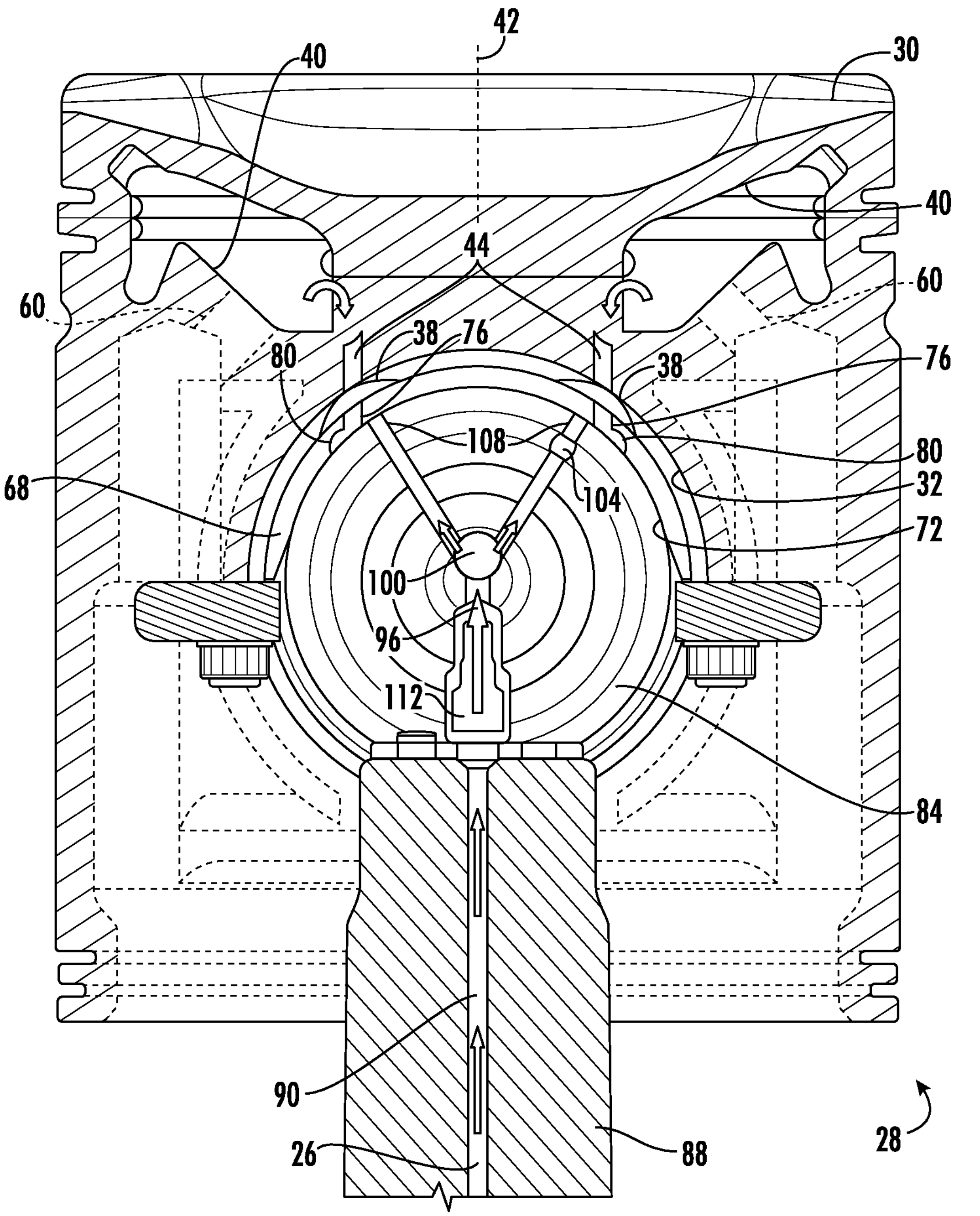
FIG. 2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28

FIG. 3

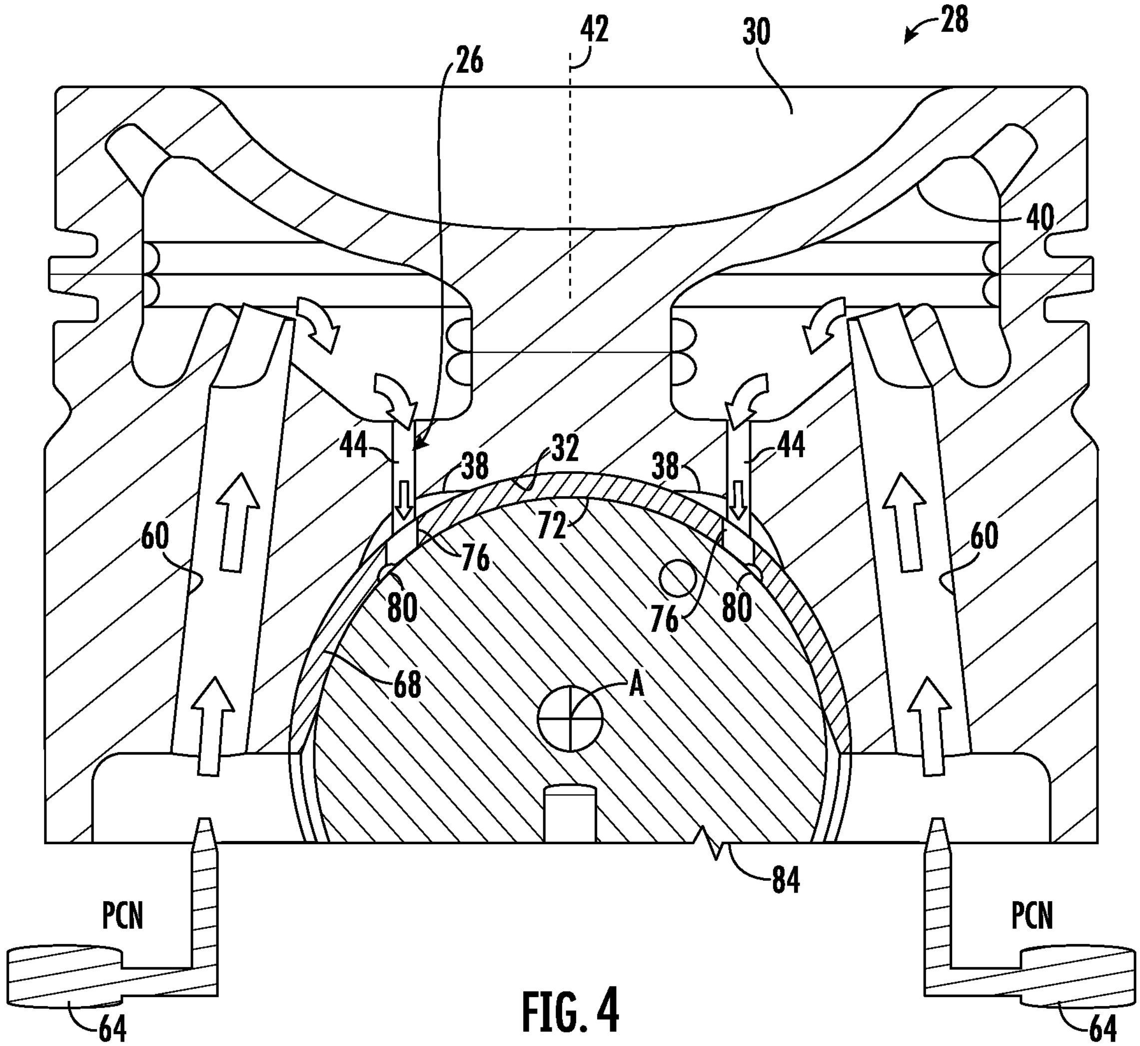

FIG. 4

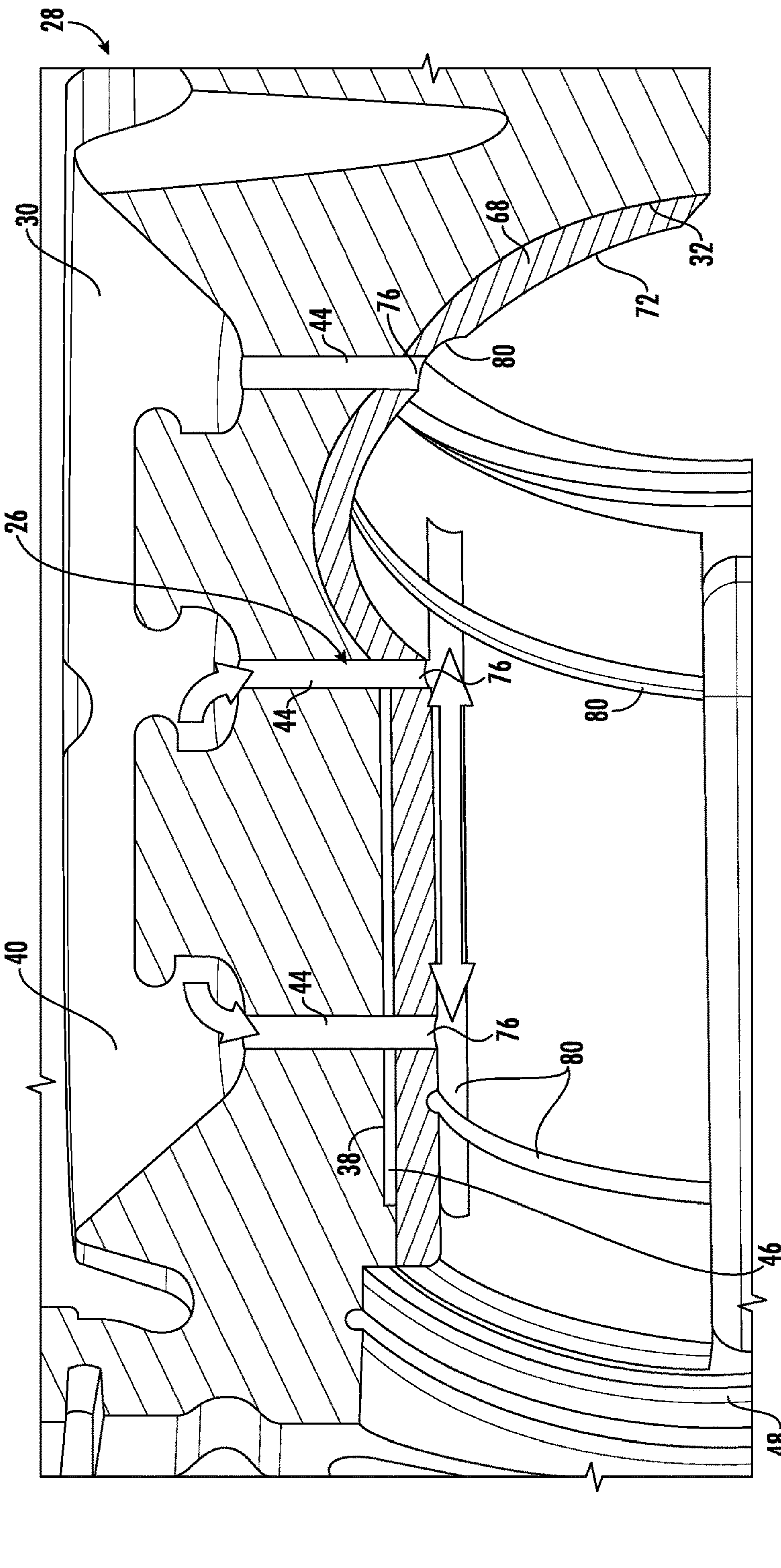

FIG. 5

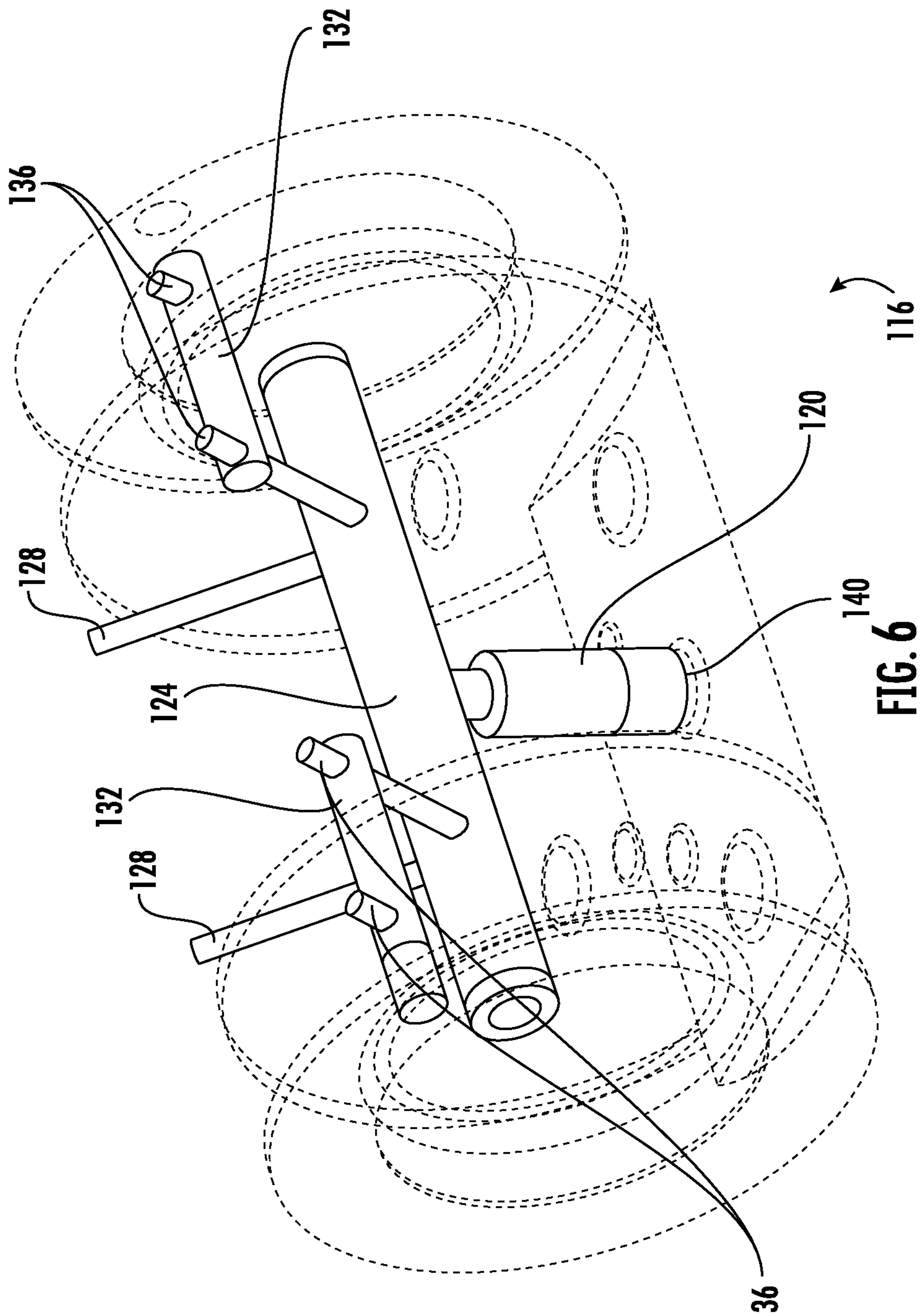

FIG. 6

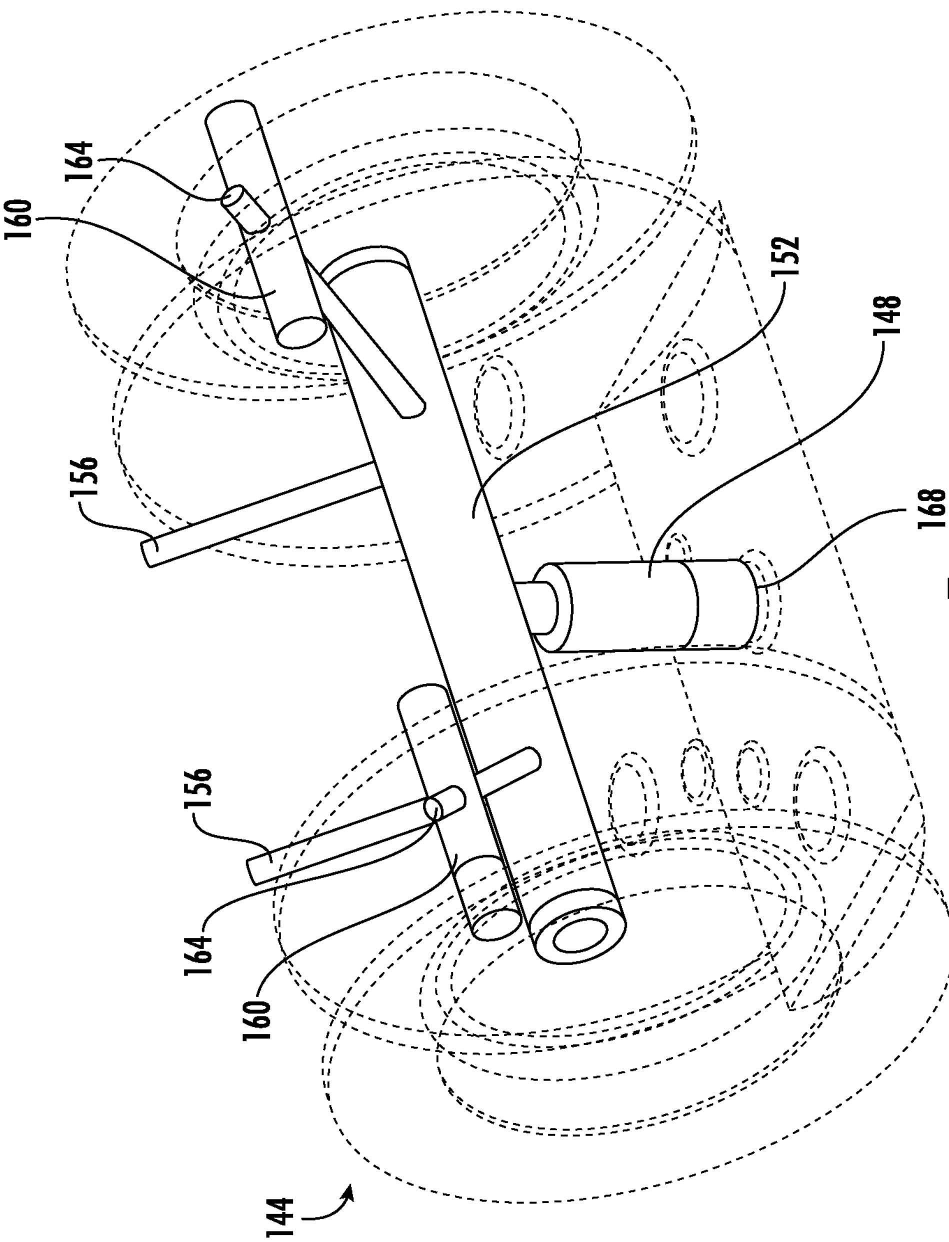

FIG. 7

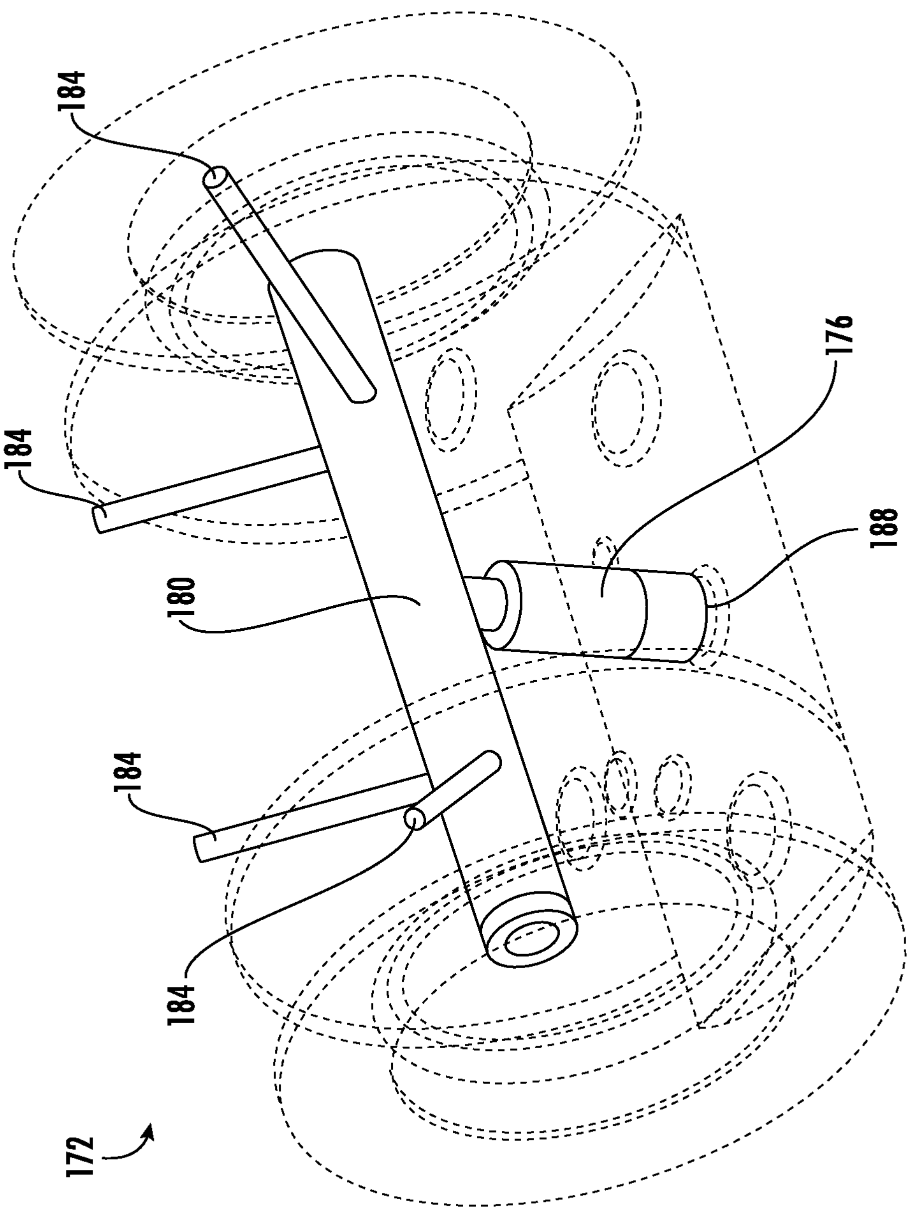

FIG. 8

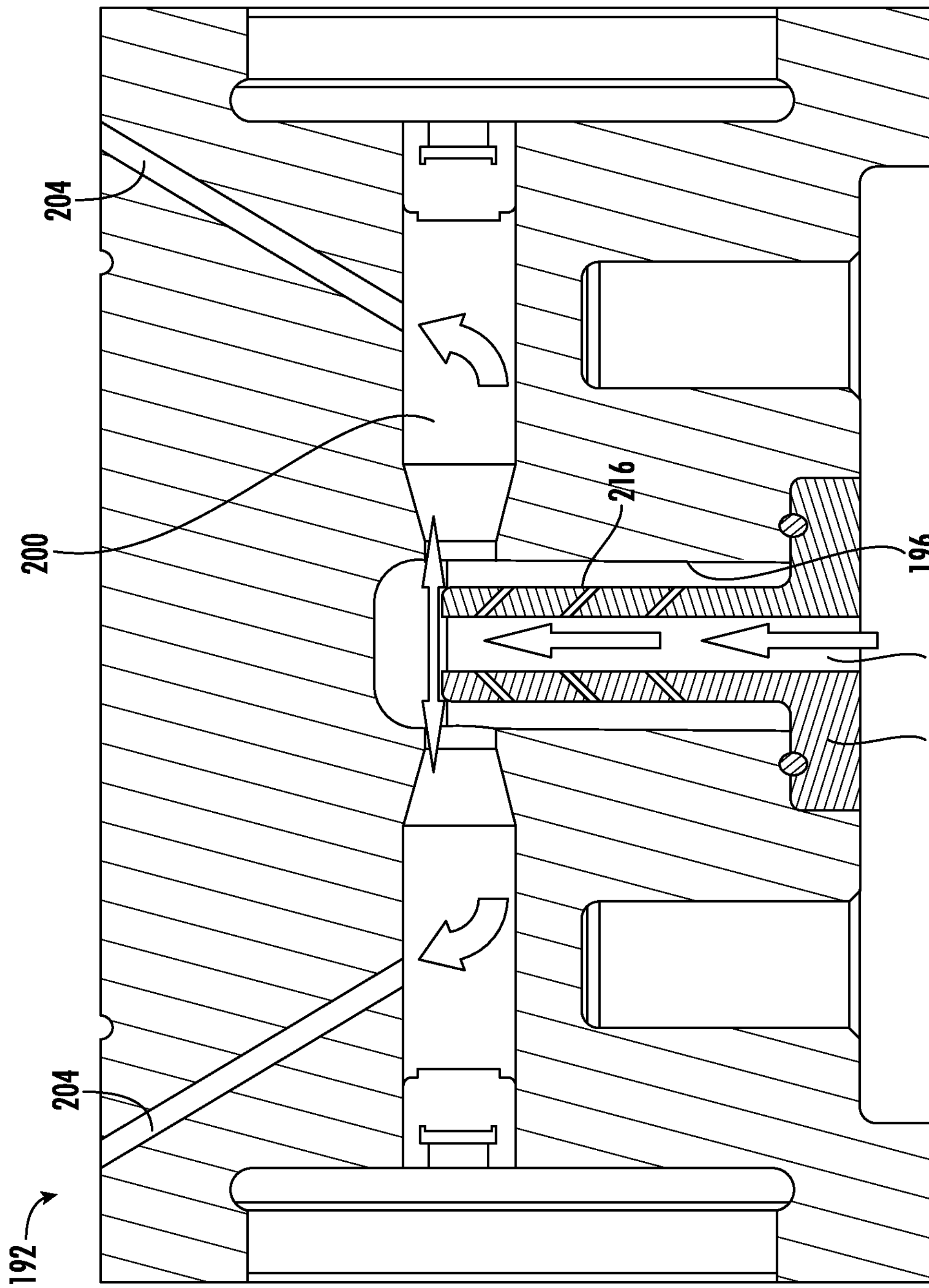

FIG. 9

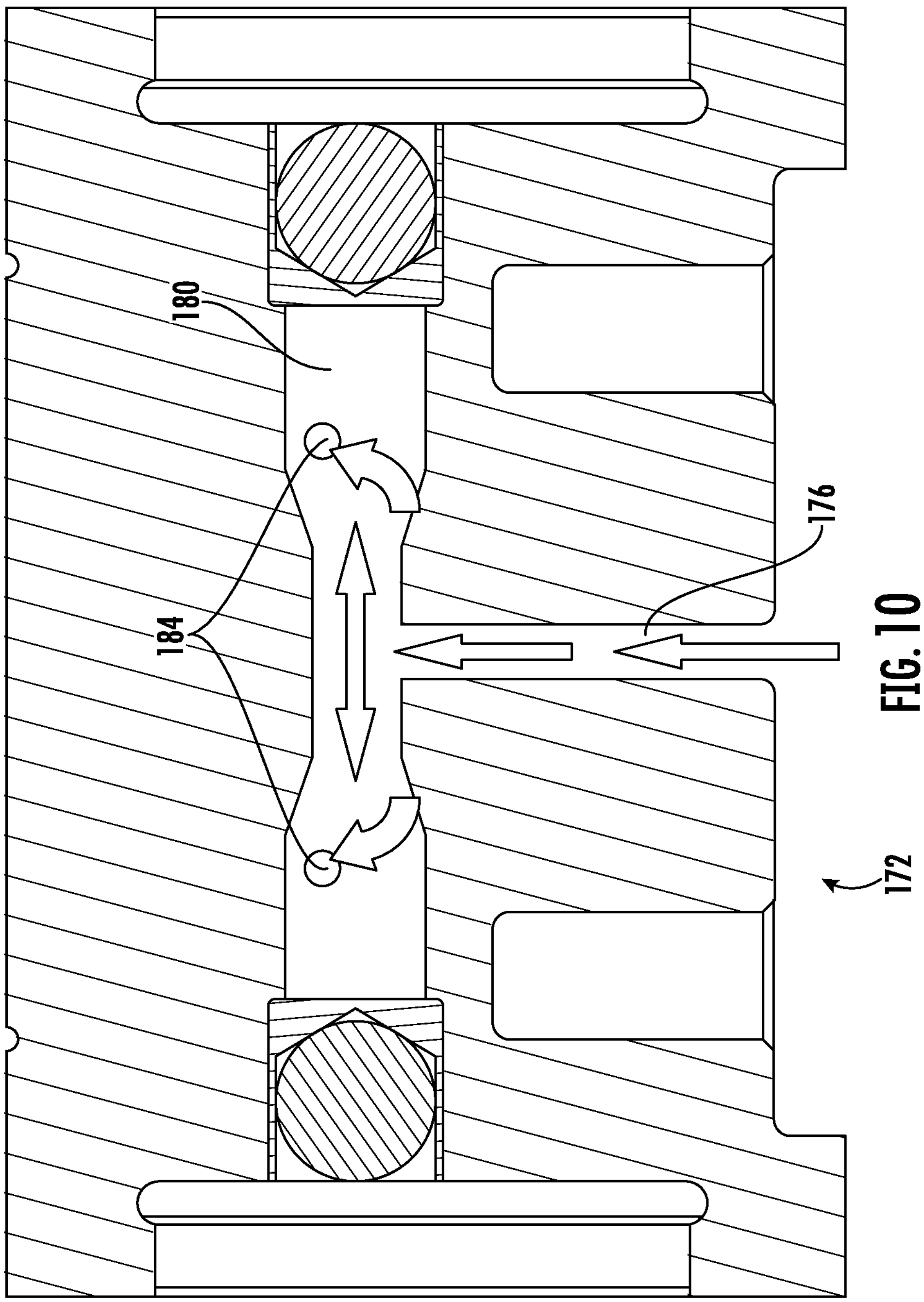

FIG. 10

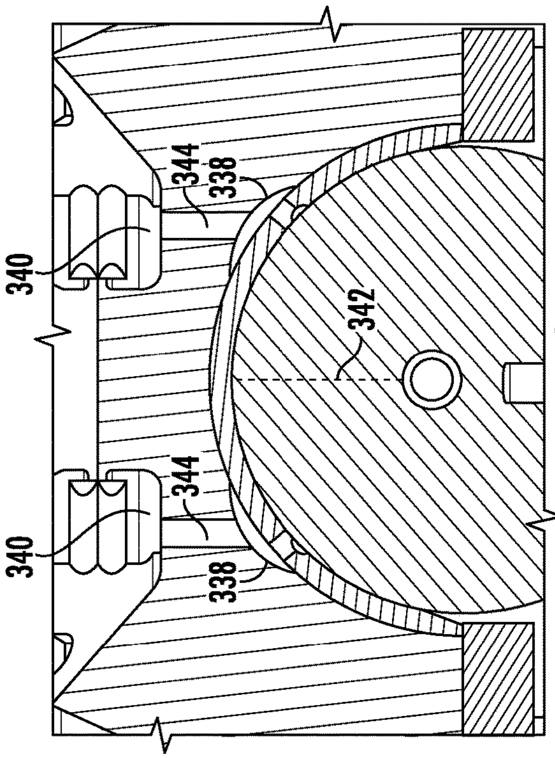

FIG. 12

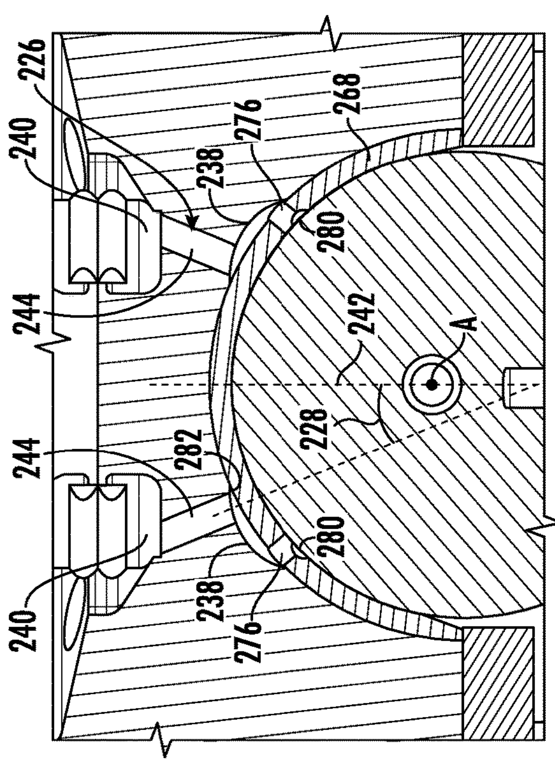

FIG. 11

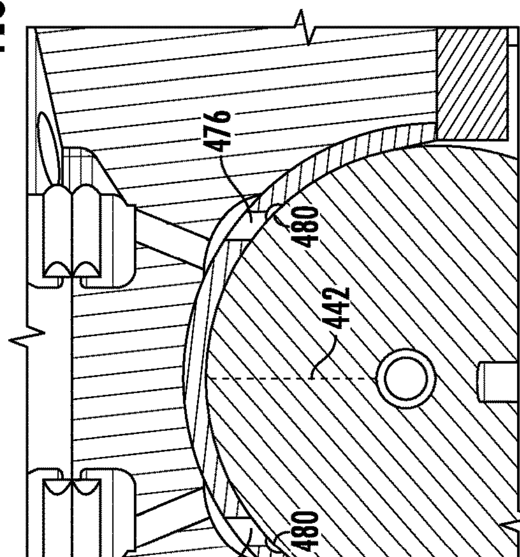

FIG. 13

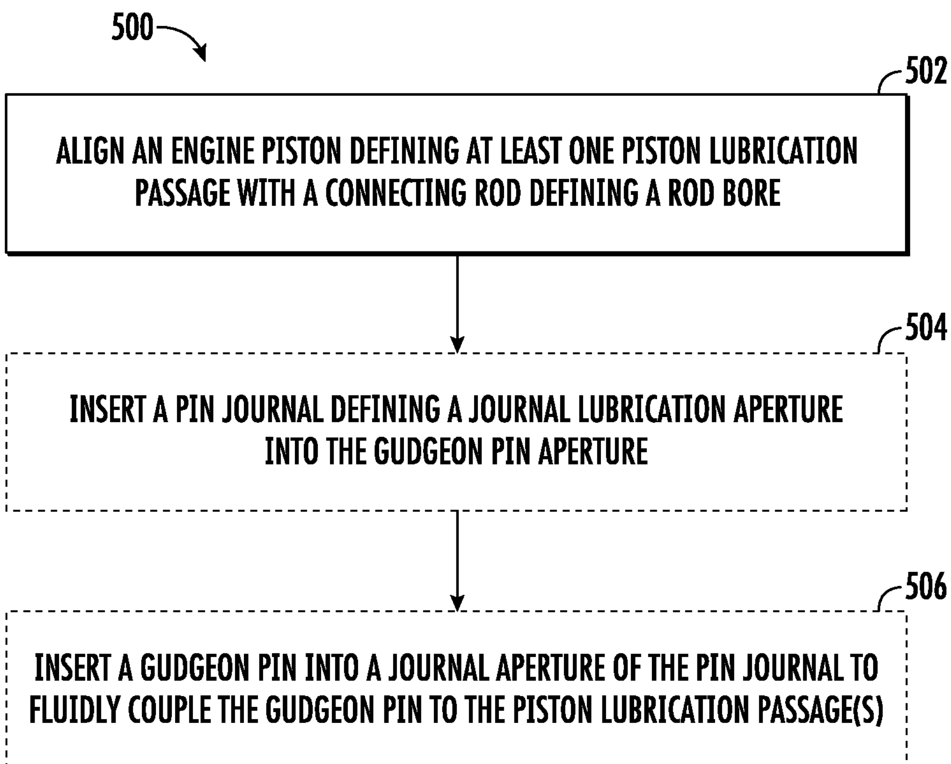
500
502
ALIGN AN ENGINE PISTON DEFINING AT LEAST ONE PISTON LUBRICATION PASSAGE WITH A CONNECTING ROD DEFINING A ROD BORE
504
INSERT A PIN JOURNAL DEFINING A JOURNAL LUBRICATION APERTURE INTO THE GUDGEON PIN APERTURE
506
INSERT A GUDGEON PIN INTO A JOURNAL APERTURE OF THE PIN JOURNAL TO FLUIDLY COUPLE THE GUDGEON PIN TO THE PISTON LUBRICATION PASSAGE(S)

FIG. 14

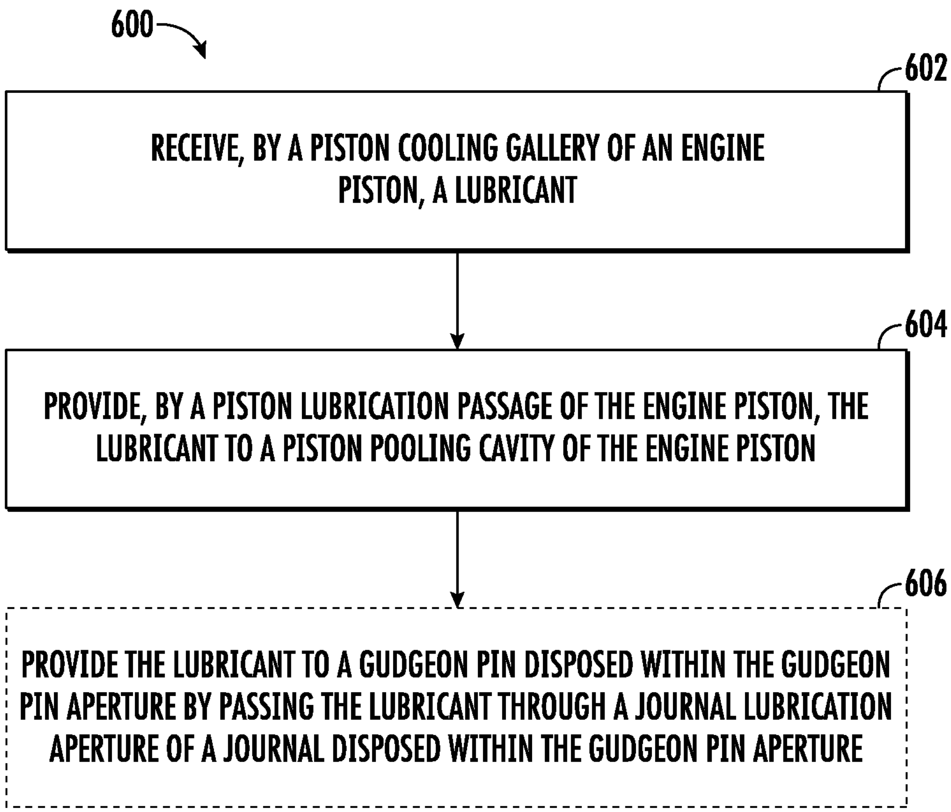
600
602
RECEIVE, BY A PISTON COOLING GALLERY OF AN ENGINE PISTON, A LUBRICANT
604
PROVIDE, BY A PISTON LUBRICATION PASSAGE OF THE ENGINE PISTON, THE LUBRICANT TO A PISTON POOLING CAVITY OF THE ENGINE PISTON
606
PROVIDE THE LUBRICANT TO A GUDGEON PIN DISPOSED WITHIN THE GUDGEON PIN APERTURE BY PASSING THE LUBRICANT THROUGH A JOURNAL LUBRICATION APERTURE OF A JOURNAL DISPOSED WITHIN THE GUDGEON PIN APERTURE

FIG. 15

LUBRICATION SYSTEM FOR A PIN JOINT OF AN ENGINE PISTON, AN ENGINE PISTON, AND A METHOD OF LUBRICATING A PIN JOINT OF AN ENGINE PISTON

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

The present application claims the benefit of and priority to U.S. Provisional Patent Application No. 63/445,112, filed Feb. 13, 2023, the entire contents of which are hereby incorporated by reference herein.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under Agreement No. W56HZV-21-9-C001, awarded by the U.S. Army Contracting Command. The Government has certain rights in the invention.

BACKGROUND

The present disclosure relates generally to lubrication systems for use with pin joints of an engine system. More specifically, the present disclosure relates to lubrication systems for piston assemblies of opposed-piston compression ignition engines.

SUMMARY

One embodiment relates to a lubrication system that includes an engine piston defining a gudgeon pin aperture, a piston pooling cavity extending radially outward from the gudgeon pin aperture, a piston cooling gallery, and a piston lubrication passage in fluid communication with the piston cooling gallery and the piston pooling cavity; a pin journal received in the gudgeon pin aperture of the engine piston and defining a journal aperture in fluid communication with the piston pooling cavity, and a journal pooling cavity in fluid communication with the journal aperture; and a gudgeon pin received within the gudgeon pin aperture adjacent the pin journal to provide fluid communication between the journal pooling cavity and the gudgeon pin.

In some embodiments, a piston cooling nozzle is configured to provide lubricant to the piston cooling gallery.

In some embodiments, the piston pooling cavity defines a convex profile in cross-section.

In some embodiments, the piston pooling cavity extends along a wrist axis defined by the gudgeon pin aperture.

In some embodiments, the engine piston includes a plurality of piston lubrication passages, and the plurality of piston lubrication passages provide fluid communication between the piston cooling gallery and the piston pooling cavity.

In some embodiments, the piston pooling cavity defines a volume that is larger than a volume defined by the plurality of piston lubrication passages.

In some embodiments, the gudgeon pin defines a pin bore that is in fluid communication with the journal pooling cavity. In such embodiments, the lubrication system can further include a connecting rod defining a rod bore therethrough. The connecting rod can be fluidly coupled to the pin bore by a check valve.

Another embodiment relates to an engine piston including a piston body. The piston body defines a gudgeon pin

aperture, a piston pooling cavity, a piston cooling gallery, and a piston lubrication passage. The piston pooling cavity extends radially outward from the gudgeon pin aperture and defines a channel that extends parallel to a wrist axis defined by the gudgeon pin aperture. The piston cooling gallery extends in a circumferential direction about a piston axis of the piston body. The piston lubrication passage extends between the piston cooling gallery and the piston pooling cavity.

In some embodiments, the piston lubrication passage extends radially away from the piston pooling cavity.

In some embodiments, the piston lubrication passage extends from an end of the piston pooling cavity proximate to a circumferential edge of the piston pooling cavity.

In some embodiments, the piston lubrication passage extends axially away from the piston cooling gallery relative to the piston axis.

In some embodiments, the piston pooling cavity is a semi-circular groove having a constant radius of curvature that extends between two circumferential positions along the gudgeon pin aperture.

In some embodiments, the piston lubrication passage is one of a plurality of piston lubrication passages that extend from the piston cooling gallery toward the wrist axis.

In some embodiments, the piston pooling cavity is one of a plurality of piston cooling cavities disposed at different circumferential positions along the gudgeon pin aperture.

In some embodiments, the piston pooling cavity is spaced axially apart from opposing axial ends of the gudgeon pin aperture relative to the wrist axis.

Yet another embodiment relates to a method of lubricating a pin joint of an engine piston. The method includes receiving, by a piston cooling gallery of the engine piston, a lubricant. The method also includes providing, by a piston lubrication passage of the engine piston that extends from the piston cooling gallery, the lubricant to a piston pooling cavity of the engine piston that extends radially away from a gudgeon pin aperture of the engine piston.

In some embodiments, the method further includes providing the lubricant to a gudgeon pin disposed within the gudgeon pin aperture by passing the lubricant through a journal lubrication aperture of a journal disposed within the gudgeon pin aperture.

In some embodiments, providing the lubricant to the gudgeon pin further includes distributing the lubricant across a journal pooling cavity in fluid communication with the journal lubrication aperture and extending radially away from a journal aperture that is coaxial with a wrist axis of the gudgeon pin.

In some embodiments, the method includes providing the lubricant to the gudgeon pin through a connecting rod that is coupled to the gudgeon pin by passing the lubricant through a check valve that is positioned in a feed bore of the gudgeon pin.

This summary is illustrative only and is not intended to be in any way limiting. Other aspects, inventive features, and advantages of the devices and/or processes described herein will become apparent in the detailed description set forth herein, taken in conjunction with the accompanying figures, wherein like reference numerals refer to like elements.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a schematic diagram of an engine system including a lubrication system for a pin joint of an engine piston, according to some embodiments.

FIG. **2** is a front, right, top perspective section view of the lubrication system for the pin joint of the engine piston of FIG. **1**, according to some embodiments.

FIG. **3** is a right side section view of the lubrication system for the pin joint of the engine piston of FIG. **1**, according to some embodiments.

FIG. **4** is a right side section view of the lubrication system for the pin joint of the engine piston of FIG. **1**, according to some embodiments.

FIG. **5** is a section view of the engine piston of FIG. **1**, according to some embodiments.

FIG. **6** is a perspective view of a gudgeon pin of the pin joint of FIG. **1**, according to some embodiments.

FIG. **7** is a perspective view of an alternative gudgeon pin of the pin joint of FIG. **1**, according to some embodiments.

FIG. **8** is a perspective view of an alternative gudgeon pin of the pin joint of FIG. **1**, according to some embodiments.

FIG. **9** is a section view of a gudgeon pin of the pin joint of FIG. **1**, according to some embodiments.

FIG. **10** is a section view of an alternative gudgeon pin of the pin joint of FIG. **1**, according to some embodiments.

FIG. **11** is a section view of an alternative lubrication system for the pin joint of the engine piston of FIG. **1**, according to some embodiments.

FIG. **12** is a section view of yet another lubrication system for the pin joint of the engine piston of FIG. **1**, according to some embodiments.

FIG. **13** is a section view of still another lubrication system for the pin joint of the engine piston of FIG. **1**, according to some embodiments.

FIG. **14** is a flow diagram of a method of making an engine system, a lubrication system for an engine system, and/or an engine piston thereof, according to some embodiments.

FIG. **15** is a flow diagram of a method of lubricating a pin joint of an engine piston, according to some embodiments.

DETAILED DESCRIPTION

Following below are more detailed descriptions of various concepts related to, and implementations of a lubrication system for a pin joint of an engine piston, an engine piston, and a method of lubricating a pin joint of an engine piston. Before turning to the figures, which illustrate certain exemplary embodiments in detail, it should be understood that the present disclosure is not limited to the details or methodology set forth in the description or illustrated in the figures. It should also be understood that the terminology used herein is for the purpose of description only and should not be regarded as limiting.

Referring to the figures generally, the various embodiments disclosed herein relate to systems, apparatuses, and methods for lubricating a pin joint of an engine piston, such as a piston of a horizontal, opposed-piston engine. The lubrication system can provide lubricant to a wrist pin joint (e.g., a gudgeon pin joint, etc.) of the piston that is used to connect the piston to a connecting rod of an engine. The lubrication system includes the engine piston that defines a gudgeon pin aperture, a piston pooling cavity extending radially outward from the gudgeon pin aperture, a piston cooling gallery, and a piston lubrication passage in fluid communication between the piston cooling gallery and the piston pooling cavity. The piston pooling cavity holds a volume of lubricant that can be greater than the volume stored in a nominal lubricant passageway used in typical horizontal, opposed-piston engines.

The piston pooling cavity is positioned adjacent the gudgeon pin aperture for quick delivery of lubricant thereto. A pin journal is received within the gudgeon pin aperture and defines a journal aperture in fluid communication with the piston pooling cavity, and a journal pooling cavity in fluid communication with the journal aperture. As noted above, the journal pooling cavity holds a volume of lubricant that is larger than that in a typical lubricant passageway and provides fast delivery of lubricant to the journal aperture.

In some embodiments, a gudgeon pin is received within the journal aperture so that fluid communication is provided between the journal pooling cavity and the gudgeon pin. In some embodiments, the gudgeon pin also includes internal lubricant passageways that provide lubricant to the pin journal. In some embodiments, the internal lubricant passageways include an accumulation chamber that holds a volume of lubricant. In some embodiments, at least one of the internal lubricant passageways includes a check valve configured to inhibit reverse flow of lubricant from the internal lubricant passageways.

Referring generally to FIGS. **1-5**, an engine system **15** includes a lubrication system **26** that is configured to provide lubricant to a pin joint connecting an engine piston **28** to a connecting rod **88**. The lubrication system **26** includes the engine piston **28**, a pin journal **68**, and a gudgeon pin **84**. The engine piston **28** includes a piston body **30** (see FIGS. **2-5**) defining a gudgeon pin aperture **32**. The engine piston **28** also includes a piston pooling cavity **38** extending radially outward from the gudgeon pin aperture **32**. The engine piston **28** further includes a piston cooling gallery **40** and a piston lubrication passage **44** in fluid communication with the piston cooling gallery **40** and the piston pooling cavity **38**. The pin journal **68** is received in the gudgeon pin aperture **32** of the piston body **30** and defines a journal aperture **72** in fluid communication with the piston pooling cavity **38**. The pin journal **68** also defines a journal pooling cavity **80** in fluid communication with the journal aperture **72**. The gudgeon pin **84** is received within the gudgeon pin aperture **32** adjacent the pin journal **68** to provide fluid communication between the journal pooling cavity **80** and the gudgeon pin **84**.

The engine system **15** includes an engine block **20** including a cylinder **24** and a piston **28** movable within the cylinder **24**. In some embodiments, the engine system **15** is a two-stoke opposed piston engine. In some embodiments, the engine block **20** includes four cylinders **24** and eight pistons **28**. In some embodiments, the engine system **15** is a compression ignition engine (e.g., a diesel engine). The engine system **15** further includes a lubrication system **26** that provides lubricant (e.g., an engine oil) to the piston **28**. In some embodiments, the engine block **20** includes more than four or fewer than four cylinders **24** and more or fewer than eight pistons **28**. In some embodiments, the engine system **15** is arranged with a single piston **28** arranged in each cylinder **24**.

Referring to FIGS. **2-4**, the engine piston **28** includes a piston body **30**. The piston body **30** defines a gudgeon pin aperture **32**. The piston body **30** can also define a piston pooling cavity **38** extending radially outward from the gudgeon pin aperture **32** (see FIG. **3**). In some embodiments, the piston pooling cavity **38** defines a channel **46** that extends parallel to a wrist axis A defined by the gudgeon pin aperture **32** (see FIG. **5**). The piston body **30** can further define a piston cooling gallery **40** extending in a circumferential direction about a piston axis **42** of the piston body **30**. In some embodiments, the piston body **30** further defines a piston lubrication passage **44** extending between the piston cooling gallery **40** and the piston pooling cavity **38** (see FIG. **3**).

In some embodiments, the piston body **30** includes a piston crown and a piston skirt coupled to the piston crown and extending axially away from the piston crown. Together, the piston crown and the piston skirt define the piston cooling gallery **40** therebetween. The piston cooling gallery **40** extends in a circumferential direction relative to a piston axis **42** (e.g., a central axis) of the engine piston **28**.

In some embodiments, the piston pooling cavity **38** is one of a plurality of piston pooling cavities **38** disposed at different circumferential positions along the gudgeon pin aperture **32**. For example, as shown in FIG. **5**, the piston **28** includes two piston pooling cavities **38** extending parallel to the wrist axis A. In some embodiments, the piston **28** includes more than two or fewer than two piston pooling cavities **38**. In some embodiments, as shown in FIG. **5**, the piston pooling cavity **38** is spaced axially apart from opposing axial ends of the gudgeon pin aperture **32** relative to the wrist axis A such that there is an axial gap between both axial ends of the gudgeon pin aperture **32** and the piston pooling cavity **38**.

The piston lubrication passage **44** extends axially away from the piston cooling gallery **40** relative to the piston axis **42**. In some embodiments, the piston lubrication passage **44** is one of a plurality of piston lubrication passages **44** that extend from the piston cooling gallery **40** toward the wrist axis A. In some embodiments, the piston **28** includes four piston lubrication passages **44** (see FIG. **5**). First and second piston lubrication passages **44** are configured to feed a first piston pooling cavity **38**. Third and fourth piston lubrication passages **44** are configured to feed a second piston pooling cavity **38**. In some embodiments, the piston **28** includes fewer than four or more than four piston lubrication passages **44**.

In some embodiments, the piston pooling cavity **38** is a semi-circular groove having a constant radius of curvature R that extends between two circumferential positions along the gudgeon pin aperture **32** (see FIG. **4**). In some embodiments, at least one piston pooling cavity **38** defines a convex profile in cross section. The convex profile can extend parallel to the wrist axis A. For example, as shown in FIG. **3**, the piston pooling cavities can be shaped as rounded protrusions extending from above journal lubrication apertures **76** when viewed from an axial direction. In other words, the piston pooling cavity **38** defines a scalloped shaped profile. In some embodiments, the piston pooling cavities **38** are semi-circular in cross section, rectangular in cross section, or define a different cross sectional profile. In some embodiments, the piston pooling cavity **38** extends along the wrist axis A defined by the gudgeon pin aperture **32**. The gudgeon pin aperture **32** can extend coaxially with a wrist axis A.

In some embodiments, the engine piston **28** includes (e.g., the piston body **30** defines) a plurality of piston lubrication passages **44** and the plurality of piston lubrication passages **44** provide fluid communication between the piston cooling gallery **40** and the piston pooling cavity **38**. As used herein, “provide fluid communication between,” “in fluid communication with,” and the like refers to regions, passages, channels, etc. that fluidly connect one element to another element so that fluid (e.g., lubricant) can flow therebetween. In some embodiments, the piston pooling cavity **38** defines a volume that is larger than a volume defined by the plurality of piston lubrication passages **44**. The piston pooling cavities **38** can provide a faster response to a need for lubrication than systems that do not employ piston pooling cavities **38**. In particular, the volume defined by the piston pooling cavity **38** can be larger than the collective volume of the sum of each internal volume of the plurality of piston lubrication passages **44**.

The piston **28** includes shoulders **48** adjacent the gudgeon pin aperture **32** and structured to receive end caps **52**. The piston **28** also includes a crank shaft aperture **56** and gallery feed passages **60** (see FIG. **3**). The gallery feed passages **60** are configured to provide communication between at least one piston cooling nozzle **64** and the piston cooling gallery **40**. In some embodiments, the piston cooling nozzle **64** is configured to provide lubricant to the piston cooling gallery **40**. In some embodiments, only one piston cooling nozzle **64** provides lubricant to the piston cooling gallery **40**. In other embodiments, the lubrication system includes multiple piston cooling nozzles **64** that provide lubricant to the piston cooling gallery **40** (e.g., through respective ones of a plurality of gallery feed passages **60**). In some embodiments, the piston **28** includes two gallery feed passages **60**. In some embodiments, the piston **28** includes more than two or one gallery feed passages **60**.

In some embodiments, a journal **68** is received within the gudgeon pin aperture **32** and defines a journal aperture **72** coaxial with the wrist axis A. Two pairs of journal lubrication apertures **76** (see FIG. **3**) provide communication between the piston pooling cavities **38** and the journal aperture **72**. Each of the journal lubrication apertures **76** is aligned with one of the piston pooling cavities **38** to receive lubricant therefrom. In some embodiments, the journal **68** includes more than four or fewer than four journal lubrication apertures **76**. The journal **68** further includes journal pooling cavities **80** in fluid communication with the journal lubrication apertures **76** and shaped to distribute lubricant within the journal aperture **72**. In some embodiments, the journal pooling cavities **80** extend both axially parallel to the wrist axis A and radially about the wrist axis A.

A gudgeon pin **84** is received within the journal aperture **72** and maintained axially by engagement with a connecting rod **88**. The gudgeon pin is supported within the journal aperture **72** and the gudgeon pin aperture **32** for rotation about the wrist axis A during operation of the engine system **15**. The gudgeon pin **84** is coupled (e.g., fastened) to the connecting rod **88** through the crank shaft aperture **56**. The gudgeon pin **84** includes a pin lubrication system **92** including a feed bore **96** structured to receive lubricant from the connecting rod **88**. In some embodiments, the connecting rod **88** defines a rod bore **90** therethrough (see FIGS. **2-3**) that supplies lubricant to an opposite side of the gudgeon pin **84** as the engine piston **28**. The gudgeon pin **84** further defines a pin bore **100** that is in fluid communication with the journal pooling cavity **80**. The pin bore **100** receives lubricant from the feed bore **96**.

In some embodiments, the gudgeon pin **84** further includes one or more distribution bores **104** receiving lubricant from the pin bore **100**. Additionally, journal feeds **108** can be provided that extend from either the pin bore **100** or the distribution bore **104** and provide lubricant to the interface of the gudgeon pin **84** and the journal **68**. In some embodiments, the pin lubrication system **92** includes one distribution bore **104** and a plurality of journal feeds **108**. For example, five journal feeds **108** can be provided. In some embodiments, the pin lubrication system **92** includes more than one distribution bore **104** or the distribution bore **104** is eliminated, and more than five or fewer than five journal feeds **108** can be provided.

In some embodiments, the connecting rod **88** (e.g., the rod bore **90**) is fluidly coupled to the pin bore **100** by a check valve **112**. In some embodiments, a check valve **112** is positioned in the feed bore **96** to inhibit flow of lubricant from the gudgeon pin **84** to the connecting rod **88**. In some embodiments, reversal of lubricant flow can occur because of inertial effects. When the piston **28** moves from outer dead center to inner dead center, the lubricant column in the connecting rod **88** tries to flow back (i.e., downward in FIGS. **2** and **3**, opposite the arrows). Flow reversal affects the flowrate of lubricant to the pin joint in a way that can impede sufficient supply of lubricant. In particular, the effect is compounded more particularly in 2-stroke engines (e.g., the engine system **15**) where the gudgeon pin **84** and the journal **68** do have little separation. In particular, a clearance can be provided between the gudgeon pin **84** and the journal **68**. It is desirable to operate the pin joint on the piston **28** in a hydrodynamic lubrication regime and not in a mixed or boundary regime to inhibit scuffing and seizure. It is desirable to maintain a high and stable lubricant flowrate to the journal **68**. The pin lubrication system **92** is designed to hold a certain amount of lubricant in the pin bore **100** and the journal feed **108** include precise drillings to feed lubricant to the journal **68** at a precise flowrate. The pin lubrication system **92** is maintained to operate at different engine speeds and loads while maintaining required flowrate at those conditions.

The pin joint system is also fed from piston cooling gallery **40** of the piston **28**. The piston lubrication passages **44** helps in filling in the journal pooling cavities **80** which helps in pin joint lubrication and helps in effective draining from the piston cooling gallery **40**, which improves a filling ratio and heat transfer from the piston **28**.

The flow from the piston cooling gallery **40** to the journal **68** happens just momentarily after the piston cooling nozzles **64** deliver lubricant into the piston cooling gallery **40**. When the piston **28** starts its movement from outer dead center to inner dead center, the inertia of the lubricant pushes it into the journal pooling cavities **80** through lubrication passages **44**. As the biaxial gudgeon pin **84** rotates, a gap opens between the journal **68** and bearing running face of the gudgeon pin **84** which creates suction in the lubrication column. This mechanism replenishes the lubricant in the journal aperture **72**. The piston lubrication passages **44** are sized to deliver a desired amount of lubricant from the piston cooling gallery **40** into the journal **68**. When included, the check valve **112** restricts a flow of lubricant from the gudgeon pin aperture **32** into the connecting rod **88**. As a result, pressure remains unaffected in the pin bore **100** which results in a steady stream of lubricant reaching the journal **68**.

As shown in FIG. **5**, the journal pooling cavities **80** extend both axially parallel to the wrist axis A and radially about the wrist axis A and receive lubricant from the four piston lubrication passages **44** via the piston pooling cavities **38**.

As shown in FIG. **6**, an alternative gudgeon pin **116** operates similarly to the gudgeon pin **84** discussed above. The gudgeon pin **116** includes a feed bore **120**, a pin bore **124**, two primary feed passageways **128** providing fluid flow between the pin bore **124** and an external surface of the gudgeon pin **116**. The gudgeon pin **116** further includes two distribution bores **132**, and four secondary feed passageways **136** (e.g., two pairs of secondary feed passageways **136**) providing fluid flow between the distribution bores **132** and the external surface of the gudgeon pin **116**. In some embodiments, more or fewer primary feed passageways **128** and secondary feed passageways **136** can be included. In some embodiments, a check valve **140** is included in the feed bore **120**.

As shown in FIG. **7**, an alternative gudgeon pin **144** operates similarly to the gudgeon pin **84** discussed above. The gudgeon pin **144** includes a feed bore **148**, a pin bore **152**, two primary feed passageways **156** providing fluid flow between the pin bore **152** and an external surface of the gudgeon pin **144**, two distribution bores **160**, and two secondary feed passageways **164**. The two secondary feed passageways **164** providing fluid flow between the distribution bores **160** and the external surface of the gudgeon pin **144**. In some embodiments, more or fewer primary feed passageways **156** and secondary feed passageways **164** can be included. In some embodiments, a check valve **168** is included in the feed bore **148** to inhibit reverse flow of lubricant.

As shown in FIG. **8**, an alternative gudgeon pin **172** operates similarly to the gudgeon pin **84** discussed above. The gudgeon pin **172** includes a feed bore **176**, a pin bore **180**, and a plurality of feed passageways **184**. The feed passageways **184** are configured to provide fluid flow between the pin bore **180** and an external surface of the gudgeon pin **172**. In some embodiments, more or fewer feed passageways **184** can be included. In some embodiments, a check valve **188** is included in the feed bore **176**. The gudgeon pins **84**, **116**, **144**, **172** discussed herein demonstrate alternative layouts that can be used to efficiently provide lubricant to the exterior surface of the gudgeon pin **84**, **116**, **144**, **172** and lubricate the interface of the gudgeon pin **84**, **116**, **144**, **172** and the journal **68**.

As shown in FIG. **9**, an alternative gudgeon pin **192** can include any of the lubricant layouts discussed above. The gudgeon pin **192** includes a feed bore **196**, a pin bore **200**, and feed passageways **204**. A flow control device **208** is positioned within the feed bore **196** and includes a central aperture **212** and reflow apertures **216**. In some embodiments, both of the central aperture **212** and the reflow apertures **216** are arranged in fluid communication with and at an oblique angle relative to the central aperture **212**. The flow control device **208** allows free flow of lubricant into the feed bore **196**. In some embodiments, minimal lubricant (sufficient to provide lubrication, without excess lubrication) can flow through the reflow apertures **216**. When lubricant is caused to reverse flow (e.g., due to an inertial effect when the piston **28** moves from the outer dead center to inner dead center, the lubricant column in the rod **88** attempts to flow back), the reflow apertures **216** are structured to direct the lubricant back to into the feed bore **196** and the pin bore **200**. In particular, the reflow apertures **216** are shaped in manner conducive to allow the lubricant to return to both of the feed bore **196** and the pin bore **200**. Therefore, the flow control device **208** effectively replaces the check valves discussed above.

As shown in FIG. **10**, a sectional view of the gudgeon pin **172** shows an embodiment where the check valve **188** is eliminated.

Embodiments of the lubrication system described with reference to FIGS. **1-10** of the present disclosure should not be considered limiting. Many alternatives and combinations are possible without departing from the inventive principles disclosed herein. For example, referring to FIGS. **11-13**, arrangements of a pin joint lubrication system are shown that include a variety of different passage geometries for lubricant flow.

For example, referring to FIG. **11**, a lubrication system **226** is shown that includes a piston body **230** defining a piston lubrication passage **244** that extends at an oblique angle **228** relative to a piston axis **242** defined by the piston body **230** (e.g., a central axis of the piston body). In some embodiments, the piston lubrication passage **244** extends radially away from a piston pooling cavity **238**. In the embodiment of FIG. **11**, the piston lubrication passage **244** extend linearly (e.g, along a straight line) between the piston pooling cavity **238** and a piston cooling gallery **240** of the piston body **230**. In other embodiments, as shown in FIG. **12**, the piston lubrication passage **344** extends axially away from the piston cooling gallery **340** relative to the piston axis **342** (and also extends axially away from the piston pooling cavity **338**). For example, the piston lubrication passage **344** can extend substantially parallel to the piston axis **342**. In some embodiments, as shown in FIG. **11**, the piston lubrication passage **244** is one of a plurality of piston lubrication passages **244** that extend from the piston cooling gallery **240** toward the wrist axis A.

Still referring to FIG. **11**, the lubrication system also includes a pin journal **268** that defines a journal lubrication aperture **276**. In some embodiments, as shown in FIG. **11**, the journal lubrication aperture **276** extends at an oblique angle relative to the piston axis **242**. For example, the journal lubrication aperture **276** can extend in a substantially radial direction relative to a wrist pin axis A defined by the gudgeon pin. In other embodiments, as shown in FIG. **13**, the journal lubrication aperture **476** extends substantially parallel to the piston axis **442**.

The location of piston lubrication passage **244** relative to the piston pooling cavity **238**, the location of the journal lubrication aperture **276** relative to the piston pooling cavity **238**, and/or the location of a journal pooling cavity **280** relative to the journal lubrication aperture **276** can also be different in various embodiments. For example, in the embodiment of FIG. **11**, the piston lubrication passage **244** extends from an end of the piston pooling cavity **238** proximate to a circumferential edge **282** of the piston pooling cavity **238**. In some embodiments, the piston lubrication passage **244** can be disposed at an opposite end (e.g., an opposite circumferential end relative to the wrist axis A) of the piston pooling cavity **238** as the journal lubrication aperture **276**. Such an arrangement can reduce lubricant reversal (e.g., prevent lubricant from flowing back into the piston cooling gallery) and can improve oil retention in the area of the piston and/or journal pooling cavity. In other embodiments, at least one of the piston lubrication passage **244** or the journal lubrication aperture **276** are disposed at an intermediate (e.g., central) position between opposing edges of the piston pooling cavity **238**.

Referring to FIG. **13**, the journal pooling cavity **480** can also be offset from or extend from an edge of the journal lubrication aperture **476** so that the journal pooling cavity **480** is disposed on one side of the journal lubrication aperture **476**.

The position and/or orientation of the piston lubrication passage, the piston cooling cavity, the journal lubrication aperture, and the journal pooling cavity affect the balance of meeting fatigue margins of the piston, improving back contact pressure on the pin joint bushing/journal, and reducing oil flow reversal to improve pin joint performance. The interaction between these passage geometries can provide different performance benefits under different operating conditions.

Referring to FIG. **14**, a method **500** of making an engine, pin joint lubrication system, and/or engine piston is shown, such as any of the engine, pin joint lubrication systems, and/or engine piston arrangements described with reference to FIGS. **1-13**. The method **500** includes coupling an engine piston to a connecting rod so as to fluidly couple the engine piston to the connecting rod.

Operation **502** includes aligning the engine piston defining at least one piston lubrication passage with the connecting rod defining a rod bore by aligning a gudgeon pin aperture of the engine piston with the connecting rod. In some embodiments, operation **502** includes aligning a pin bore of the connecting rod with the gudgeon pin aperture of the engine piston. Operation **502** can include forming the engine piston by forming a piston body defining a gudgeon pin aperture, a piston cooling gallery, and at least one piston lubrication passage extending therebetween. In some embodiments, operation **502** includes forming a piston pooling cavity into the engine piston by forming a channel that extends radially outward from the gudgeon pin aperture.

Operation **504** includes inserting a pin journal defining a journal lubrication aperture into the gudgeon pin aperture. In some embodiments, operation **502** includes providing a pin journal received in a gudgeon pin aperture of an engine piston for a gudgeon pin. In some embodiments, the pin journal includes (e.g., defines) a journal pooling cavity. Operation **504** can include inserting the pin journal into the gudgeon pin aperture along a wrist axis of the gudgeon pin aperture to couple a connecting rod to the engine piston.

Operation **506** includes inserting a gudgeon pin into a journal aperture of the pin journal to support the engine piston on the connecting rod, and to fluidly couple the gudgeon pin to the piston lubrication passage(s). In some embodiments, operation **506** also includes fluidly coupling the gudgeon pin to a rod bore of the connecting rod.

In some embodiments, operation **506** includes forming the gudgeon pin, by forming a feed bore, a pin bore, and at least one primary feed passageway providing fluid flow between the pin bore and an external surface of the gudgeon pin into a pin body of the gudgeon pin. In some embodiment, operation **506** includes forming at least one distribution bore and at least one secondary feed passageway providing fluid flow between the distribution bore(s) and the external surface of the gudgeon pin. In other embodiments, the method **500** includes additional, fewer, and/or different operations.

In some embodiments, the method **500** includes storing, in the journal pooling cavity, lubricant, such as oil. The method further includes establishing a fluid connection between the journal pooling cavity and the gudgeon pin. The method includes storing lubricant in a piston pooling cavity and establishing fluidic communication between the piston pooling cavity and a piston cooling gallery. The method further includes lubricating the engine piston via lubricant stored in the piston pooling cavity.

Referring to FIG. **15**, a method **600** of lubricating a pin joint of an engine piston is shown, according to an embodiment. The method **600** can be implemented with any of the engine and/or engine piston arrangements described with reference to FIGS. **1-13**. In other embodiments, the method **600** can include additional, fewer, and/or different operations.

Operation **602** includes receiving, by a piston cooling gallery of the engine piston, a lubricant. Operation **604** includes providing, by a piston lubrication passage of the engine piston that extends from the piston cooling gallery, the lubricant to a piston pooling cavity of the engine piston that extends radially away from a gudgeon pin aperture of the engine piston. Operation **606** includes providing the lubricant to a gudgeon pin disposed within the gudgeon pin aperture by passing the lubricant through a journal lubrication aperture of a journal disposed within the gudgeon pin aperture.

In some embodiments, operation **602** includes providing, by a piston cooling nozzle, the lubricant to the piston cooling gallery.

In some embodiments, operation **606** includes distributing the lubricant across a journal pooling cavity in fluid communication with the journal lubrication aperture and extending radially away from a journal aperture that is coaxial with a wrist axis of the gudgeon pin. In some embodiments, operation **606** further includes providing the lubricant to the gudgeon pin through a connecting rod that is coupled to the gudgeon pin by passing the lubricant through a check valve that is positioned in a feed bore of the gudgeon pin or along a rod bore defined by the connecting rod so as to prevent oil reversal through the connecting rod.

In some embodiments, operation **602** includes providing a first lubricant flow to the gudgeon pin from the piston cooling gallery. In such embodiments, operation **606** can include passing a second lubricant flow to the gudgeon pin from the connecting rod.

As utilized herein, the terms "approximately," "about," "substantially", and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numerical ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and claimed are considered to be within the scope of the disclosure as recited in the appended claims.

It should be noted that the term "exemplary" and variations thereof, as used herein to describe various embodiments, are intended to indicate that such embodiments are possible examples, representations, or illustrations of possible embodiments (and such terms are not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

The term "coupled" and variations thereof, as used herein, means the joining of two members directly or indirectly to one another. Such joining can be stationary (e.g., permanent or fixed) or moveable (e.g., removable or releasable). Such joining can be achieved with the two members coupled directly to each other, with the two members coupled to each other using one or more separate intervening members, or with the two members coupled to each other using an intervening member that is integrally formed as a single unitary body with one of the two members. If "coupled" or variations thereof are modified by an additional term (e.g., directly coupled), the generic definition of "coupled" provided above is modified by the plain language meaning of the additional term (e.g., "directly coupled" means the joining of two members without any separate intervening member), resulting in a narrower definition than the generic definition of "coupled" provided above. Such coupling can be mechanical, or fluidic. For example, circuit A communicably "coupled" to circuit B can signify that the circuit A communicates directly with circuit B (i.e., no intermediary) or communicates indirectly with circuit B (e.g., through one or more intermediaries).

References herein to the positions of elements (e.g., "top," "bottom," "above," "below," "inner," "outer") are merely used to describe the orientation of various elements in the FIGURES. It should be noted that the orientation of various elements can differ according to other exemplary embodiments, and that such variations are intended to be encompassed by the present disclosure.

It is important to note that the construction and arrangement of the lubrication system as shown in the various exemplary embodiments is illustrative only. Additionally, any element disclosed in one embodiment can be incorporated or utilized with any other embodiment disclosed herein. Although only one example of an element from one embodiment that can be incorporated or utilized in another embodiment has been described above, it should be appreciated that other elements of the various embodiments can be incorporated or utilized with any of the other embodiments disclosed herein.

What is claimed is:

1. A lubrication system comprising:
an engine piston comprising:
a piston body defining:
a gudgeon pin aperture;
a piston pooling cavity extending radially outward from the gudgeon pin aperture;
a piston cooling gallery; and
a piston lubrication passage in fluid communication with the piston cooling gallery and the piston pooling cavity;
a pin journal received in the gudgeon pin aperture of the piston body and defining:
a journal aperture in fluid communication with the piston pooling cavity; and
a journal pooling cavity in fluid communication with the journal aperture; and
a gudgeon pin received within the gudgeon pin aperture adjacent the pin journal to provide fluid communication between the journal pooling cavity and the gudgeon pin.

2. The lubrication system of claim **1**, further including a piston cooling nozzle configured to provide lubricant to the piston cooling gallery.

3. The lubrication system of claim **1**, wherein the piston pooling cavity defines a convex profile in cross-section.

4. The lubrication system of claim **1**, wherein the piston pooling cavity extends along a wrist axis defined by the gudgeon pin aperture.

5. The lubrication system of claim **1**, wherein the piston body defines a plurality of piston lubrication passages, and the plurality of piston lubrication passages provide fluid communication between the piston cooling gallery and the piston pooling cavity.

6. The lubrication system of claim **5**, wherein the piston pooling cavity defines a volume that is larger than a volume defined by the plurality of piston lubrication passages.

7. The lubrication system of claim **1**, wherein the gudgeon pin defines a pin bore that is in fluid communication with the journal pooling cavity.

8. The lubrication system of claim **7**, further comprising a connecting rod defining a rod bore therethrough, the connecting rod fluidly coupled to the pin bore by a check valve.

9. An engine piston assembly comprising:
a piston body defining:
a gudgeon pin aperture;
a piston pooling cavity extending radially outward from the gudgeon pin aperture and defining a channel that extends parallel to a wrist axis defined by the gudgeon pin aperture;
a piston cooling gallery extending in a circumferential direction about a piston axis of the piston body; and

a piston lubrication passage extending between the piston cooling gallery and the piston pooling cavity; and

a pin journal received in the gudgeon pin aperture of the piston body and defining:

a journal aperture in fluid communication with the piston pooling cavity; and

a journal pooling cavity in fluid communication with the journal aperture.

10. The engine piston assembly of claim **9**, wherein the piston lubrication passage extends radially away from the piston pooling cavity.

11. The engine piston assembly of claim **9**, wherein the piston lubrication passage extends from an end of the piston pooling cavity proximate to a circumferential edge of the piston pooling cavity.

12. The engine piston assembly of claim **9**, wherein the piston lubrication passage extends axially away from the piston cooling gallery relative to the piston axis.

13. The engine piston assembly of claim **9**, wherein the piston pooling cavity is a semi-circular groove having a constant radius of curvature that extends between two circumferential positions along the gudgeon pin aperture.

14. The engine piston assembly of claim **9**, wherein the piston lubrication passage is one of a plurality of piston lubrication passages that extend from the piston cooling gallery toward the wrist axis.

15. The engine piston assembly of claim **9**, wherein the piston pooling cavity is one of a plurality of piston cooling cavities disposed at different circumferential positions along the gudgeon pin aperture.

16. The engine piston assembly of claim **9**, wherein the piston pooling cavity is spaced axially apart from opposing axial ends of the gudgeon pin aperture relative to the wrist axis.

17. A method of lubricating a pin joint of an engine piston, the method comprising:

receiving, by a piston cooling gallery of the engine piston, a lubricant;

providing, by a piston lubrication passage of the engine piston that extends from the piston cooling gallery, the lubricant to a piston pooling cavity of the engine piston that extends radially away from a gudgeon pin aperture of the engine piston; and

providing the lubricant to a gudgeon pin disposed within the gudgeon pin aperture by passing the lubricant through a journal lubrication aperture of a journal disposed within the gudgeon pin aperture.

18. The method of claim **17**, wherein providing the lubricant to the gudgeon pin further comprises distributing the lubricant across a journal pooling cavity in fluid communication with the journal lubrication aperture and extending radially away from a journal aperture that is coaxial with a wrist axis of the gudgeon pin.

19. The method of claim **17**, further comprising providing the lubricant to the gudgeon pin through a connecting rod that is coupled to the gudgeon pin by passing the lubricant through a check valve that is positioned in a feed bore of the gudgeon pin.

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