US012394694B2

(12) **United States Patent**
Downs et al.

(10) **Patent No.: US 12,394,694 B2**
(45) **Date of Patent: Aug. 19, 2025**

(54) **INTEGRATED POWER SWITCHING DEVICE HEAT SINK**

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(72) Inventors: **James P. Downs**, South Lyon, MI (US); **Paul J. Valente**, Berkley, MI (US); **Chi-Wai David Lau**, LaSalle (CA)

(73) Assignee: **AMERICAN AXLE & MANUFACTURING, INC.**, Detroit, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 477 days.

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(22) Filed: **Oct. 25, 2022**

(65) **Prior Publication Data**

US 2023/0041227 A1 Feb. 9, 2023

Related U.S. Application Data

(63) Continuation of application No. 17/503,433, filed on Oct. 18, 2021, now Pat. No. 12,199,020, which is a (Continued)

(51) **Int. Cl.**
H01L 23/495 (2006.01)
H02K 1/16 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC .... ***H01L 23/49568*** (2013.01); ***H02K 1/16*** (2013.01); ***H02K 1/20*** (2013.01); (Continued)

(58) **Field of Classification Search**
CPC .... H01L 23/3726; H01L 23/49513; H01L 23/49562; H01L 23/49568; H01L 24/48; (Continued)

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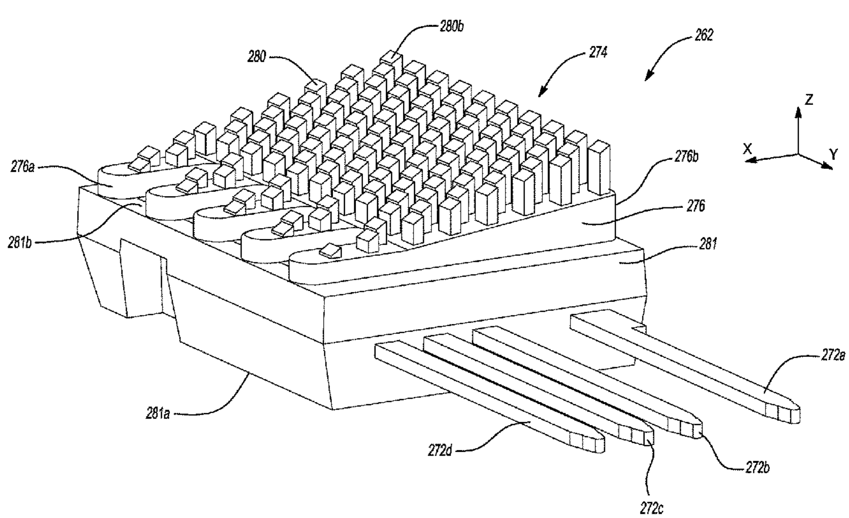
Primary Examiner — Hoai V Pham
(74) *Attorney, Agent, or Firm* — DICKINSON WRIGHT PLLC

(57) **ABSTRACT**

An electrical assembly that with an inverter that is mounted to the field windings of a stator. The inverter has a plurality of power semiconductor packages (PSP), each of which including a semiconductor die, a plurality of electric terminals, which are electrically coupled to the semiconductor die, and a heat sink with a base, which is fixedly and electrically coupled to one of the electric terminals, and a plurality of fins that extend axially from the base in a direction away from the semiconductor die. The PSP's are arranged in a circumferentially spaced apart manner. The fins are arranged in rows and are progressively longer in length from a radially-inner most fin to a radially-outer most fin. Slots are formed in the base on a radially-inner side of the base. Each slot extends toward a radially-outer side of the base and intersects a corresponding one of the rows of fins.

10 Claims, 33 Drawing Sheets



Related U.S. Application Data

continuation-in-part of application No. PCT/US2020/029925, filed on Apr. 24, 2020.

(60) Provisional application No. 62/904,199, filed on Sep. 23, 2019, provisional application No. 62/838,893, filed on Apr. 25, 2019, provisional application No. 63/263,830, filed on Nov. 10, 2021.

(51) **Int. Cl.**

H02K 1/20	(2006.01)
H02K 5/15	(2006.01)
H02K 5/20	(2006.01)
H02K 5/22	(2006.01)
H02K 7/116	(2006.01)
H02K 9/19	(2006.01)
H02K 9/22	(2006.01)
H02K 11/00	(2016.01)
H02K 11/27	(2016.01)
H02K 11/33	(2016.01)
H01L 23/00	(2006.01)
H01L 23/373	(2006.01)

(52) **U.S. Cl.**
CPC ***H02K 5/15*** (2013.01); ***H02K 5/203*** (2021.01); ***H02K 5/225*** (2013.01); ***H02K 7/116*** (2013.01); ***H02K 9/19*** (2013.01); ***H02K 9/227*** (2021.01); ***H02K 11/00*** (2013.01); ***H02K 11/27*** (2016.01); ***H02K 11/33*** (2016.01); *H01L 23/3736* (2013.01); *H01L 23/49513* (2013.01); *H01L 23/49562* (2013.01); *H01L 24/48* (2013.01); *H01L 24/73* (2013.01); *H01L 24/92* (2013.01); *H01L 2224/48175* (2013.01); *H01L 2224/73265* (2013.01); *H01L 2224/92247* (2013.01); *H01L 2924/13091* (2013.01); *H02K 2211/03* (2013.01)

(58) **Field of Classification Search**
CPC H01L 24/73; H01L 24/92; H01L 2224/48175; H01L 2224/73265; H01L 2224/92247; H01L 2224/13091
USPC 257/675, 718
See application file for complete search history.

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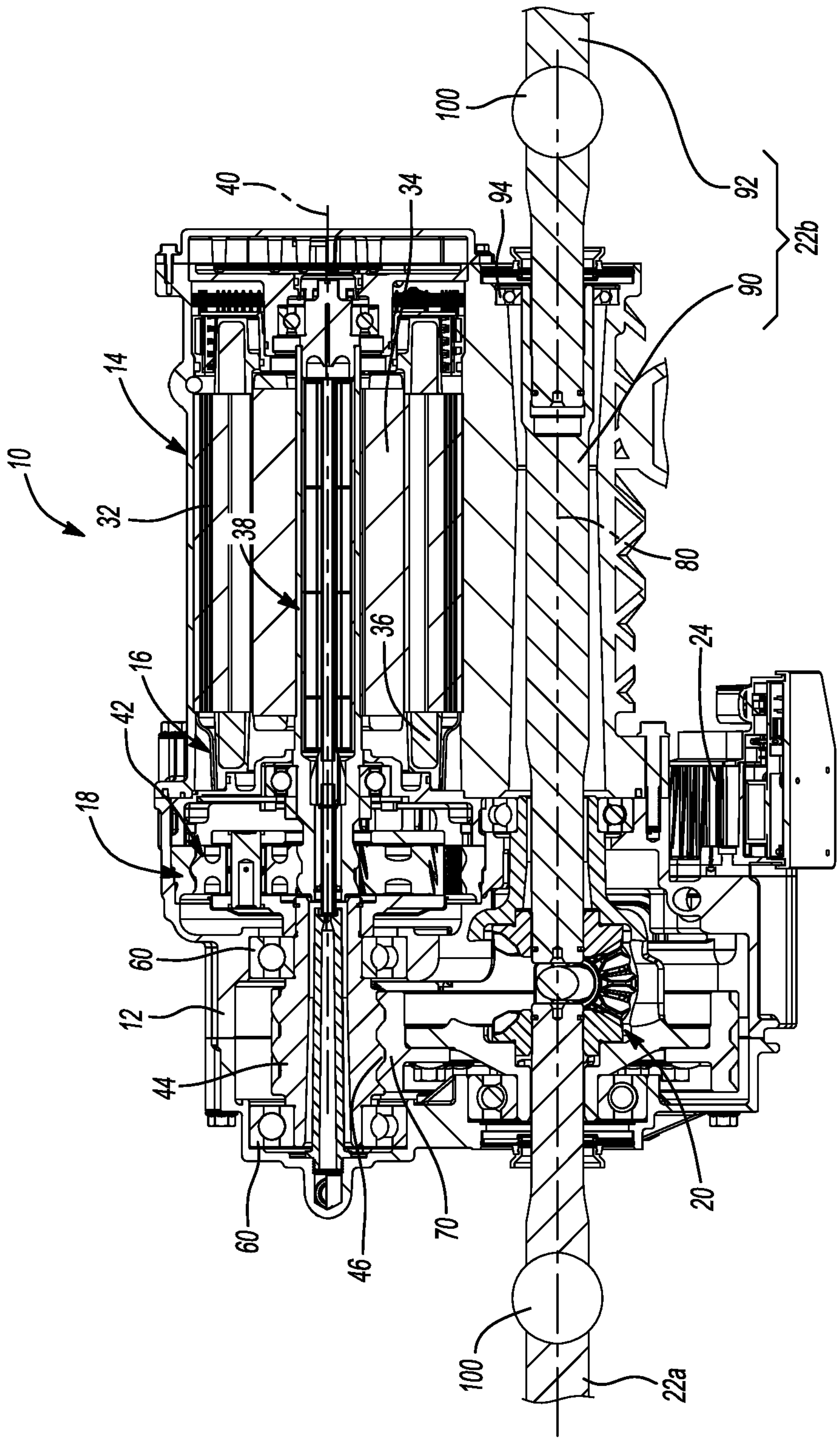

10
14
32
38
34
40
94
100
92
22b
90
80
24
36
16
42
18
60
12
44
60
46
70
20
100
22a

Fig-1

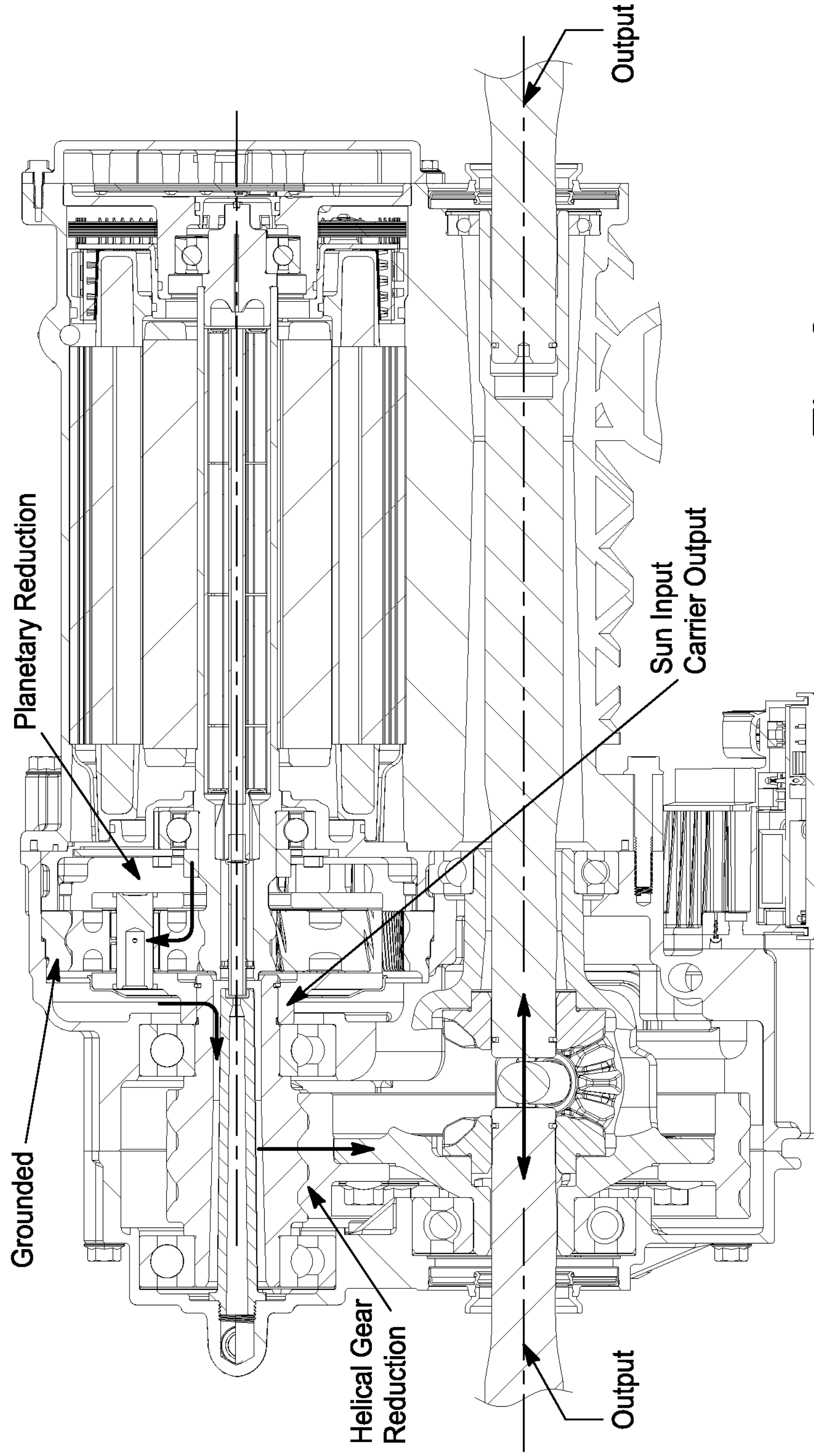

Output
Planetary Reduction
Sun Input
Carrier Output
Grounded
Helical Gear
Reduction
Output

Fig-2

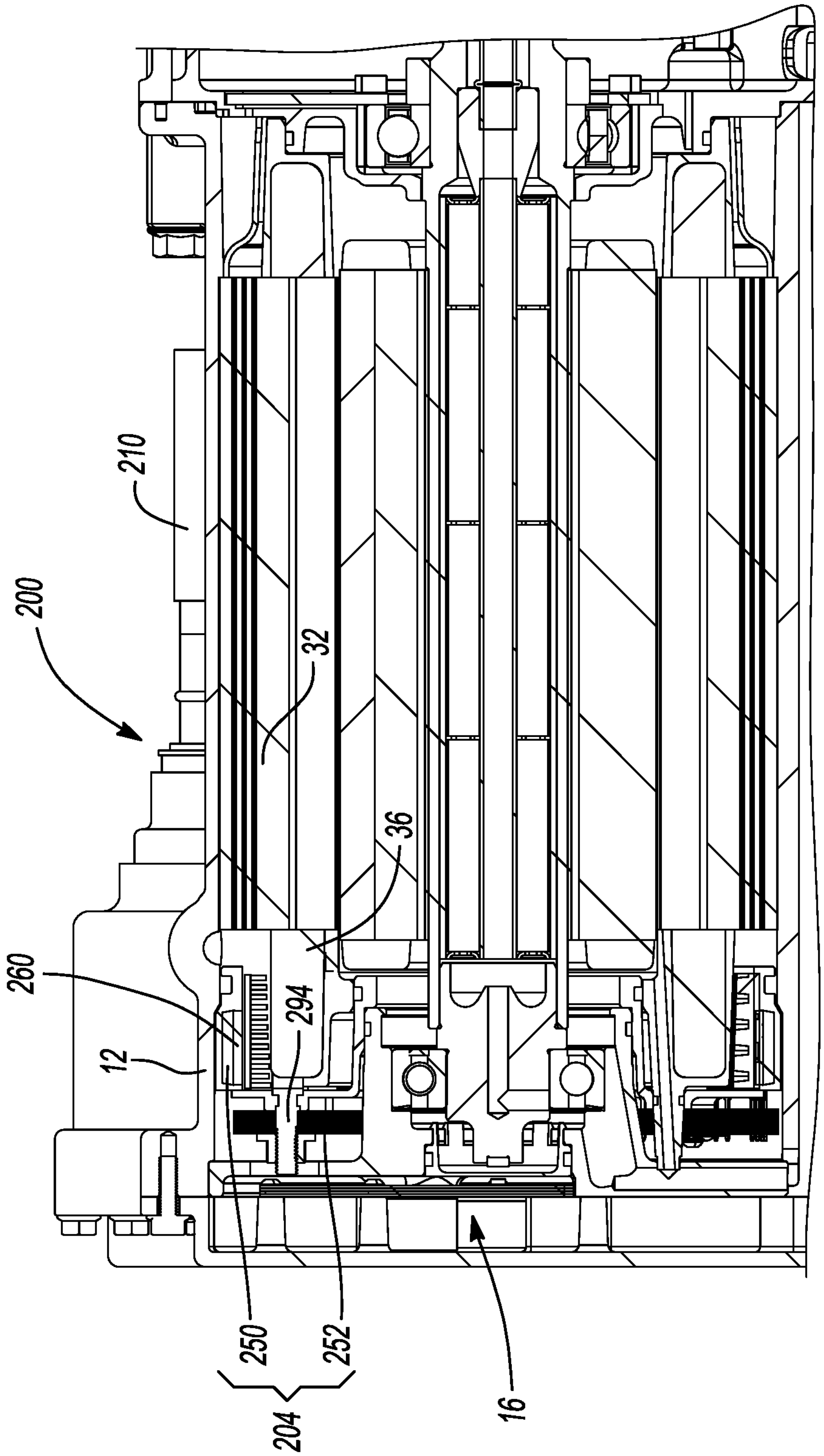
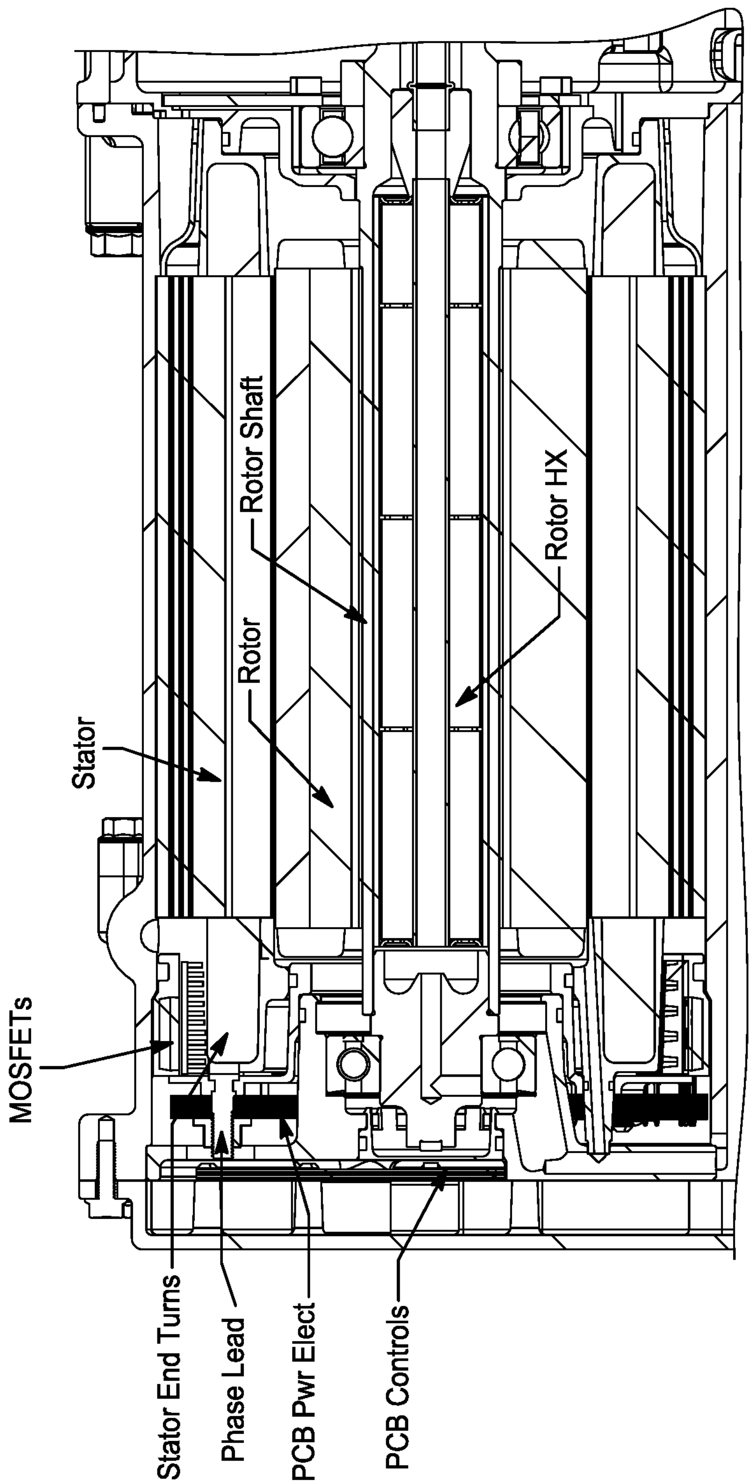


Fig-3



Stator
Rotor
Rotor Shaft
Rotor HX
MOSFETs
Stator End Turns
Phase Lead
PCB Pwr Elect
PCB Controls

Fig-4

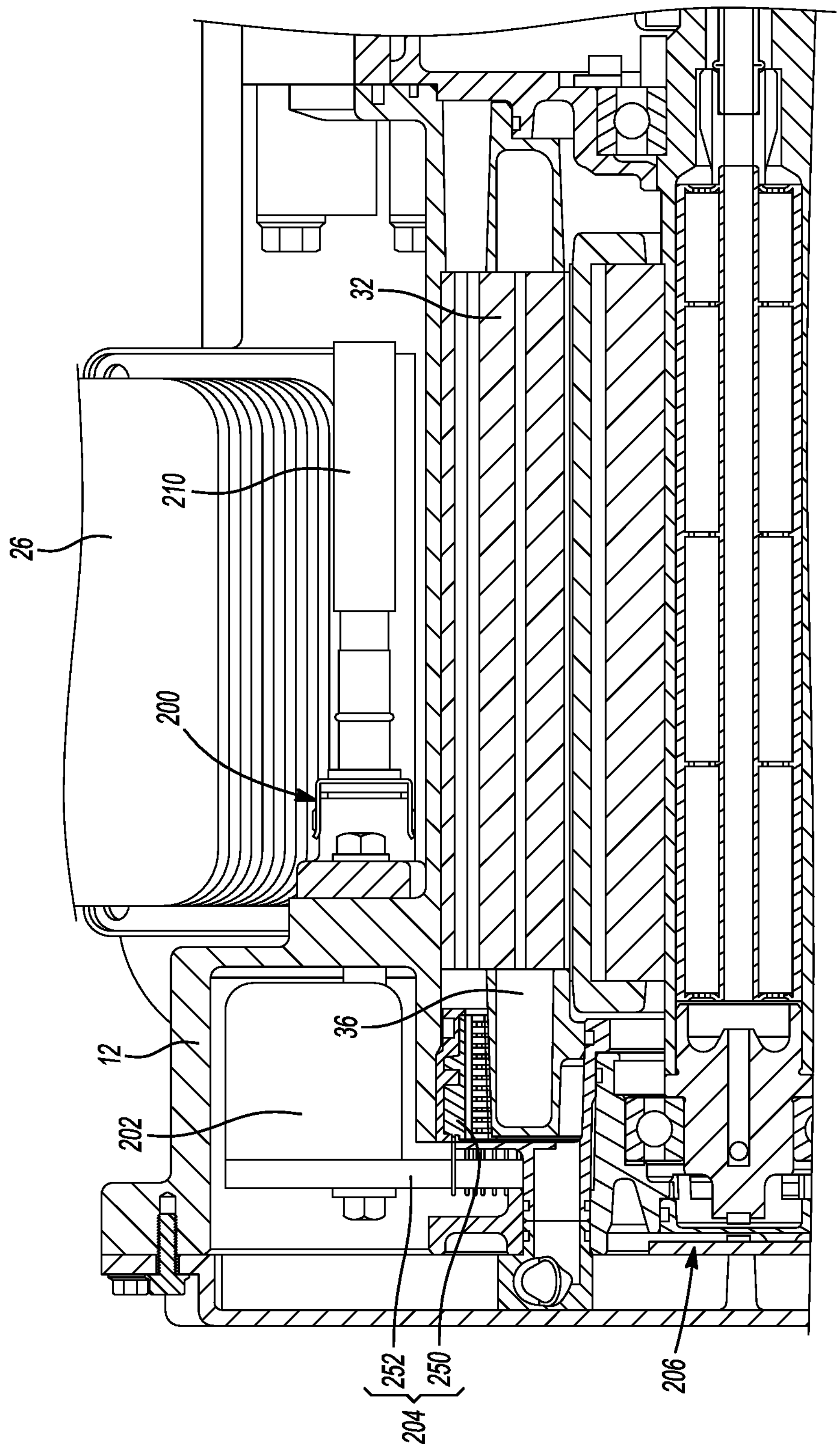


Fig-5

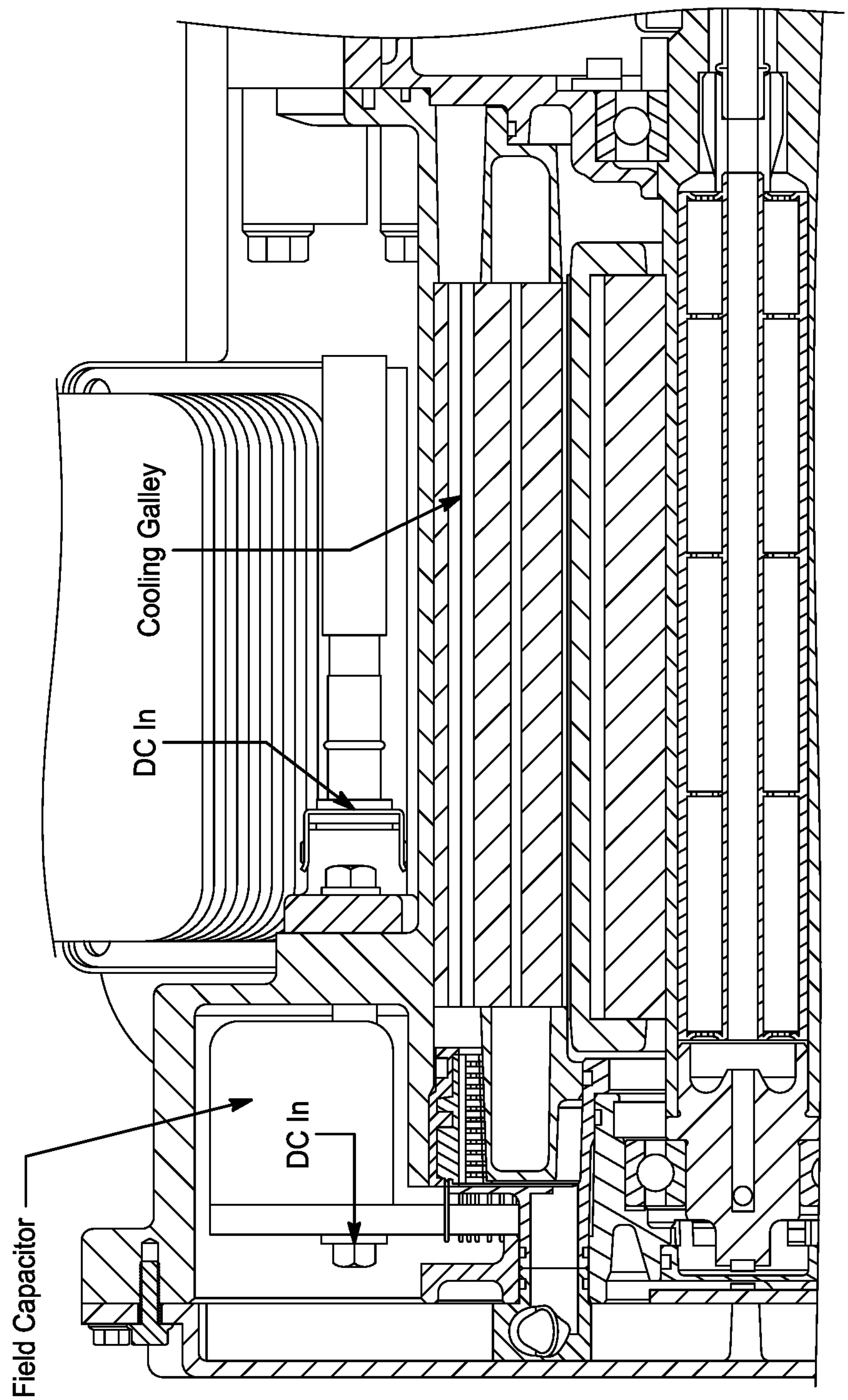


Fig-6

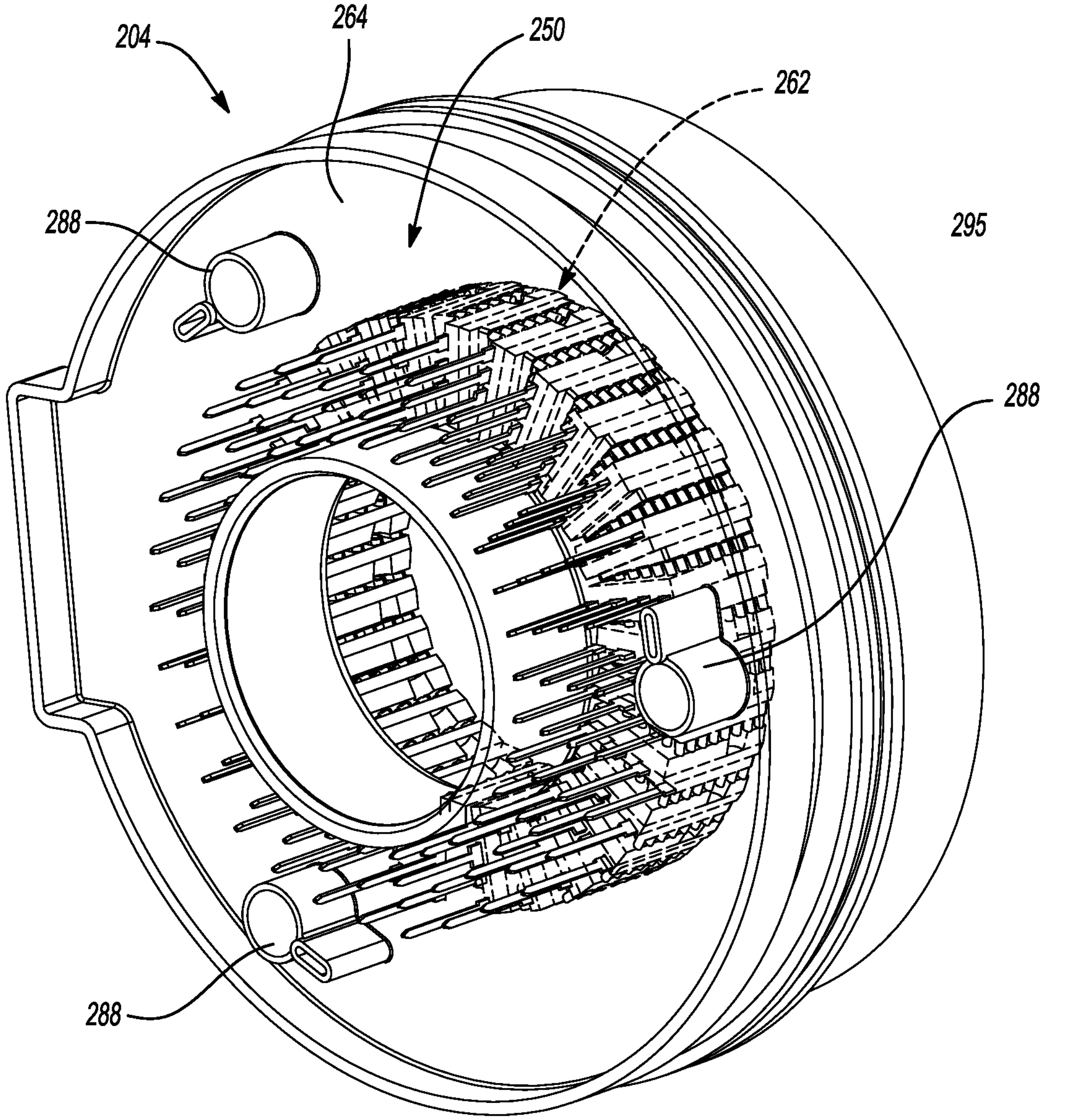


Fig-7

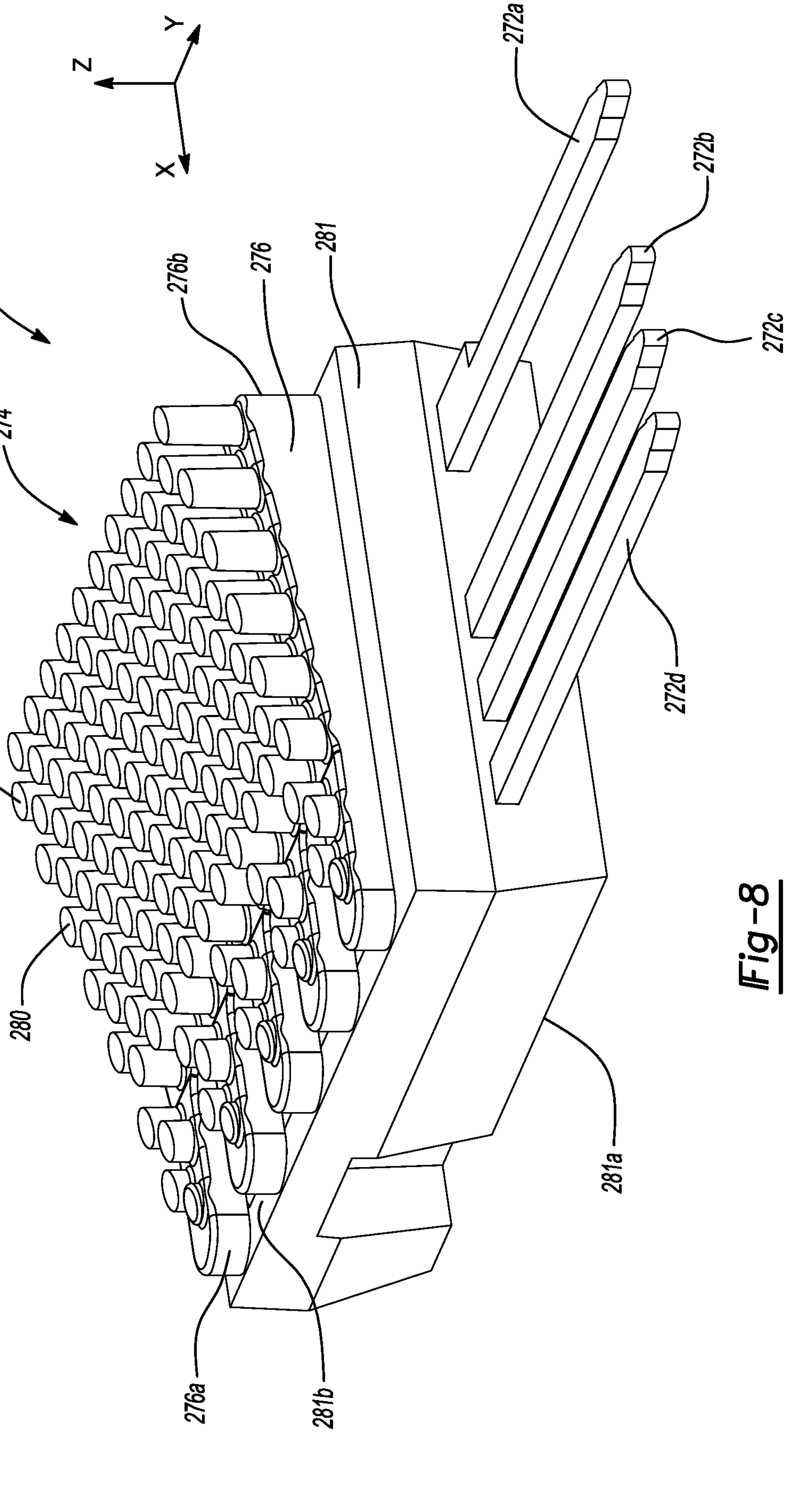

Y
Z
X
262
274
276b
276
281
272a
272b
272c
272d
280a
280
276a
281b
281a

Fig-8

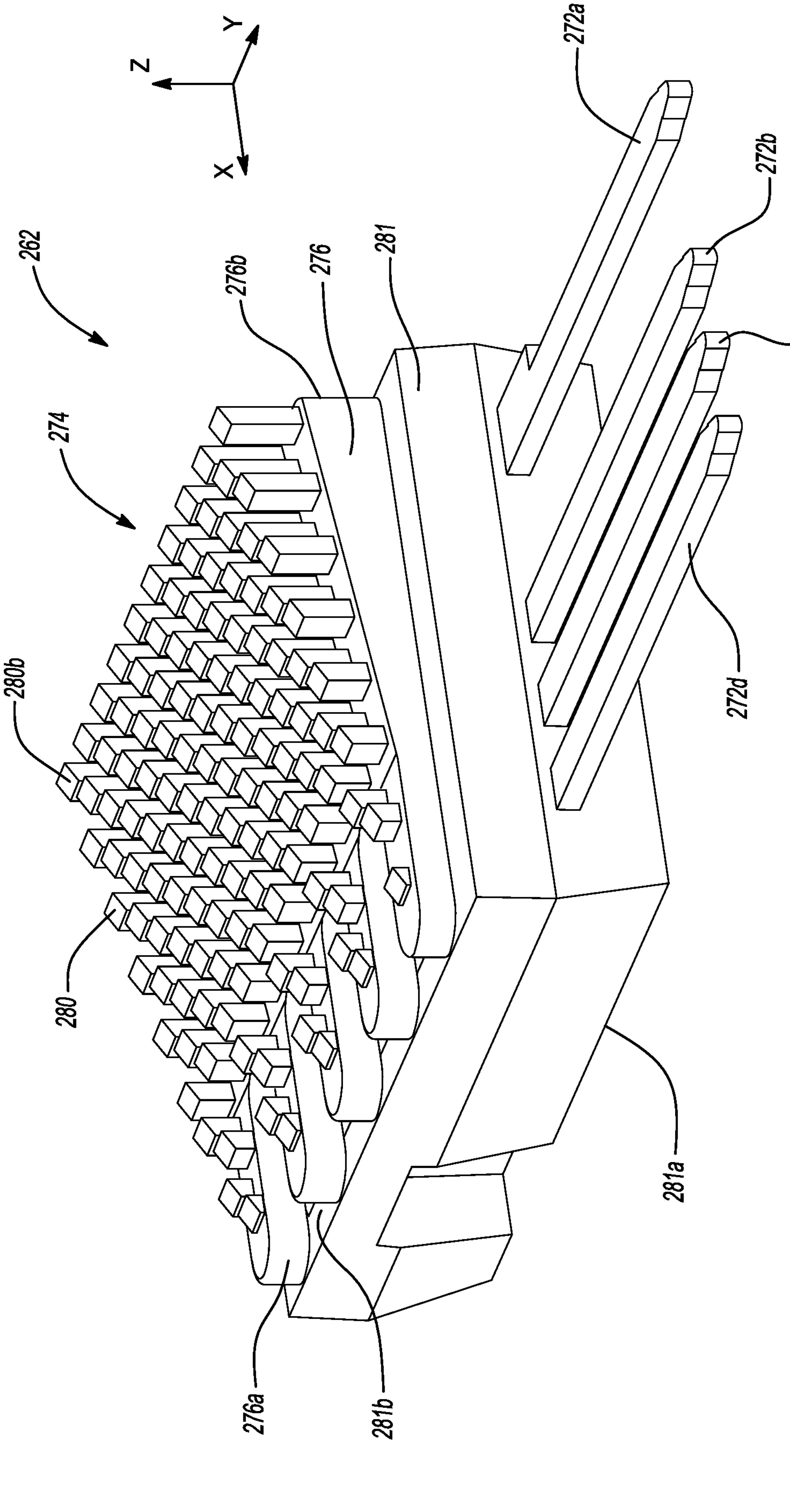

Y
Z
X
262
274
276b
276
281
272a
272b
272c
272d
280b
280
281a
276a
281b

Fig-9

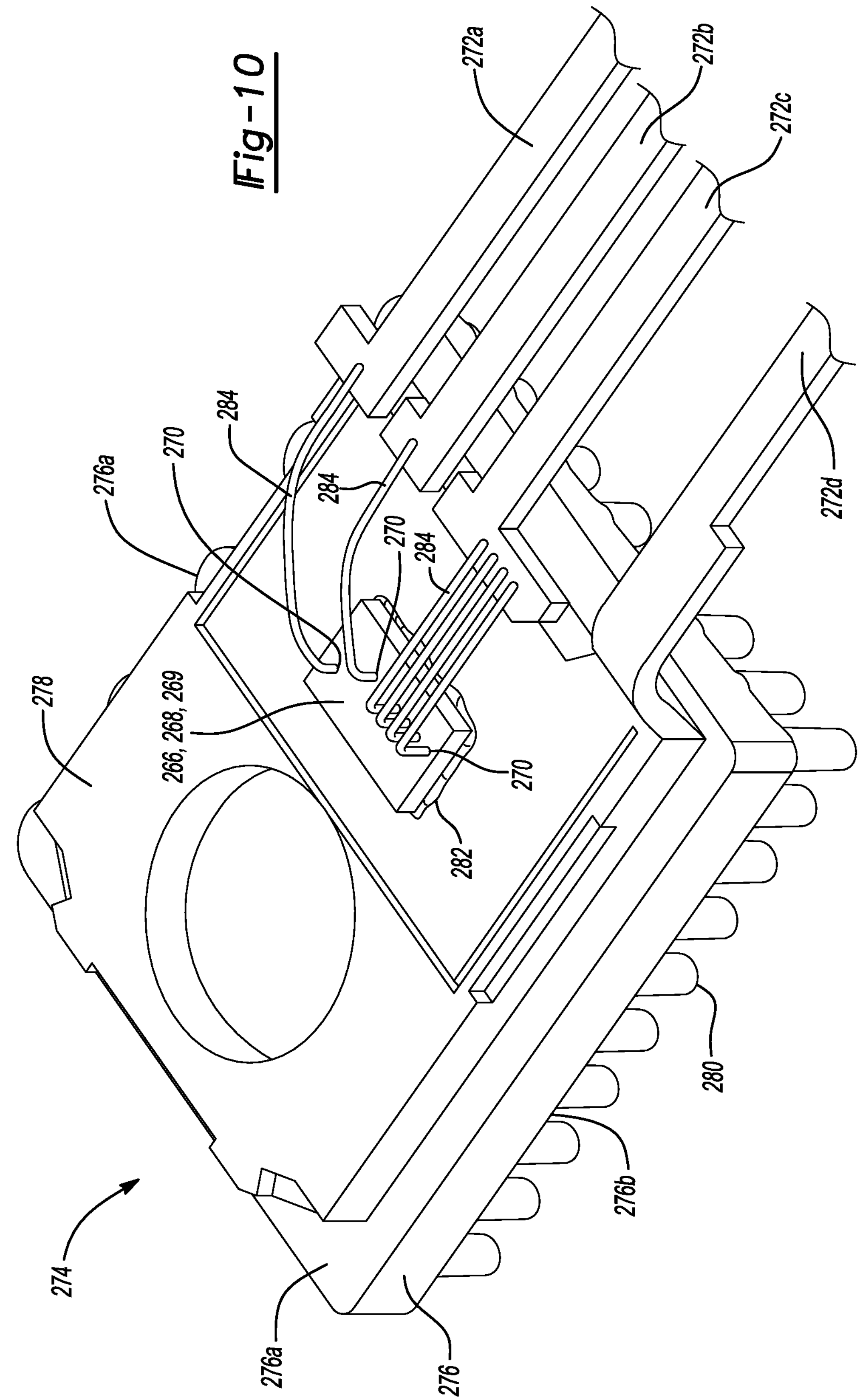

272a
272b
272c
272d
284
284
284
270
270
270
276a
278
266, 268, 269
282
280
276b
274
276a
276

Fig-10

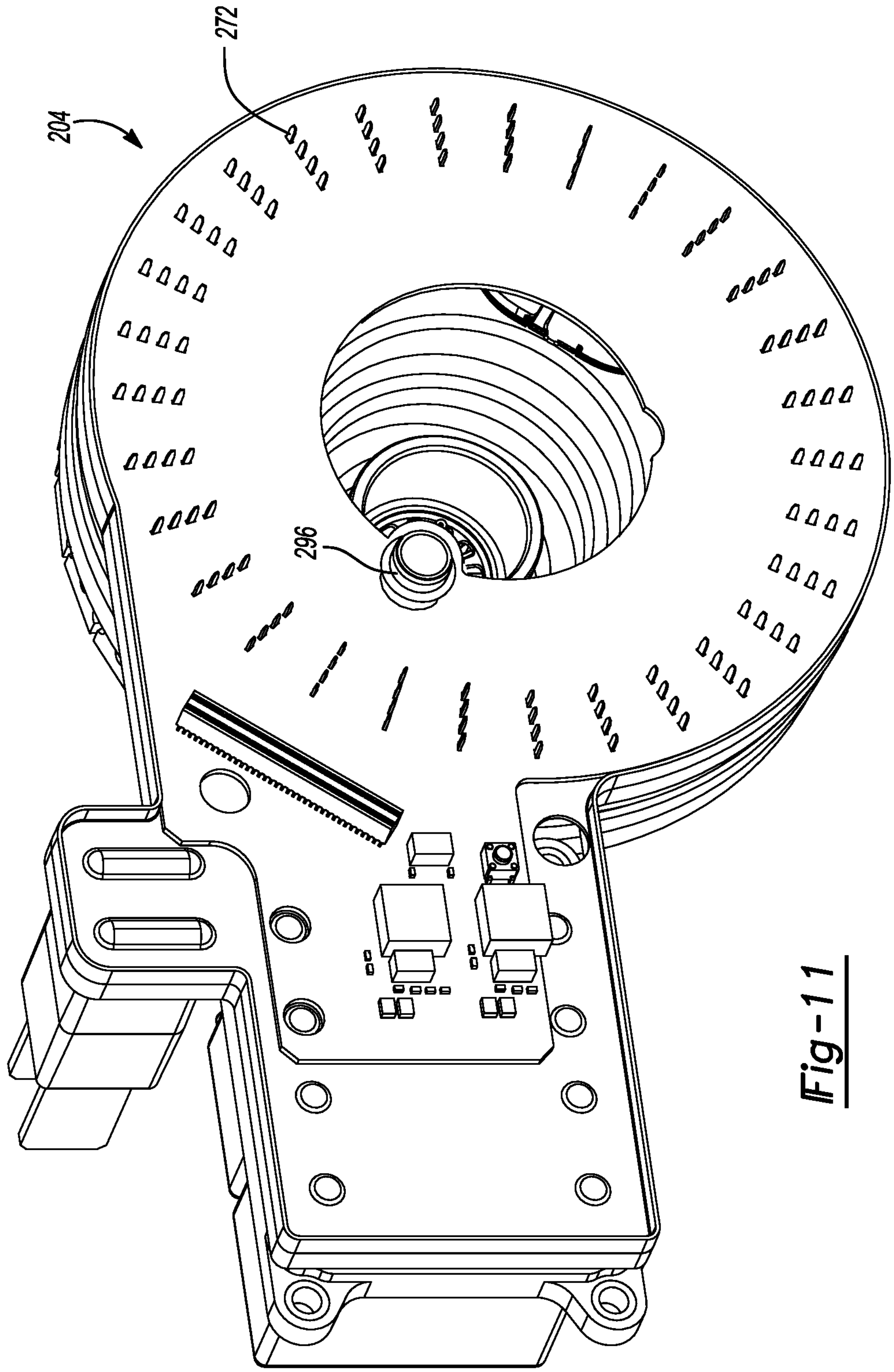


Fig-11

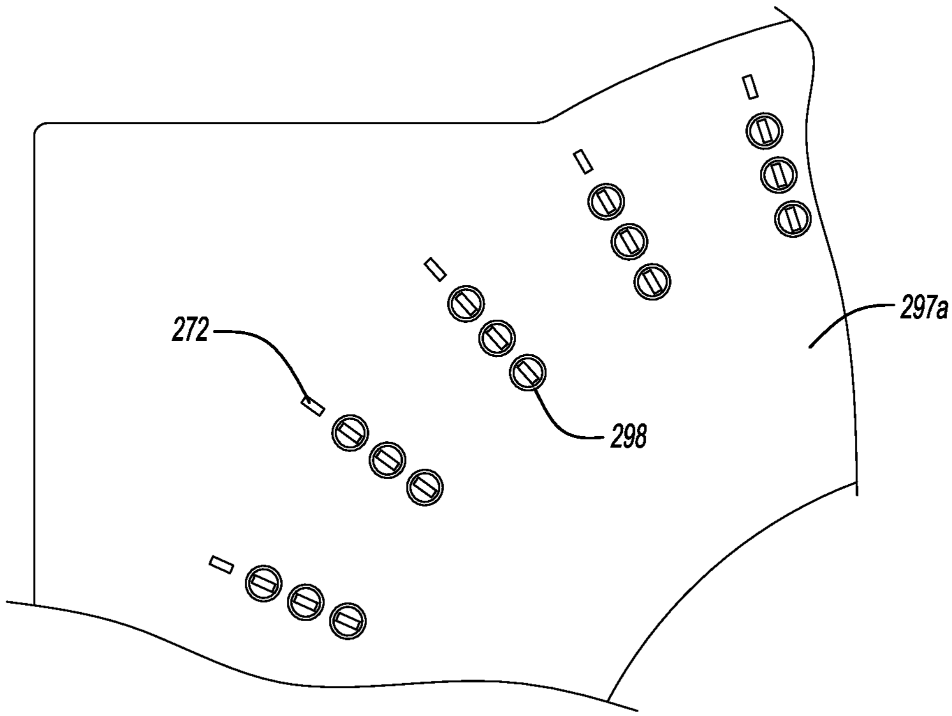


Fig-12

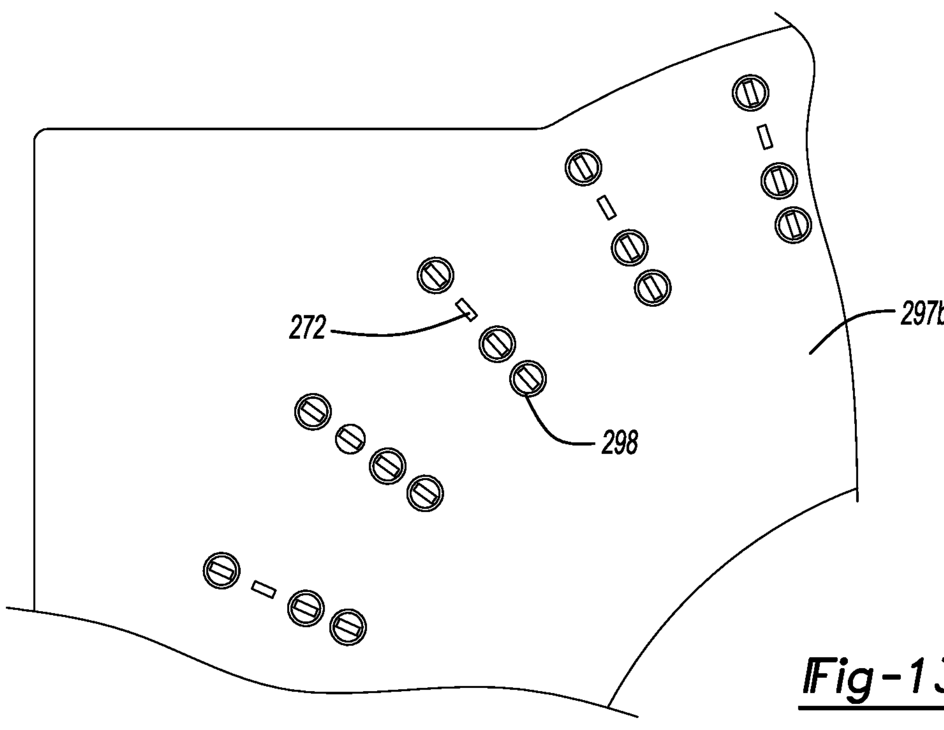


Fig-13

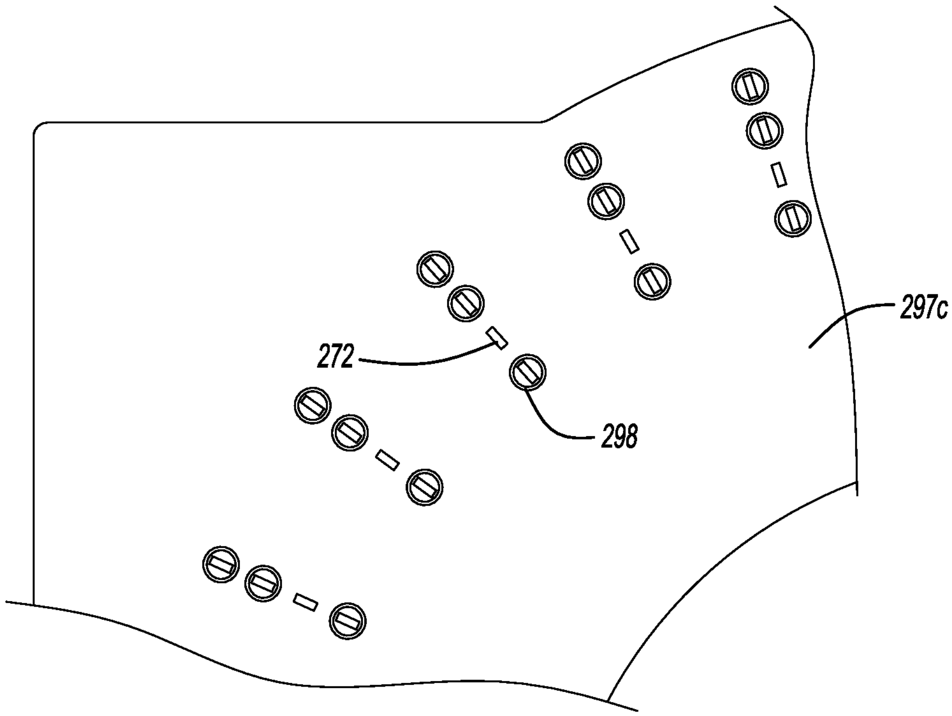


Fig-14

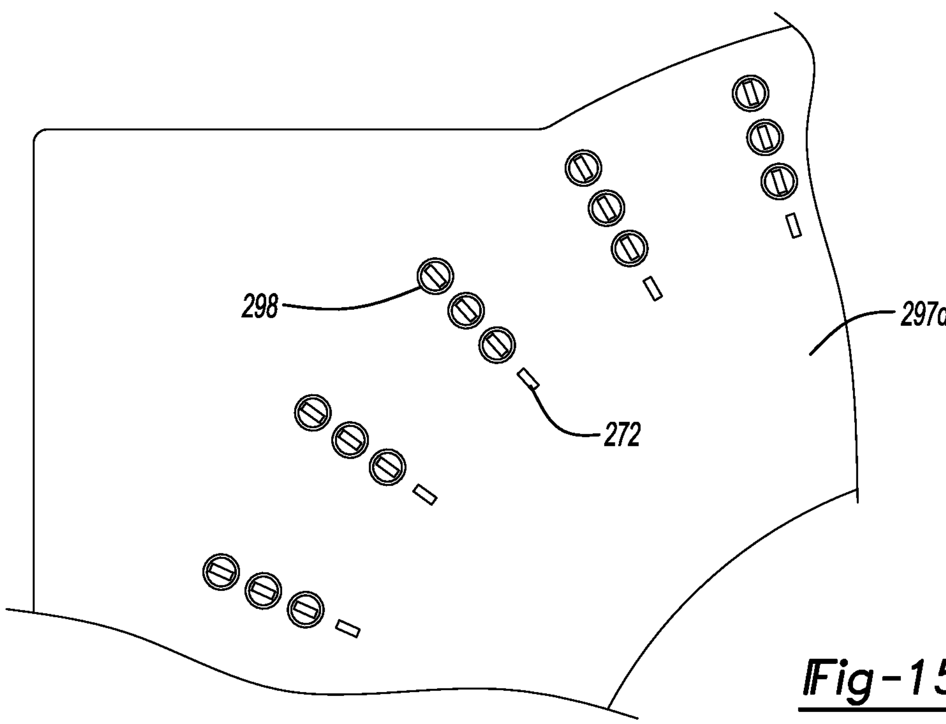


Fig-15

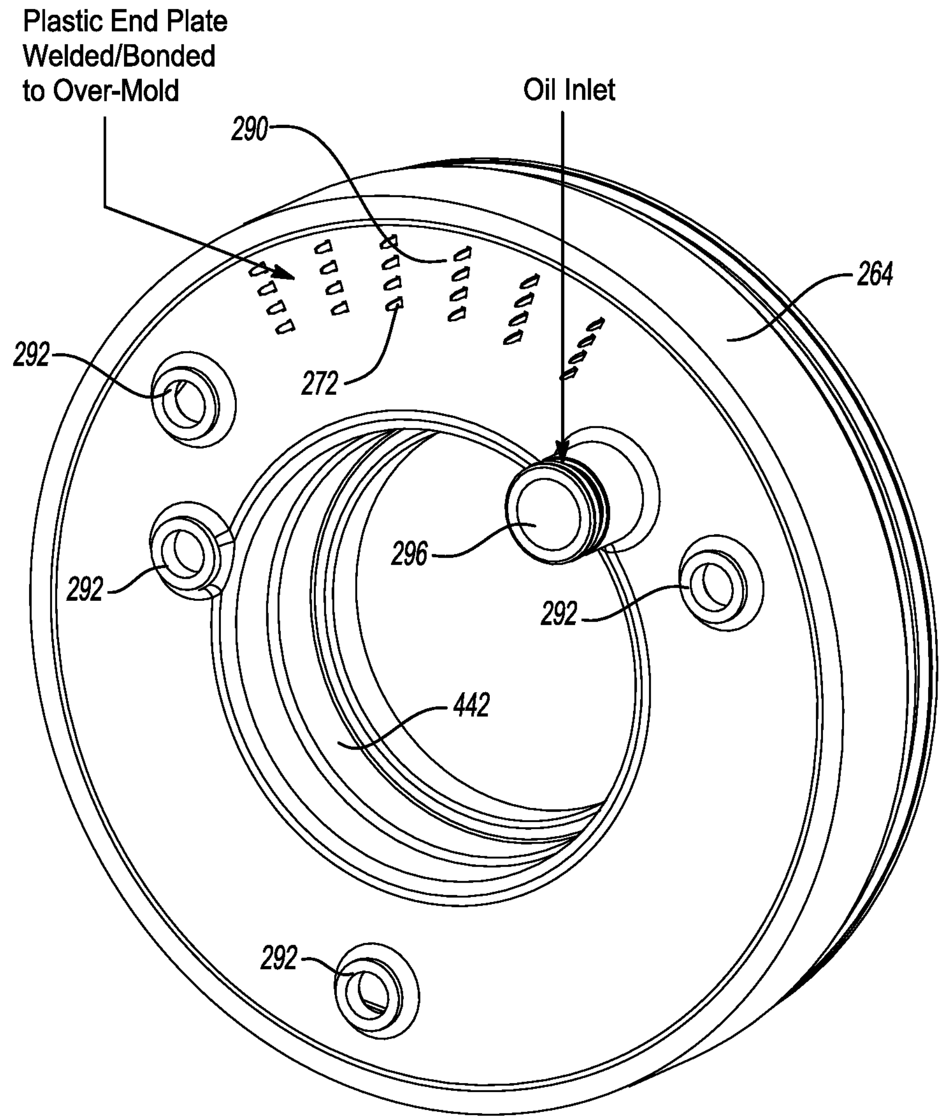

Plastic End Plate
Welded/Bonded
to Over-Mold
Oil Inlet
290
264
292
272
296
292
292
442
292

Fig-16

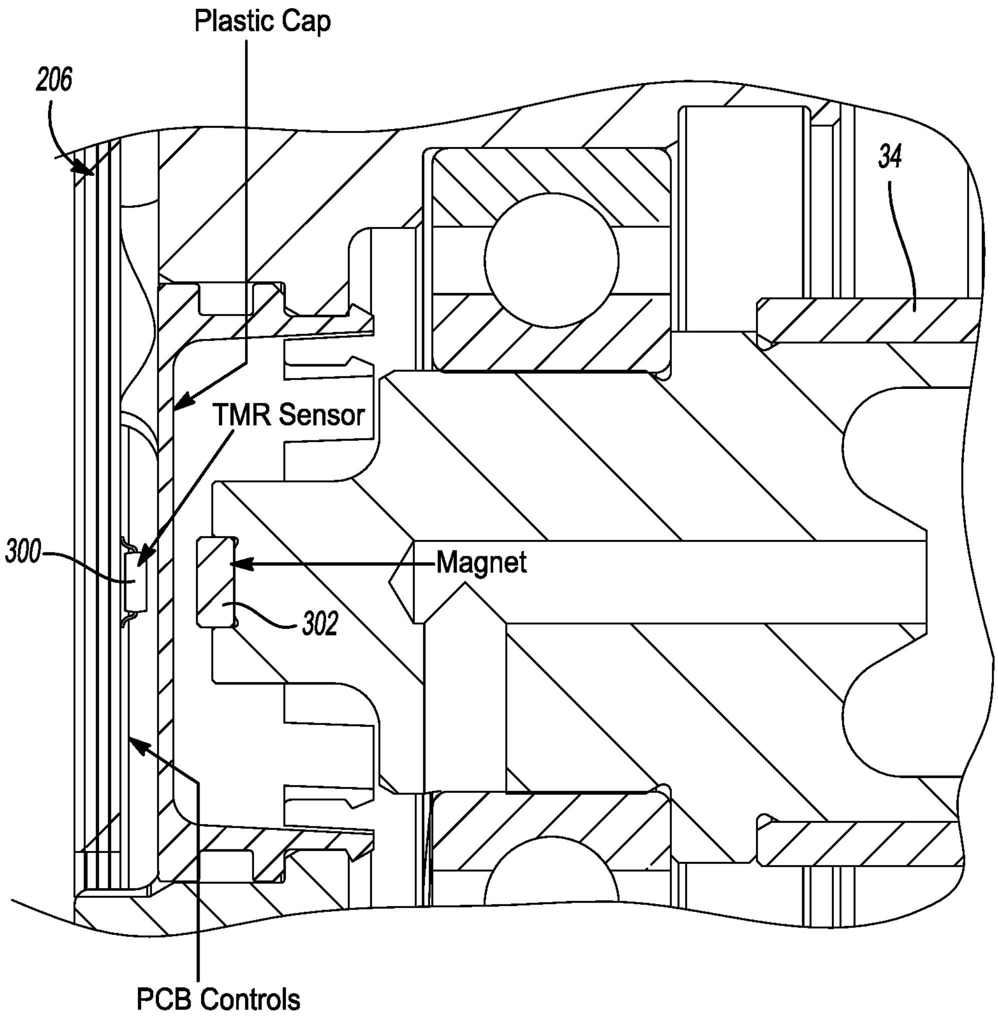


Fig-17

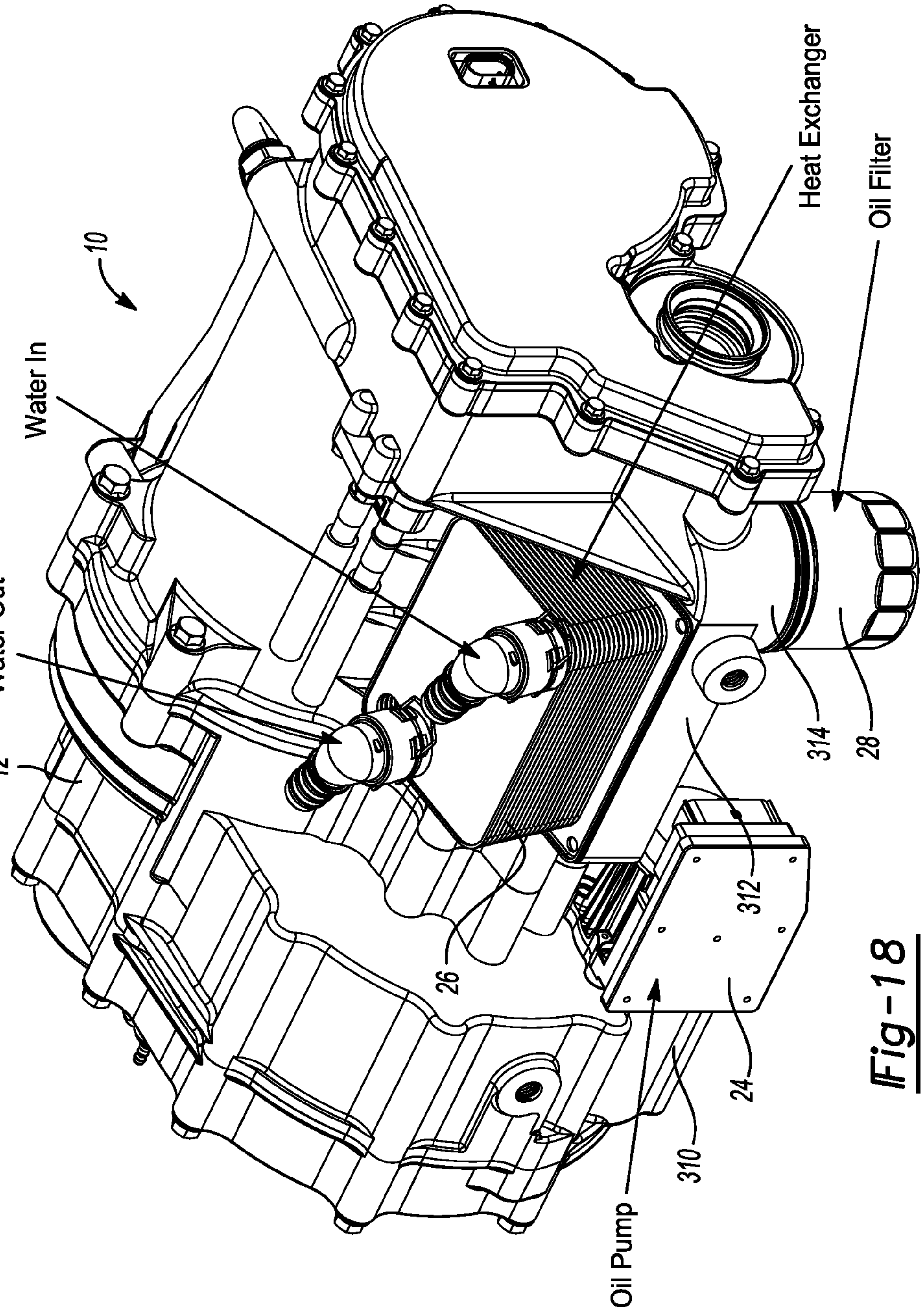

10
Water In
Water Out
12
Heat Exchanger
Oil Filter
314
28
312
26
24
310
Oil Pump

Fig-18

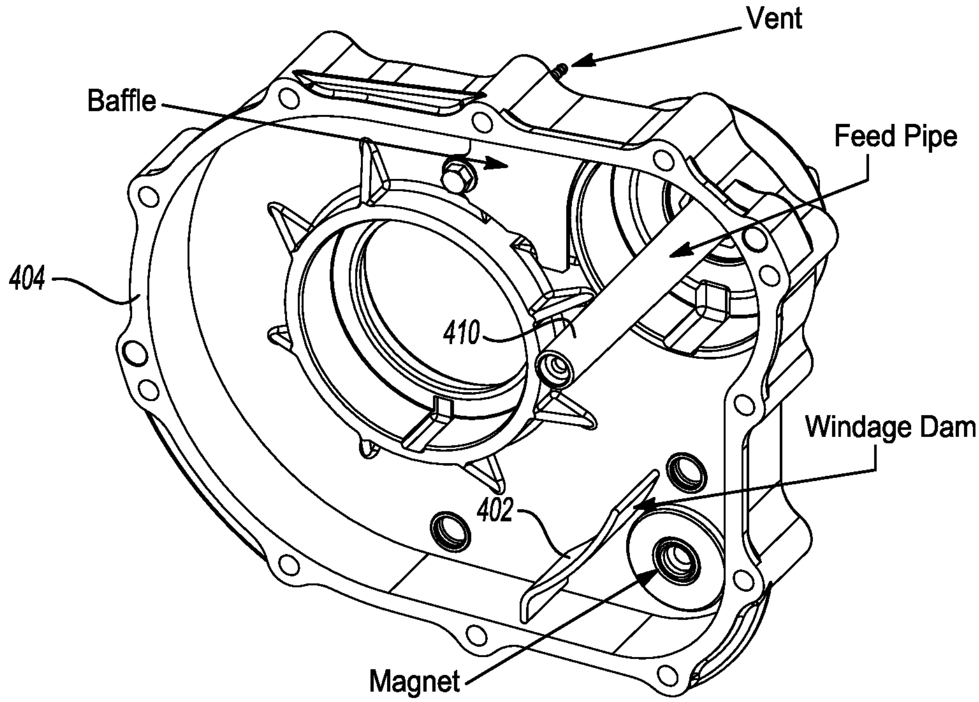

Vent
Baffle
Feed Pipe
404
410
Windage Dam
402
Magnet

Fig-19

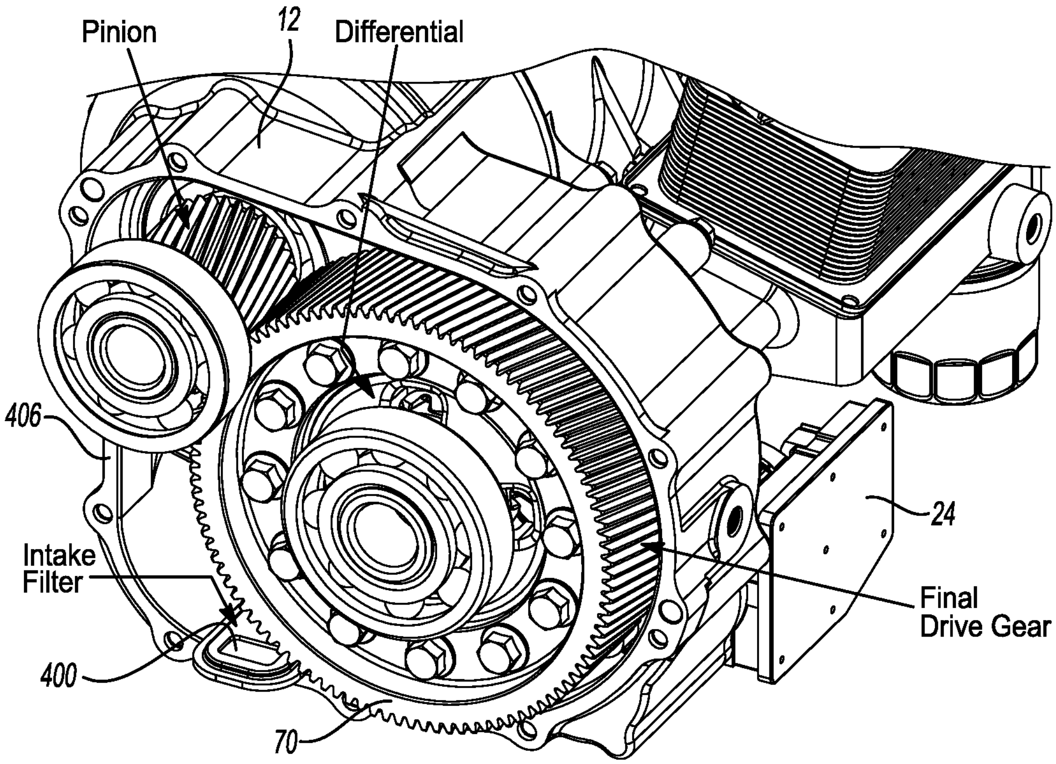

Pinion
12
Differential
406
24
Intake
Filter
Final
Drive Gear
400
70

Fig-20

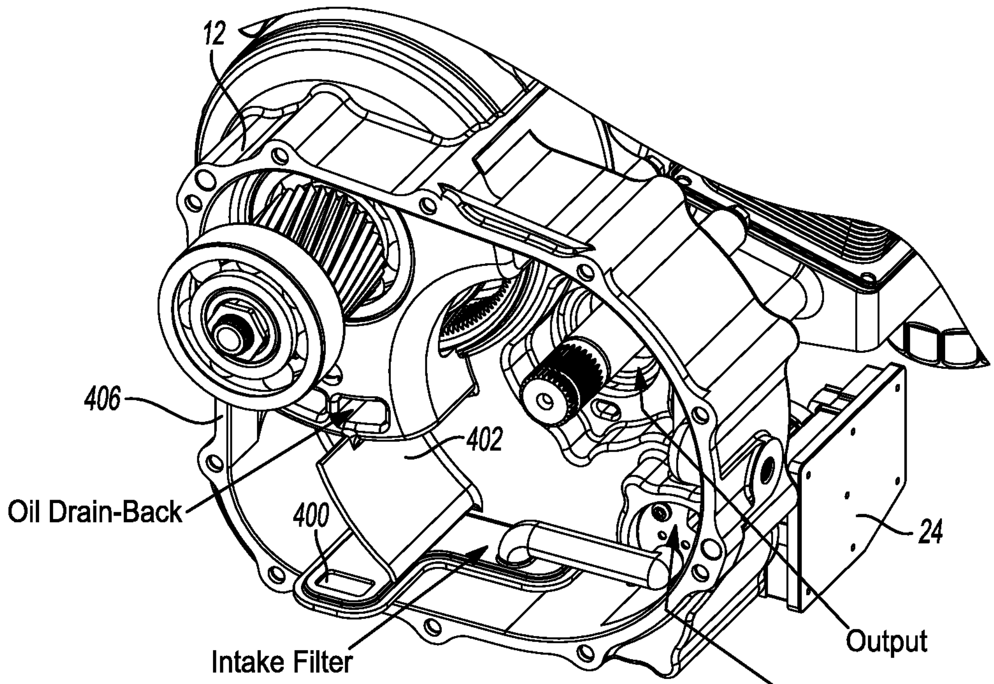

12
406
402
Oil Drain-Back
400
24
Intake Filter
Output
Oil Pump

Fig-21

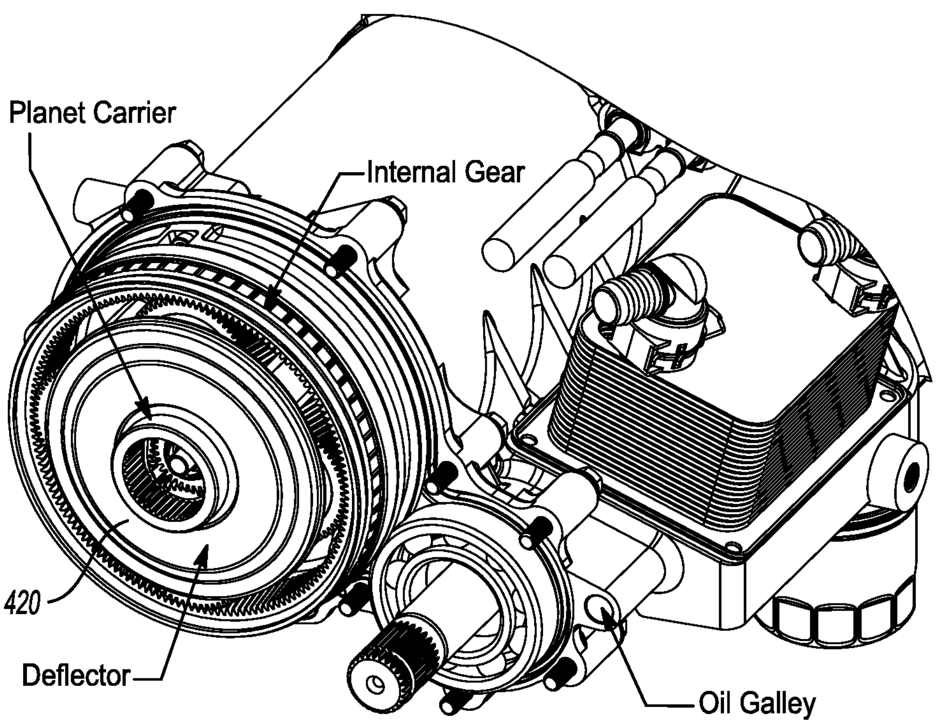

Planet Carrier
Internal Gear
420
Deflector
Oil Galley

Fig-22

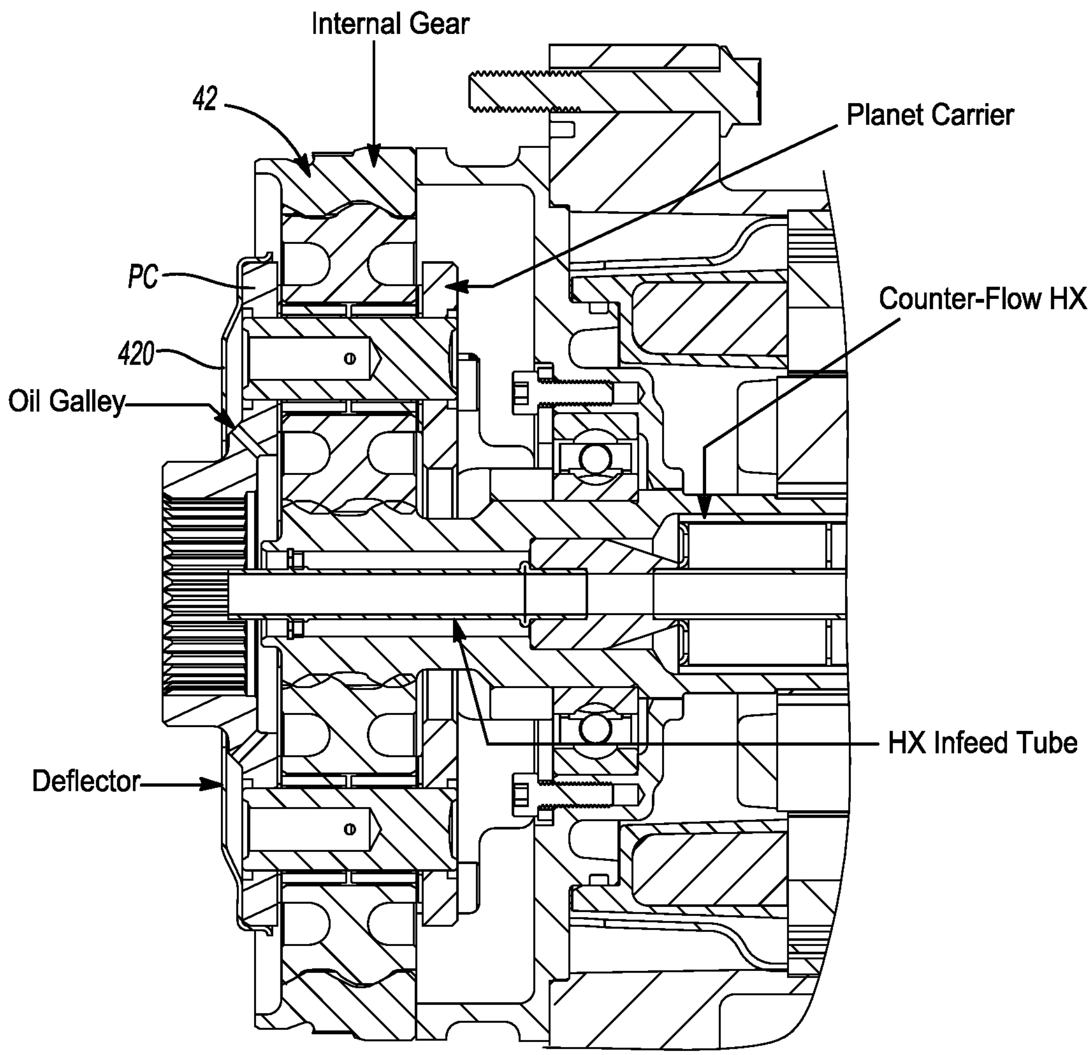

Internal Gear
42
Planet Carrier
PC
Counter-Flow HX
420
Oil Galley
HX Infeed Tube
Deflector

Fig-23

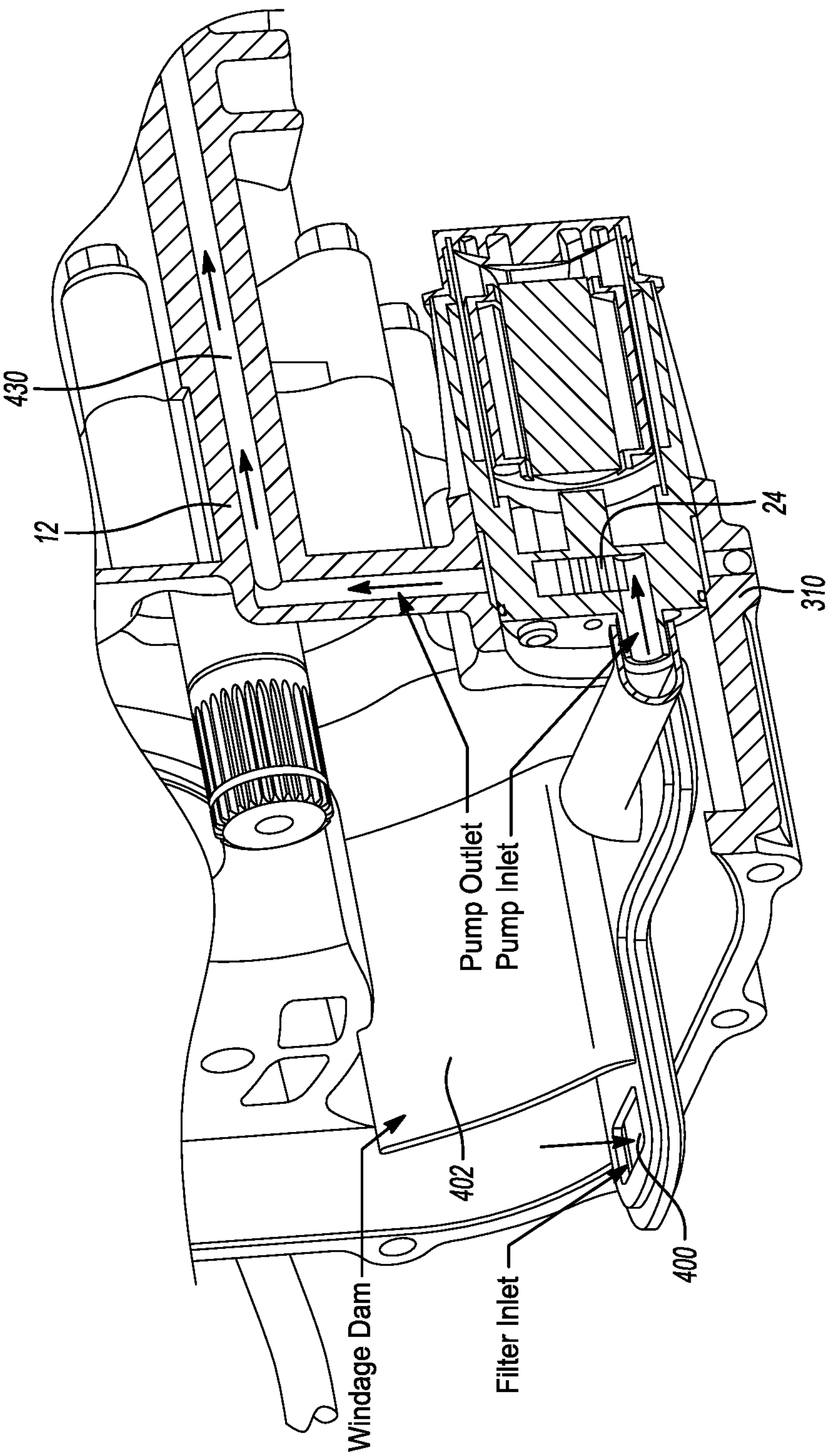

430
12
24
310
Pump Outlet
Pump Inlet
402
400
Windage Dam
Filter Inlet

Fig-24

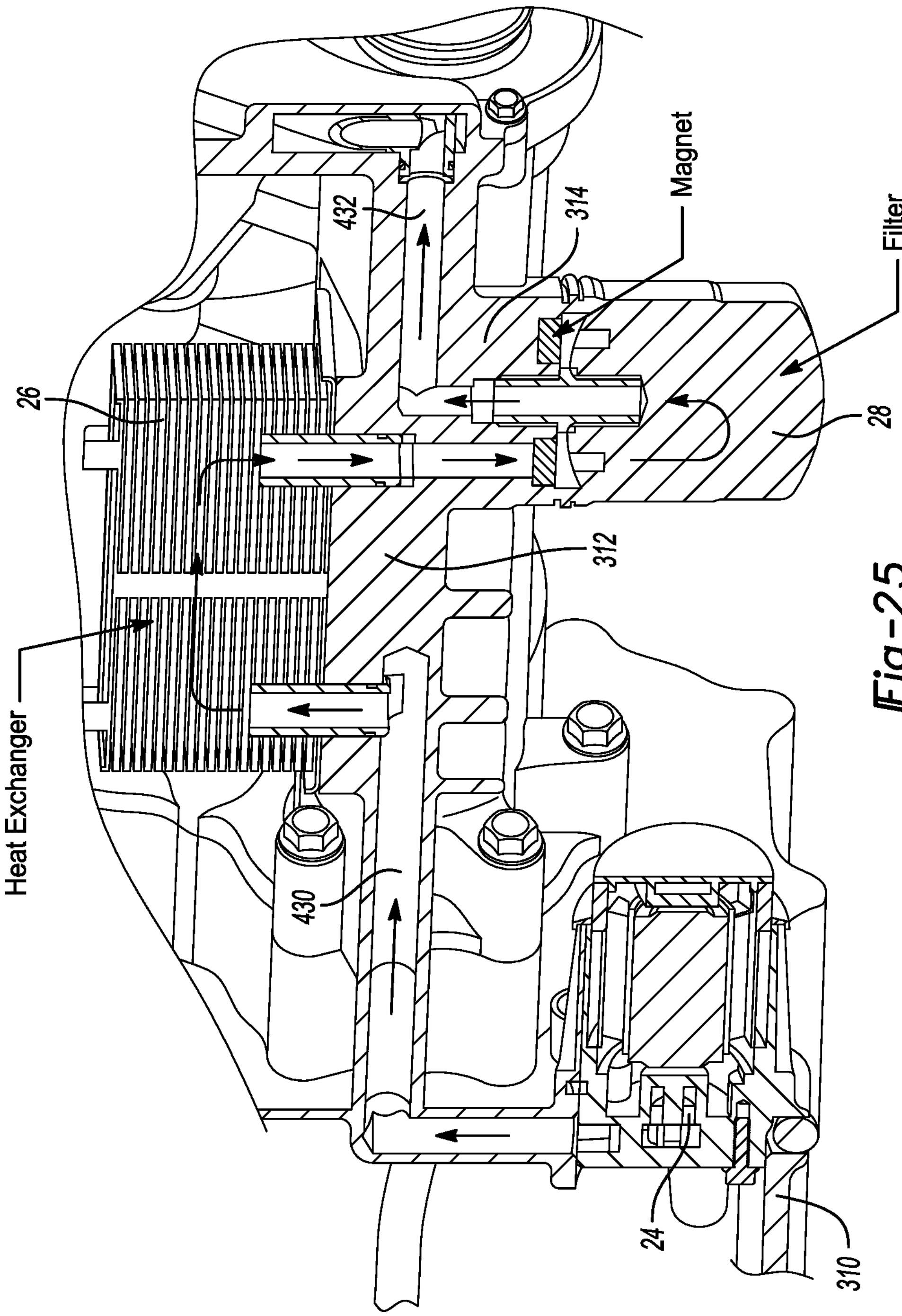


Fig-25

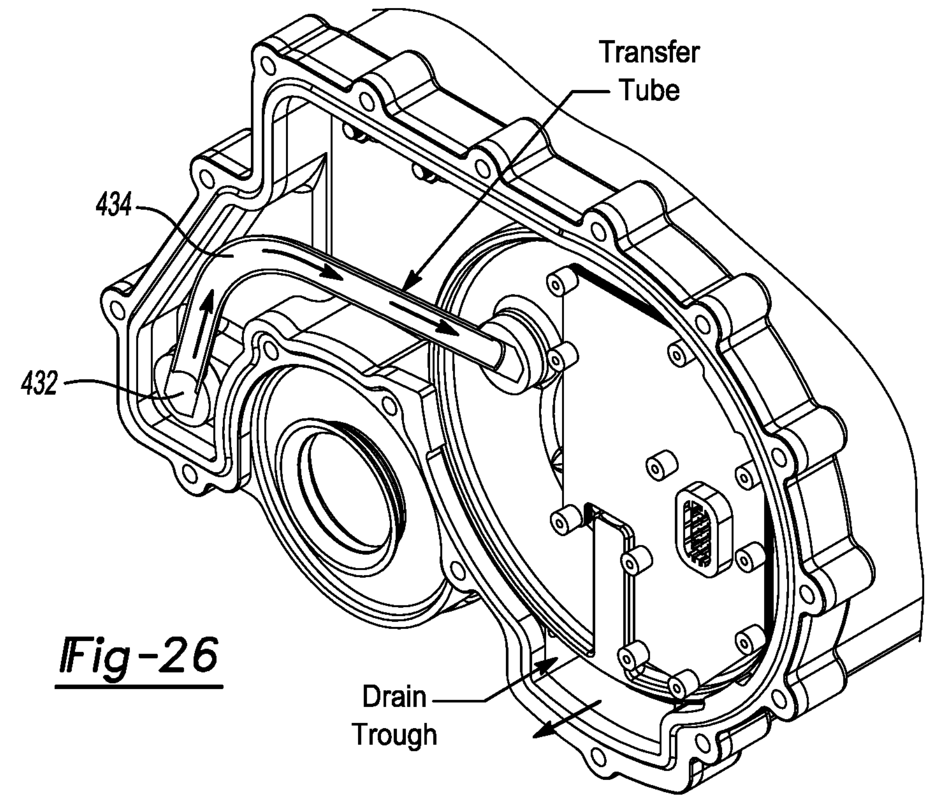

Transfer
Tube
434
432
Drain
Trough

Fig-26

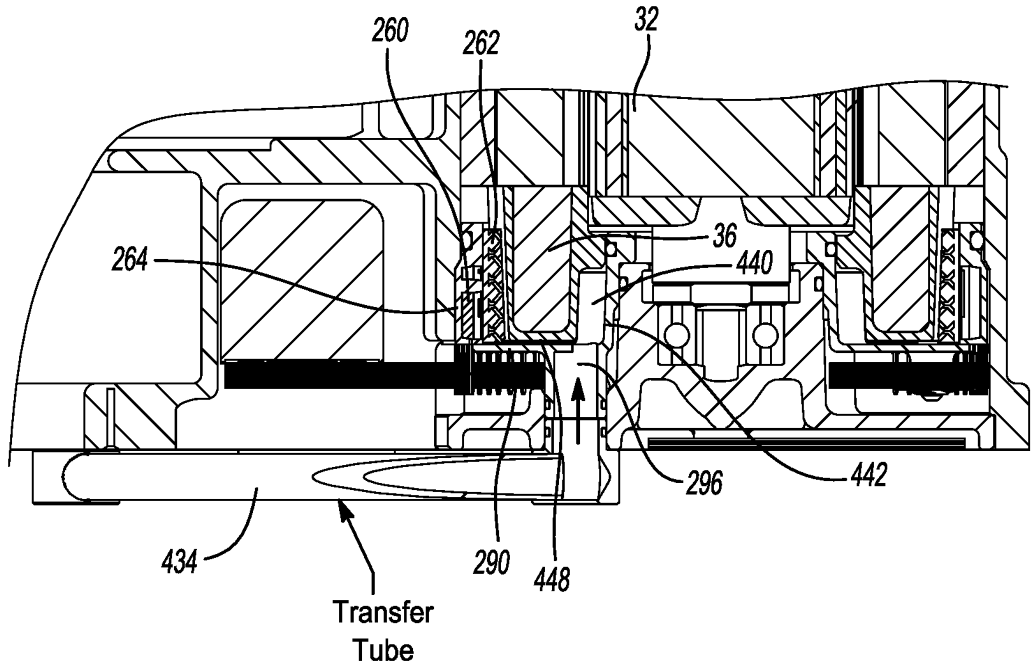

260
262
32
264
36
440
296
442
434
290
448
Transfer
Tube

Fig-27

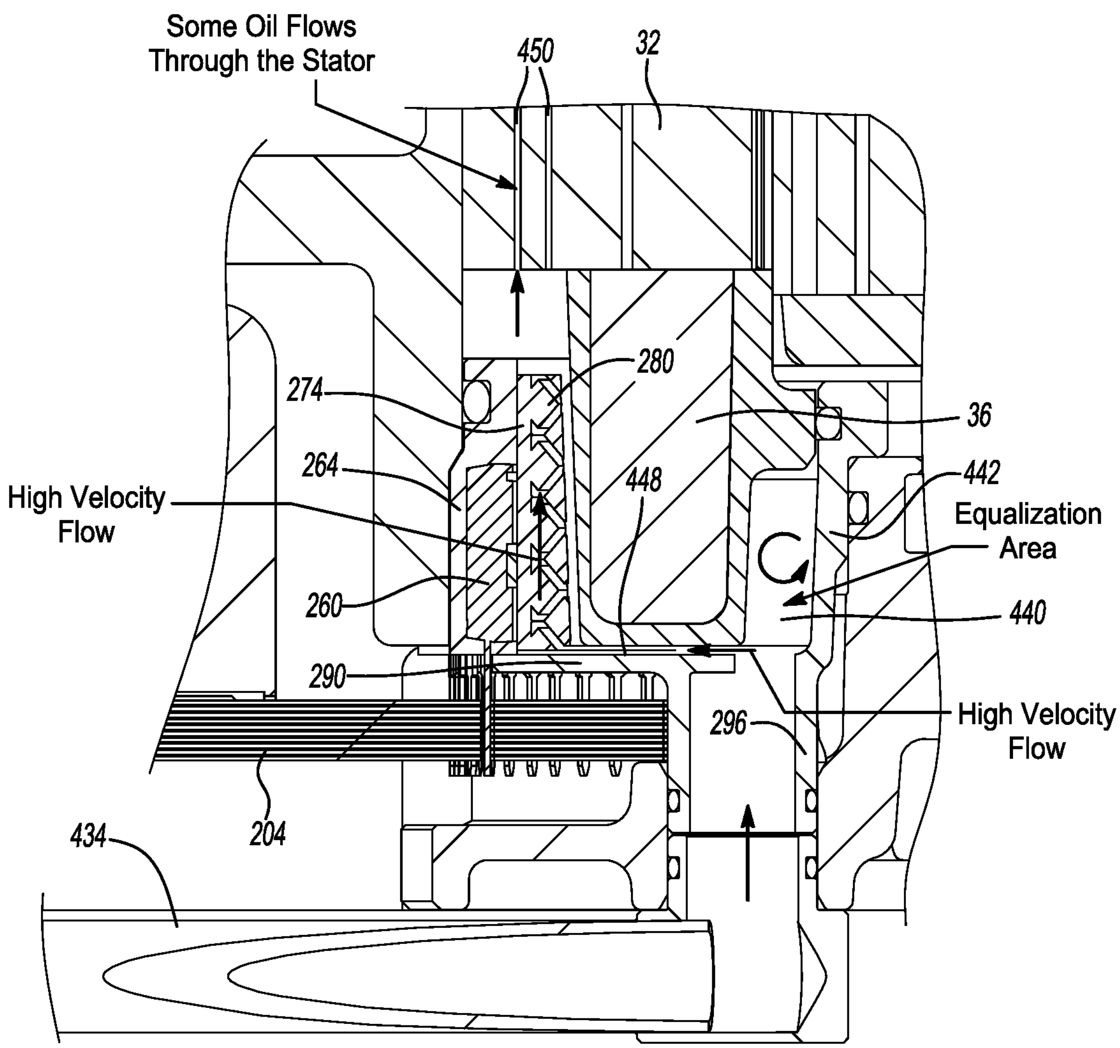

Some Oil Flows
Through the Stator
450
32
280
274
36
264
448
442
High Velocity
Flow
Equalization
Area
260
440
290
High Velocity
Flow
296
434
204

Fig-28

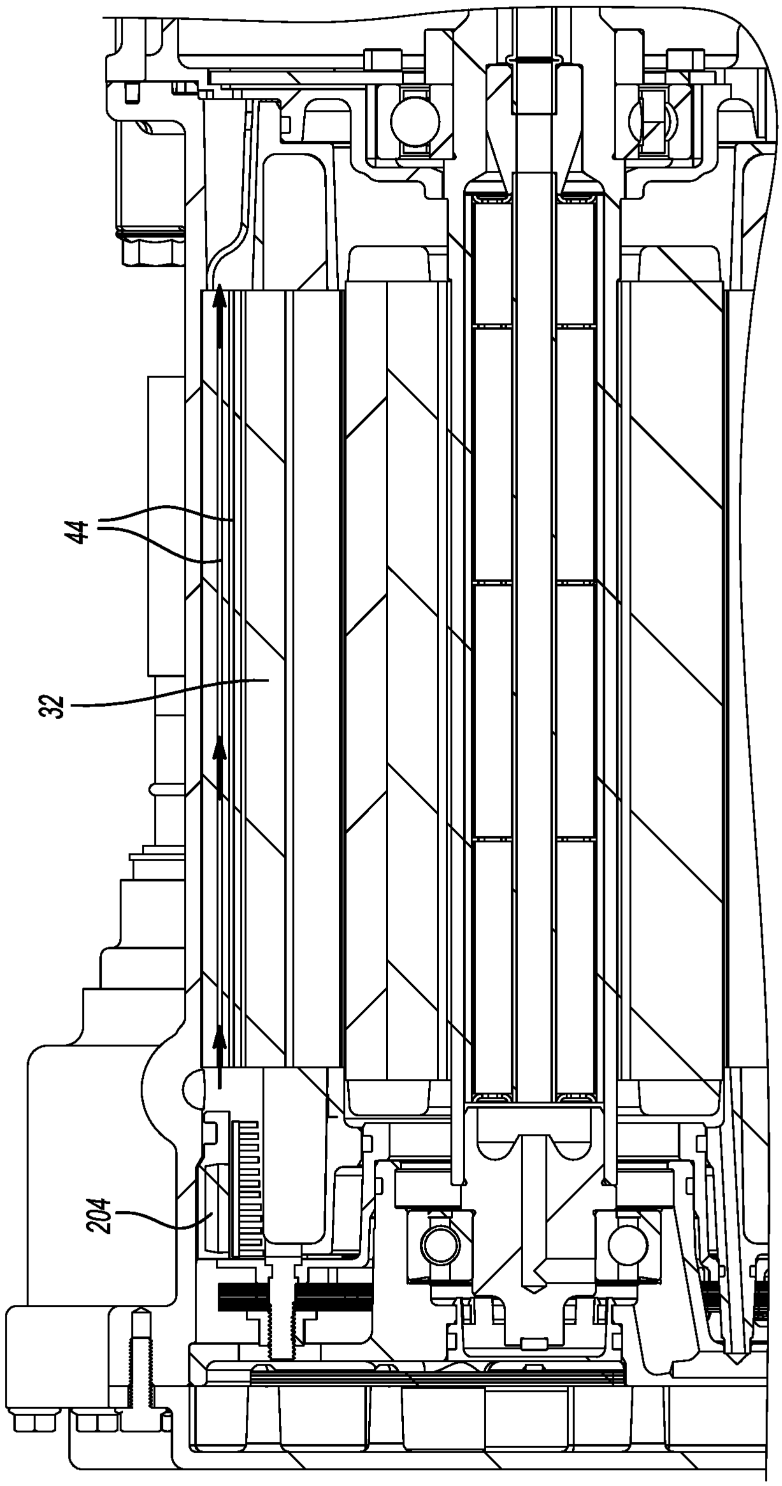


Fig-29

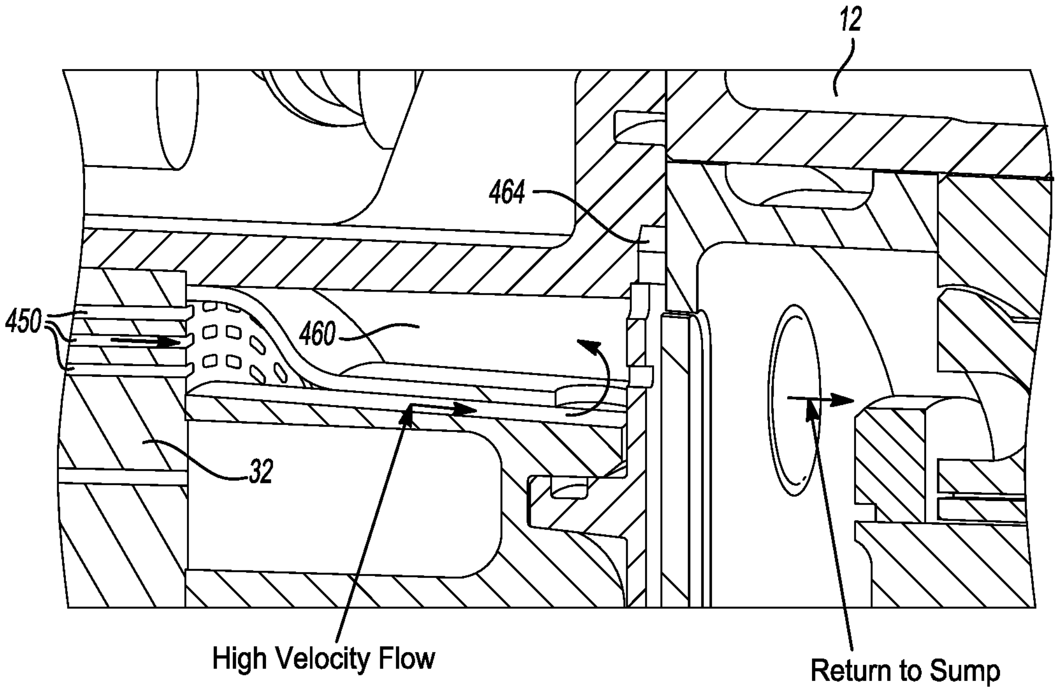

12
464
450
460
32
High Velocity Flow
Return to Sump

Fig-30

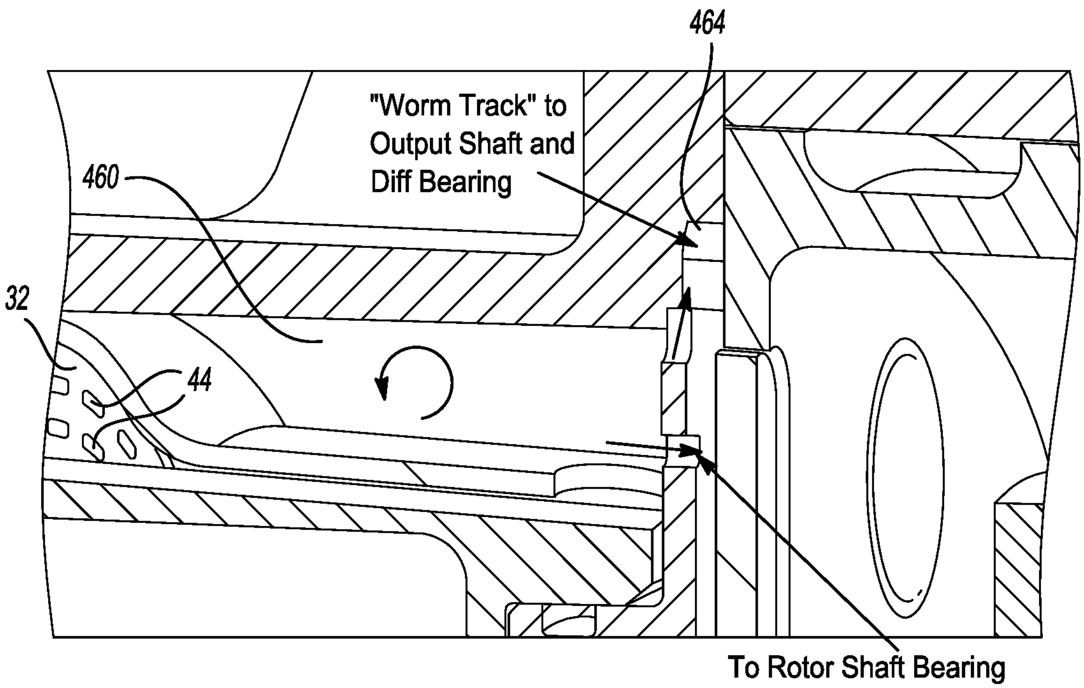

464
"Worm Track" to
Output Shaft and
Diff Bearing
460
32
44
To Rotor Shaft Bearing

Fig-31

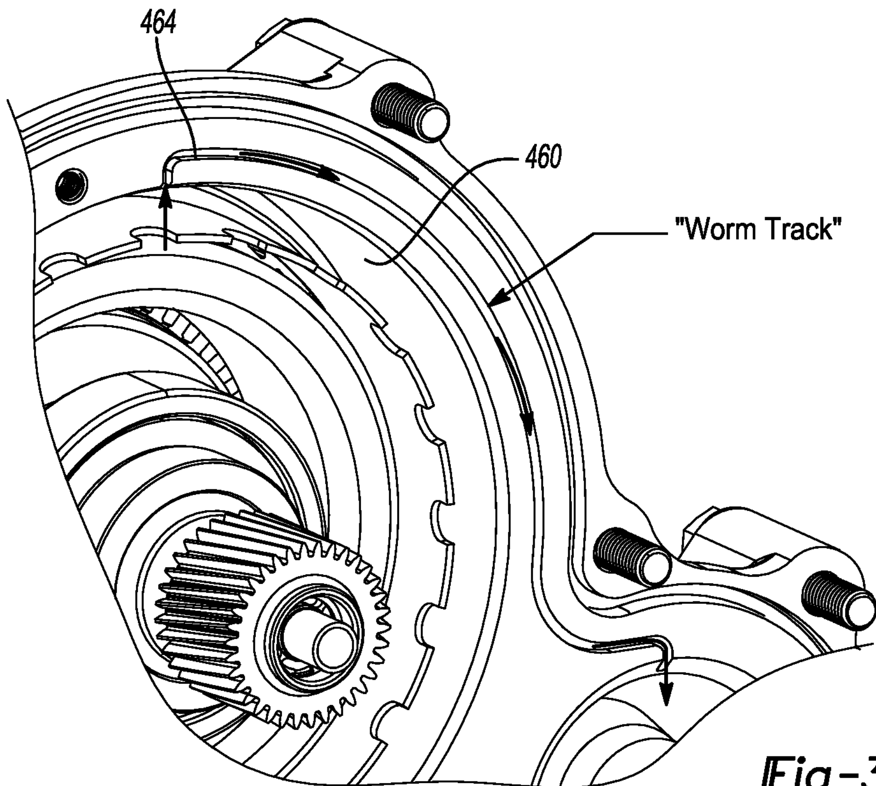

464
460
"Worm Track"

Fig-32

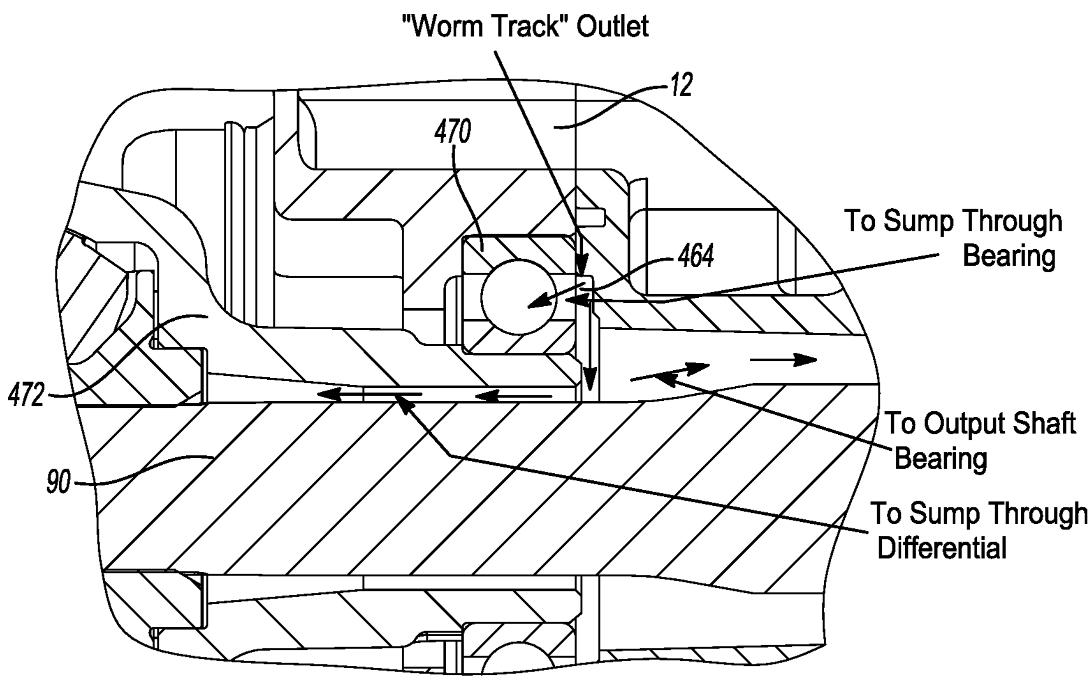

"Worm Track" Outlet
12
470
464
To Sump Through Bearing
472
To Output Shaft Bearing
90
To Sump Through Differential

Fig-33

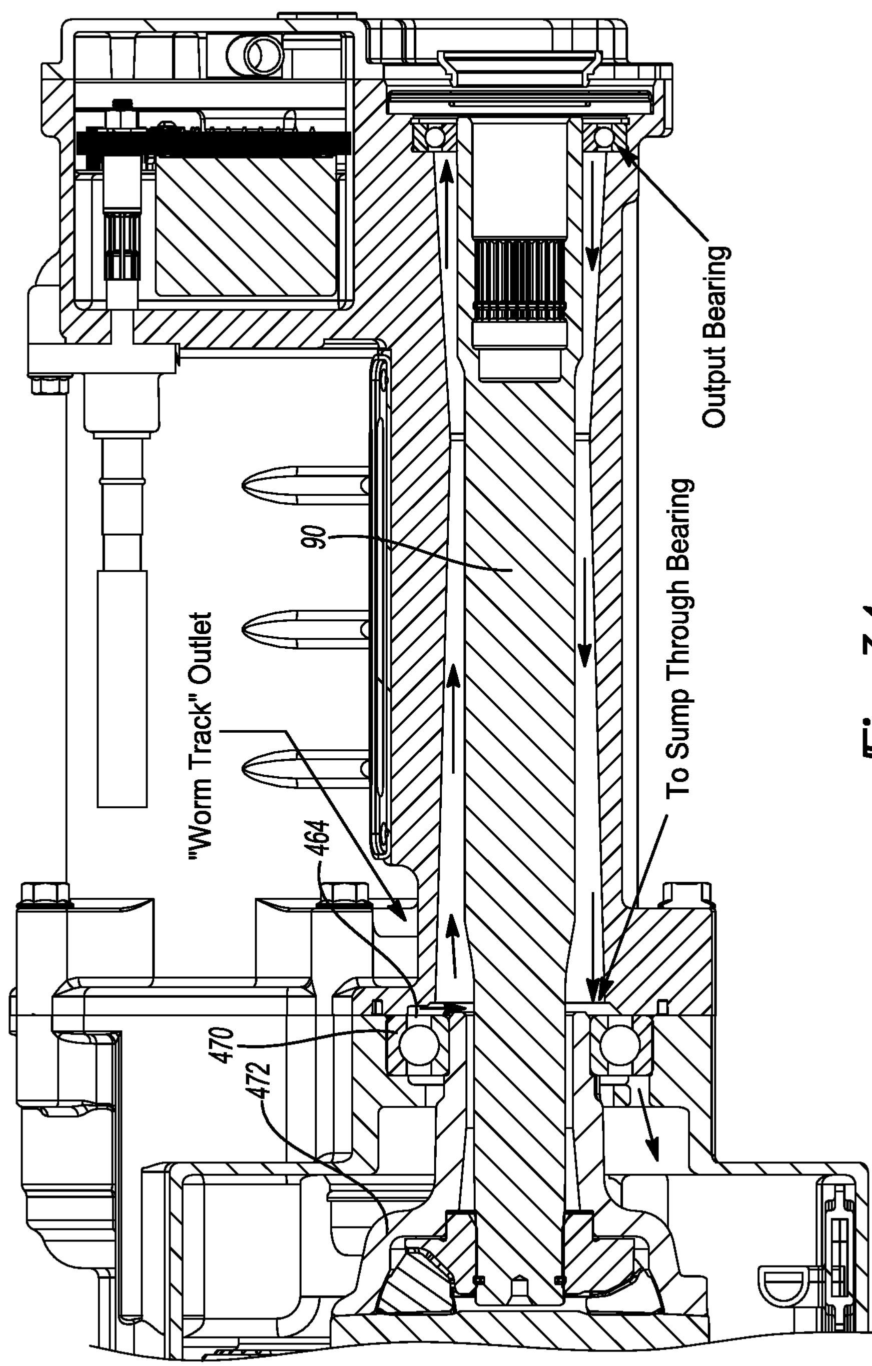

Output Bearing
To Sump Through Bearing
"Worm Track" Outlet
90
464
470
472

Fig-34

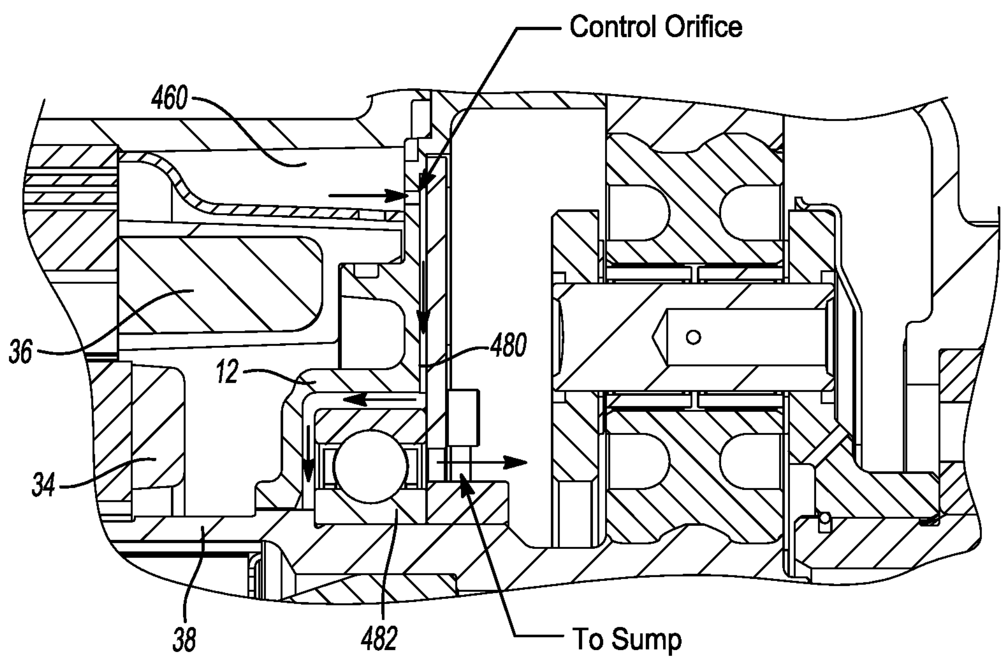

Control Orifice
460
36
480
12
34
38
482
To Sump

Fig-35

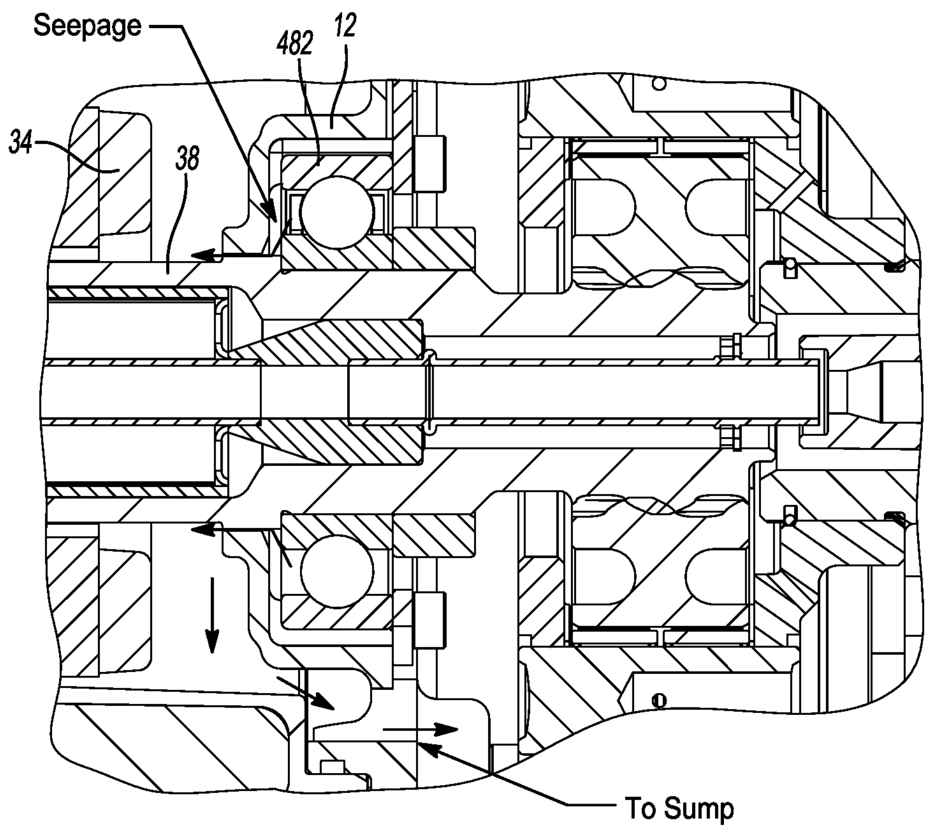

Seepage
482
12
34
38
To Sump

Fig-36

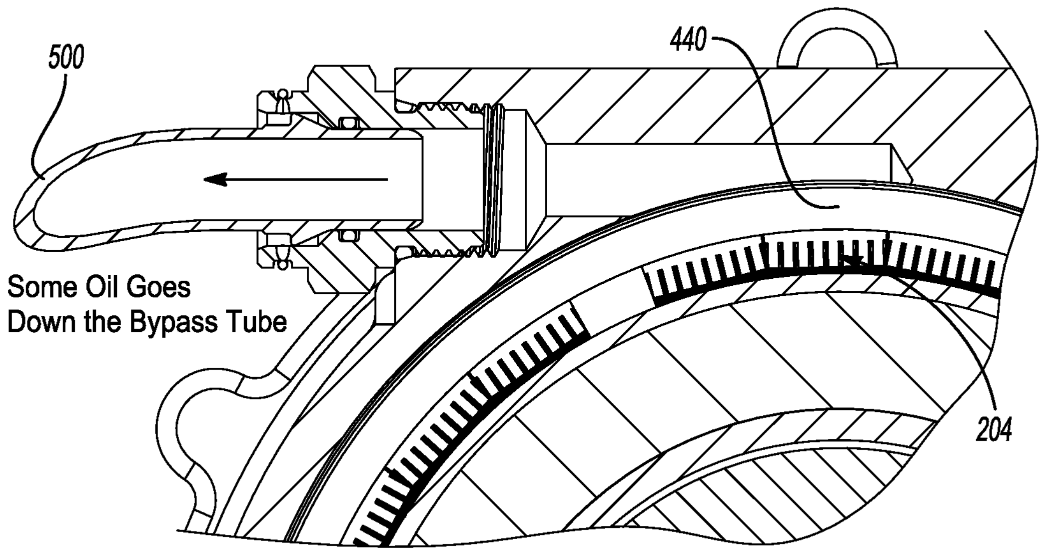

500
440
Some Oil Goes
Down the Bypass Tube
204

Fig-37

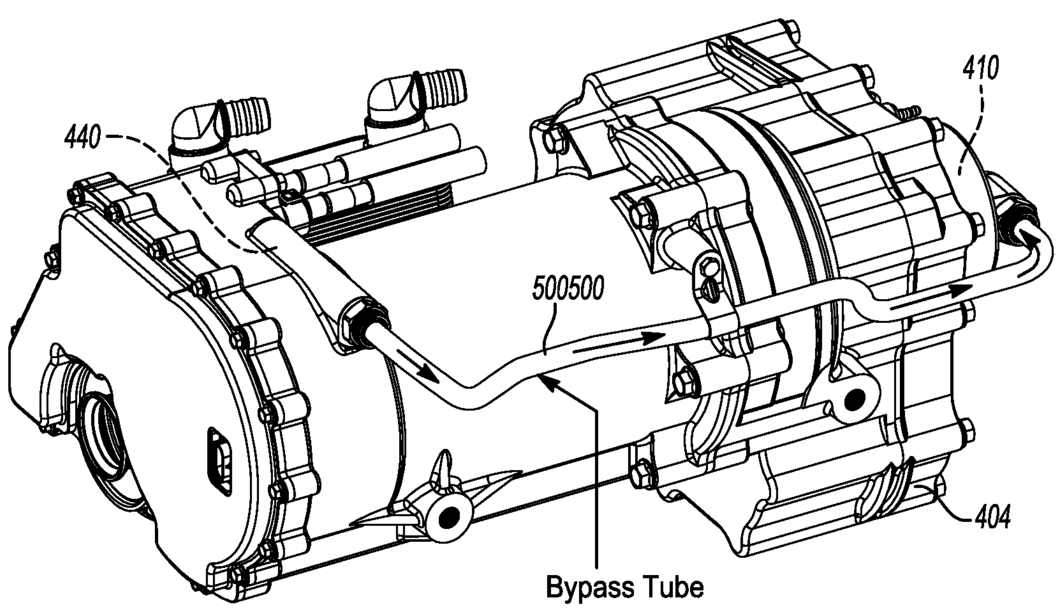

440
410
500500
Bypass Tube
404

Fig-38

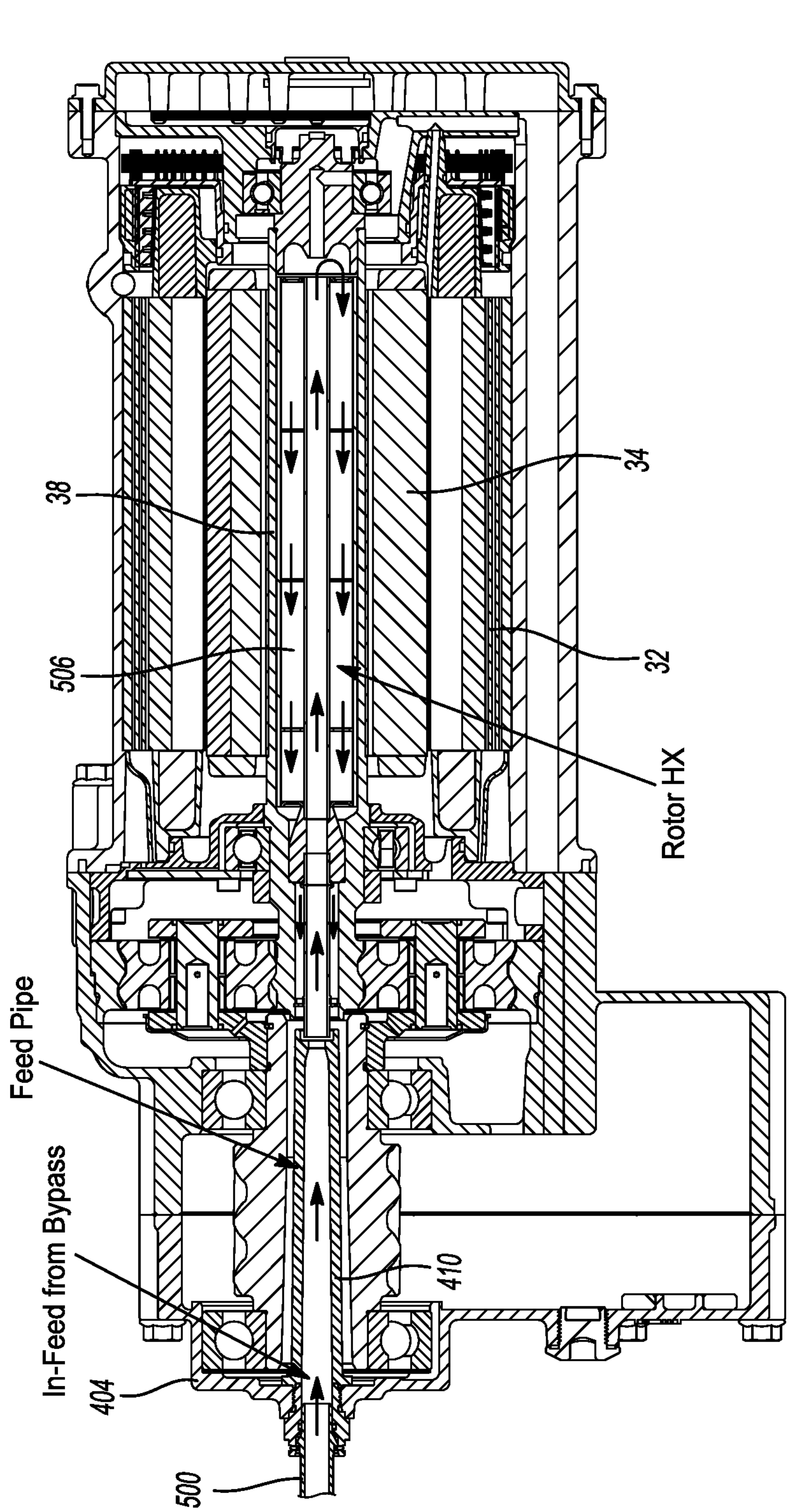


Fig-39

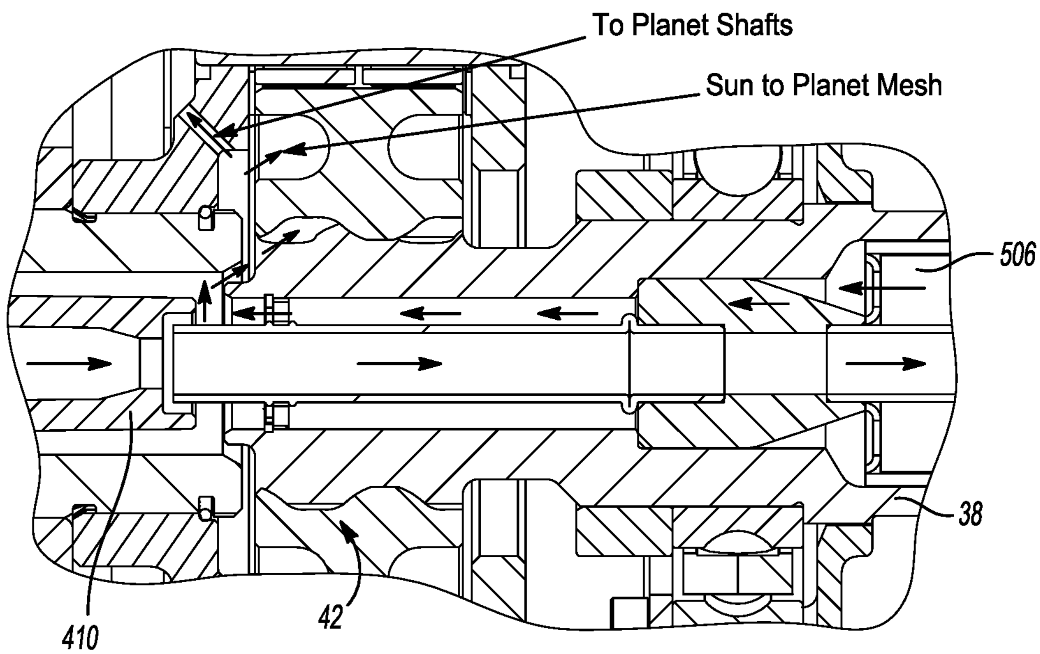

To Planet Shafts
Sun to Planet Mesh
506
38
410
42

Fig-40

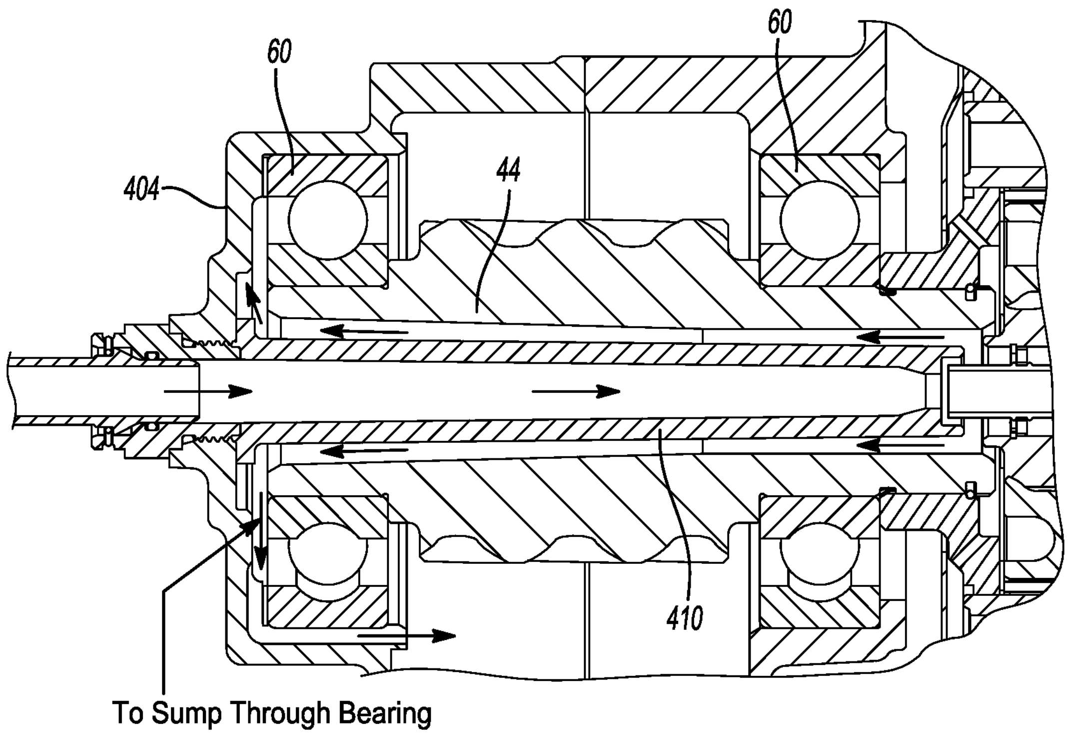

60
60
404
44
410
To Sump Through Bearing

Fig-41

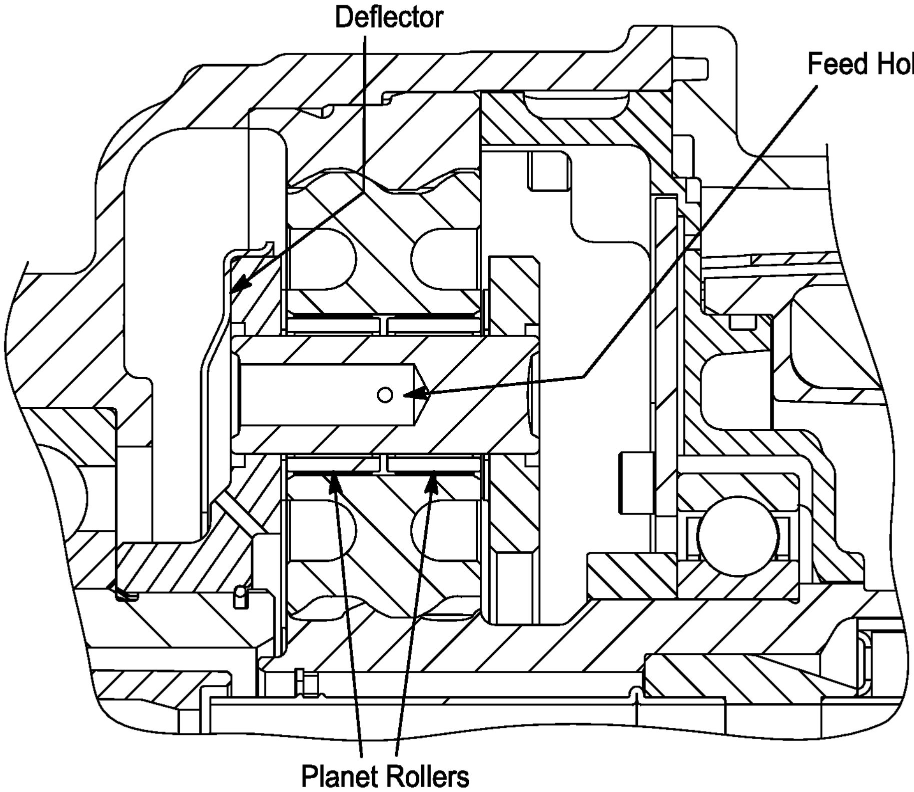

Deflector
Feed Hole
Planet Rollers

Fig-42

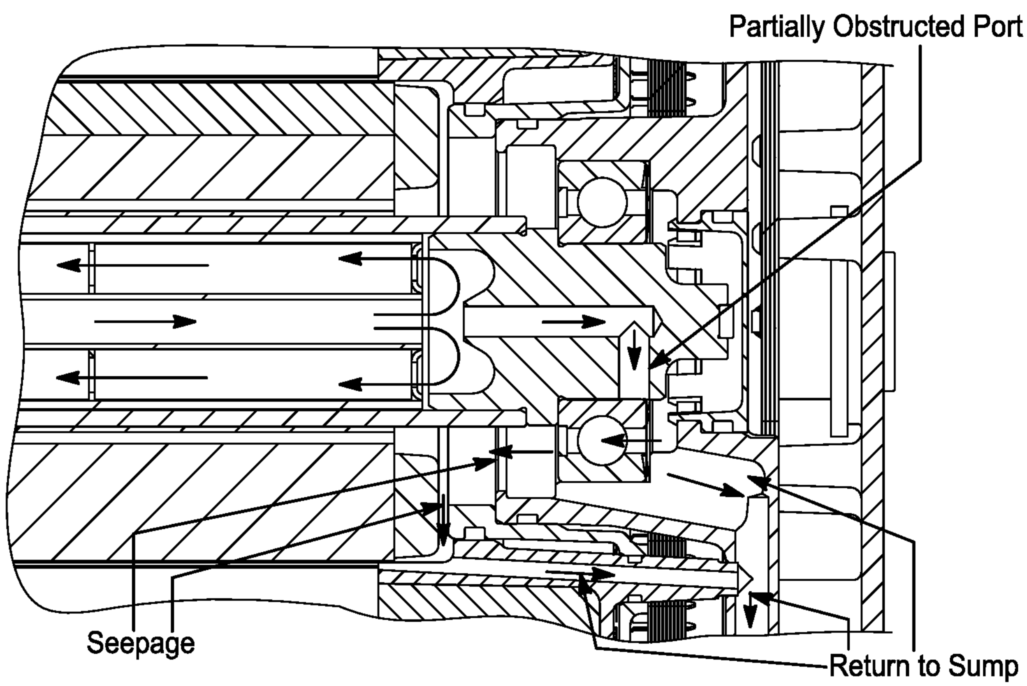

Partially Obstructed Port
Seepage
Return to Sump

Fig-43

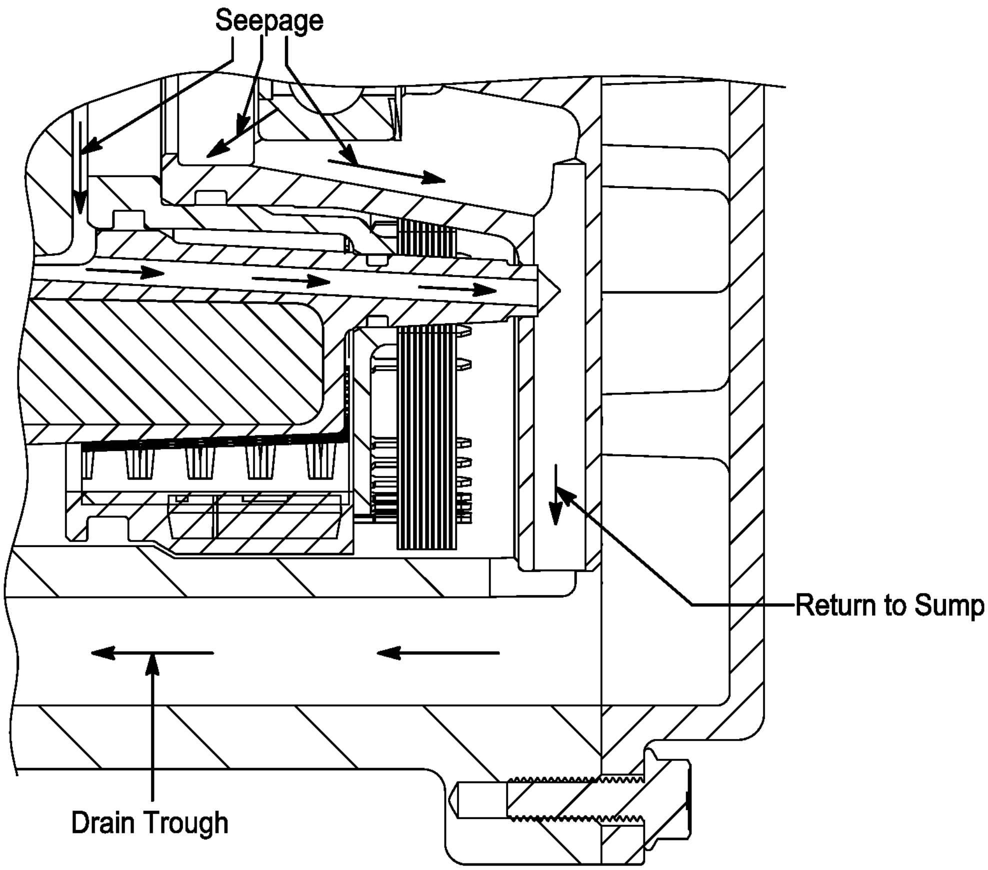


Fig-44

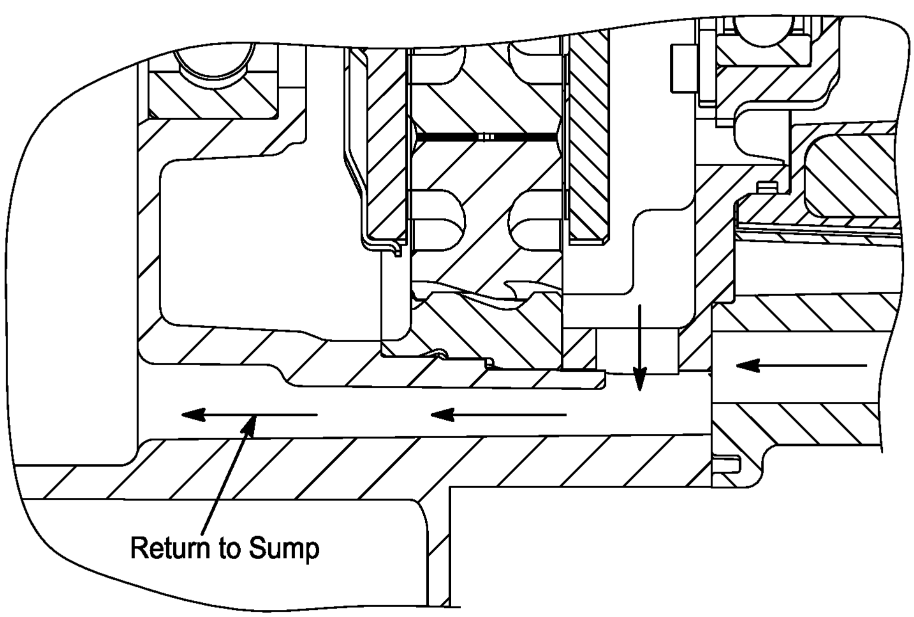


Fig-45

INTEGRATED POWER SWITCHING DEVICE HEAT SINK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 17/503,433 filed Oct. 18, 2021, which is a continuation-in-part application of International Application No. PCT/US2020/029925 filed Apr. 24, 2020, which claims the benefit of U.S. Provisional Application U.S. Provisional Application No. 62/904,199 filed Sep. 23, 2019 and No. 62/838,893 filed Apr. 25, 2019. This application also claims the benefit of U.S. Provisional Application No. 63/263,830 filed Nov. 10, 2021. The disclosure of each of the above-identified application is incorporated by reference as fully set forth in detail herein.

FIELD

The present disclosure relates to an electrical assembly having a heat sink that is unitarily and integrally formed with a lead of a power semiconductor.

BACKGROUND

This section provides background information related to the present disclosure which is not necessarily prior art.

While there is increasing interest in the electrification of vehicle drivelines, there are significant issues that must be overcome before vehicles with electrified drivelines substantially displace vehicle drivelines that are powered solely by internal combustion engines. Some of these issues include the cost of the electrified driveline, the volume of the electrified driveline and its ability to be packaged into available space within a vehicle, as well as the robustness of the electronics that are employed to operate and control the electrified driveline.

SUMMARY

This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

In one form, the present disclosure provides an electrical assembly that includes a semiconductor die, a plurality of electrically conductive leads, a heat sink and a case. The semiconductor die includes a power semiconductor device having a plurality of terminals. Each of the electrically conductive leads is electrically coupled to an associated one of the terminals on the power semiconductor device. The heat sink is formed of an electrically and thermally conductive material and includes a base, a mount, and a plurality of fins. The mount extends from a first side of the base and is coupled to the semiconductor die. The fins are fixedly coupled to the base and extend from a second side of the base that is opposite the first side of the base. The case is formed of a first electrically insulating material. A first one of the plurality of leads is integrally and unitarily formed with the mount.

In one form, each of the leads that is not unitarily and integrally formed with the mount is electrically coupled to its associated one of the terminals via a bond wire. In one form, the semiconductor die is coupled to the mount using at least one of a solder material and a sinter material. In one form, the plurality of fins are unitarily and integrally formed with the base. In one form, the electrically and thermally

conductive material from which the heat sink is formed comprises at least one of copper and aluminum. In one form, the base and the mount are integrally formed. In one form, the power semiconductor device comprises a field effect transistor. In one form, the field effect transistor is a metal oxide silicone field effect transistor. In one form, at least a portion of each of the plurality of fins has a cuboid shape. In one form, at least a portion of each of the plurality of fins has a rod-like shape. In one form, the plurality of fins are orthogonal to the leads. In one form, the base of the heat sink has a first side that has a corrugated shape and a second side opposite the first side, where the second side has a linear shape. In one form, a length of the plurality of fins increases from a first edge of the heat sink to a second edge of the heat sink. In one form, the electrical assembly further includes an inverter mount and a plurality of bus bars, the inverter mount being formed of a second electrically insulating material and defining a mounting flange, where a portion of the electrically conductive leads are received through the mounting flange and are electrically and mechanically coupled to associated ones of the bus bars. In one form, the electrical assembly includes a stator, the stator having a motor winding, and wherein the heat sink is electrically coupled to the motor winding.

In one form, the present disclosure provides a method for fabricating a semiconductor package that includes a plurality of leads. The method includes: providing a heat sink that is formed of an electrically and thermally conductive material, the heat sink having a base, a mount, and a plurality of fins, where the mount extends from a first side of the base, the plurality of fins are fixedly coupled to the base and extend from a second side of the base that is opposite the first side of the base, and where a first one of the plurality of leads is integrally and unitarily formed with the mount; attaching a semiconductor die that includes a power semiconductor device to the mount of the heat sink, the power semiconductor device having a plurality of terminals; coupling each of the leads that is not unitarily and integrally formed with the mount to its associated one of the terminals via a bond wire; and encapsulating the semiconductor die and the mount with a case formed of a first electrically insulating material.

In another form, the present disclosure provides an electrical assembly that includes a stator and an inverter. The stator has a plurality of field windings, each of which having a phase lead. The inverter has an inverter mount and a plurality of power semiconductor packages. The inverter mount has an annular mounting flange and a plurality of phase lead bosses that are coupled to the annular mounting flange. Each of the phase leads is received through a corresponding one of the phase lead bosses. Each of the power semiconductor packages has a semiconductor die, a plurality of electric terminals, and a heat sink. Each of the electric terminals is electrically coupled to the semiconductor die. The heat sink has a base, which is fixedly and electrically coupled to one of the electric terminals, and a plurality of fins that extend axially from the base in a direction away from the semiconductor die. Each of the power semiconductor packages is mounted to the inverter mount such that at least a portion of the electric terminals of each of the power semiconductor packages extends through the mounting flange. The power semiconductor packages are arranged in a circumferential spaced apart manner. The fins of each heat sink are arranged in rows and the fins in each row taper such that a radially-inner most fins in each of the rows is shorter than a radially-outer most fin in each of the rows. A plurality of slots are formed in the base on a radially-inner side of the base. Each of the slots extend toward a radially-outer side of the base and intersect a corresponding one of the rows of fins.

Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

FIGS. **1** and **2** are longitudinal section views of an exemplary electric drive module constructed in accordance with the teachings of the present disclosure;

FIGS. **3** and **4** are sections view of a portion of the electric drive unit of FIG. **1**, illustrating the construction of a motor assembly in more detail;

FIGS. **5** and **6** are partly sectioned views of the electric drive unit of FIG. **1**;

FIG. **7** is a perspective view of a portion of the motor assembly, illustrating a portion of an inverter in a see-through manner and in more detail;

FIGS. **8** and **9** are perspective views of a power semiconductor package having a plurality of rod-shaped fins and cuboid-shaped fins, respectively;

FIG. **10** is a perspective view of a power semiconductor package with a case thereof removed for clarity;

FIG. **11** is a perspective view of an inverter;

FIGS. **12** through **15** are partial cross-sectional views of a bulbar;

FIG. **16** is a perspective view of the inverter shown with an end plate;

FIG. **17** is a sectional view of a portion of the electric drive unit of FIG. **1**, illustrating a sensor assembly having a TMR sensor that is mounted to a control board and a magnet that is coupled for rotation with a rotor of the motor assembly;

FIG. **18** is a perspective view of the electric drive unit of FIG. **1**;

FIG. **19** is a rear perspective view of a portion of a housing of the electric drive unit of FIG. **1**;

FIG. **20** is a perspective view of a portion of the electric drive unit of FIG. **1** with the portion of the housing shown in FIG. **18** removed;

FIG. **21** is similar to that of FIG. **19**, but depicting the electric drive unit with a portion of a transmission and a differential assembly removed;

FIG. **22** is similar to that of FIG. **20**, but depicting a further portion of the housing removed to better show a portion of the transmission;

FIG. **23** is a sectional view of a portion of the electric drive unit that is shown in FIG. **21**; and

FIGS. **24** through **45** are section views of various portions of the electric drive unit of FIG. **1**, depicting the flow of cooling and lubricating oil through various portions of the electric drive unit.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

With reference to FIGS. **1** and **2**, an exemplary electric drive module constructed in accordance with the teachings of the present disclosure is generally indicated by reference numeral **10**. The electric drive module **10** includes a housing assembly **12**, an electric motor **14**, a control unit **16**, a transmission **18**, a differential assembly **20**, a pair of output shafts **22***a* and **22***b*, a pump **24**, a heat exchanger **26** (FIG. **5**) and a filter **28**.

The housing assembly **12** can house the motor **14**, the control unit **16**, the transmission and the differential assembly **20**. The electric motor **14** can be any type of electric motor and can have a stator **32** and a rotor **34**. The stator **32** can include field windings **36**, whereas the rotor **34** can include a rotor shaft **38** that can be disposed within the stator **32** for rotation about a first rotational axis **40**.

The transmission **18** can include a planetary reduction **42**, a shaft **44** and a transmission output gear **46**. The planetary reduction can have a sun gear, which can be unitarily and integrally formed with the rotor shaft **38** to keep pitch line velocity as low as possible, a ring gear, which can be grounded to or non-rotatably coupled to the housing assembly **12**, a planet carrier and a plurality of planet gears that can be journally supported by the planet carrier and which can be meshingly engaged with both the sun gear and the ring gear. The sun gear, the ring gear and the planet gears can be helical gears. The shaft **44** can be mounted to a set of bearings **60** that support the shaft for rotation about the first rotational axis **40** relative to the housing assembly **12**. The transmission output gear **46** can be coupled to (e.g., unitarily and integrally formed with) the shaft **44** for rotation therewith about the first rotational axis **40**.

The differential assembly **20** can include a final drive or differential input gear **70** and a differential. The differential input gear **70** can be rotatable about a second rotational axis **80** and can be meshingly engaged to the transmission output gear **46**. In the example provided, the transmission output gear **46** and the differential input gear **70** are helical gears. The differential can be any type of differential mechanism that can provide rotary power to the output shafts **22***a* and **22***b* while permitting (at least in one mode of operation) speed differentiation between the output shafts **22***a* and **22***b*. In the example provided, the differential includes a differential case, which is coupled to the differential input gear **70** for rotation therewith, and a differential gearset having a plurality of differential pinions, which are coupled to the differential case and rotatable (relative to the differential case) about one or more pinion axes that are perpendicular to the second rotational axis **80**, and a pair of side gears that are meshingly engaged with the differential pinions and rotatable about the second rotational axis **80**. Each of the output shafts **22***a* and **22***b* can be coupled to an associated one of the side gears for rotation therewith. In the example provided, the output shaft **22***b* is formed as two distinct components: a stub shaft **90** and a half shaft **92**. The stub shaft **90** is drivingly coupled to an associated one of the side gears and extends between an associated gear and the half shaft **92** and is supported by a bearing **94** in the housing assembly **12** for rotation about the second rotational axis **80**. Each of the output shaft **22***a* and the half shaft **92** has a constant velocity joint **100** with a splined male stem. The splined male stem of the constant velocity joint on the output shaft **22***a* is received into and non-rotatably coupled to an associated one of the side gears. The splined male stem of the constant velocity joint on the half-shaft **92** is received into and non-rotatably coupled to the stub shaft **90**.

In FIGS. **3** through **6**, the control unit **16** includes a power terminal **200**, one or more field capacitor **202**, an inverter **204** and a controller **206**. The power terminal **200** can be mounted to the housing assembly **12** and can have contacts or terminals (not shown) that can be fixedly coupled to a respective power lead **210** to electrically couple the power lead **210** to the control unit **16**. It will be appreciated that the electric motor **14** can be powered by multi-phase electric AC power and as such, the power terminal **200** can have multiple contacts or terminals to permit the several power leads **210** to be coupled to the control unit **16**.

Each field capacitor **202** electrically couples an associated one of the power leads **210** to the inverter **204**. In the example provided, each field capacitor **202** is relatively small and is disposed in an annular space between the inverter **204** and the housing assembly **12**. The annular space can be disposed adjacent to an end of a body of the stator **32** from which the field windings **36** extend. Each field capacitor **202** can be mounted to the inverter **204**.

With reference to FIGS. **3**, **4** and **7** through **15**, the inverter **204** can be an annular structure that can be mounted about the field windings **36** that extend from the body of the stator **32**. In the example provided, the inverter **204** includes a power semiconductor assembly **250** and a circuit board assembly **252**. The power semiconductor assembly **250** can comprise a plurality of power semiconductor packages **262** and an inverter mount **264**.

The power semiconductor package **262** has a semiconductor die **266** that includes a power semiconductor device **268**. The power semiconductor device **268** can be any suitable power semiconductor device, such as an insulated gate bipolar transistor (IGBT). In the example provided, the power semiconductor device is a field effect transistor **269**, which may be a metal oxide silicon field effect transistor (MOSFET), or a junction field effect transistor (JFET). The power semiconductor package **262** has a plurality of terminals **270** and a plurality of electrically conductive leads **272***a*, **272***b*, **272***c*, **272***d* (collectively referred to hereinafter as "electrically conductive leads **272**"). Each of the electrically conductive leads **272** is electrically coupled to an associated one of the terminals **270**.

The power semiconductor package **262** has a heat sink **274** that is formed of an electrically and thermally conductive material, such as copper or aluminum. The heat sink **274** has a base **276**, a mount **278**, and a plurality of fins **280**. The mount **278** extends from a first side **276***a* of the base **276** and is coupled to the semiconductor die **266**. The plurality of fins **280** are fixedly coupled to the base **276** and extend from a second side **276***b* of the base **276** that is opposite the first side **276***a* of the base **276**. The base **276** and the mount **278** can be integrally and unitarily formed.

The power semiconductor package **262** has a case **281** having a first side **281***a* and a second side **281***b* that is opposite the first side **281***a* of the case **281**. The case **281** is formed of a first electrically insulating material, such as a resin material. The semiconductor die **266** and the mount **278** are encapsulated in the case **281** during, for example, an overmolding process. The plurality of fins **280** extend from the second side **281***b* of the case **281**.

The plurality of fins **280** are fixedly coupled to (e.g., unitarily and integrally formed with) the base **276**. The fins **280** can be disposed in any desired orientation, such as orthogonal to the electrically conductive leads **272**. In one form, the first side **276***a* has a corrugated shape, and the second side **276***b* has a linear (or substantially linear) shape. It should be understood that the first side **276***a* and the second side **276***b* can have various shapes and are not limited to the examples described herein. The length of the base **276** can gradually (or nongradually) increase from the first side **276***a* to the second side **276***b*. Likewise, the length of the fins **280** can gradually (or nongradually) increase from the first side **276***a* to the second side **276***b* (i.e., along the x-axis). The power semiconductor packages **262** of the power semiconductor assembly **250** can be arranged in an annular manner as shown in FIG. **7**. If desired, the fins **280** of a given power semiconductor package **262** contact a second side **281***b* of the case **281** of a circumferentially adjacent power semiconductor package **262**.

Each of the fins **280** on each heat sink **274** can be shaped as desired. For example, some or all of the fins **280** can be shaped as rods, such as the fins **280***a* shown in FIG. **8**, or could have a cuboid shape, such as the fins **280***b* shown in FIG. **9**. It should be understood that the fins **280** may have other shapes in other forms and are not limited to the examples described herein.

The semiconductor die **266** is coupled to the mount **278** using a bonding material **282**, which may be at least one of a solder material and a sinter material. One of the electrically conductive leads **272** (e.g., the electrically conductive lead **272***a*) is integrally and unitarily formed with the mount **278**. The remaining electrically conductive leads **272** (e.g., electrically conductive leads **272***b*, **272***c*, **272***d*) that are not unitarily and integrally formed with the mount **278** are electrically coupled to an associated terminal **270** via a bond wire **284**.

The power semiconductor package **262** has phase lead bosses **288**, which can accept phase leads **294** (FIG. **3**) of the field windings **36** (FIG. **3**) therethrough. The power semiconductor package **262** can also have an oil inlet port **296** (FIG. **11**).

A method for fabricating the power semiconductor package **262** includes providing the heat sink **274** and attaching the semiconductor die **266** including the power semiconductor device **268** to the mount **278** of the heat sink **274**. The method includes coupling each of the leads that is not unitarily and integrally formed with the mount **278** (e.g., electrically conductive leads **272***b*, **272***c*, **272***d*) to an associated terminal **270** via the bond wires **284** and encapsulating the semiconductor die **266** and the mount **278** with the case **281** using an overmolding process.

With reference to FIGS. **3**, **4**, **7**, and **11** through **15**, the inverter mount **264** can be formed of a second electrically insulating material that is different than the first insulating material of the case **281**, such as a plastic material. The inverter mount **264** can define a mounting flange **295** disposed circumferentially about the power semiconductor assembly **250**. At least a portion of the electrically conductive leads **272** can be received through the mounting flange **295** and can be electrically and mechanically coupled to the circuit board assembly **252** via one or more bus bars **297***a*, **297***b*, **297***c*, **297***d* (collectively referred to hereinafter as "bus bars **297**"), such as a printed circuit board. The bus bars **297** can be stacked against stacked against one another and electrically coupled to the electrically conductive leads **272** as well as to the phase leads **294** of the field windings **36** of the stator **32**. The quantity of printed circuit boards is dependent upon the thickness of the electrical traces or conductors on each of the printed circuit boards and the amount of current that is to pass through between each power semiconductor package **262** and an associated one of the field windings **36**. The bus bars **297** may be electrically insulated from each other via insulating spacers **298** such that each of the electrically conductive leads **272** is electrically and mechanically coupled to one of the bus bars **297**.

With reference to FIG. **17**, the controller **206** is configured to sense a rotational position of the rotor **34** relative to the stator **32** (FIG. **1**) and responsively control the flow of electric power from the inverter **204** (FIG. **3**) to the field windings **36** (FIG. **3**) to rotate the magnetic field that is produced by the field windings **36** (FIG. **3**). The controller **206** can include a second circuit board assembly that can comprise a plurality of stacked printed circuit boards. The second circuit board assembly can have conventional hardware and control programming for operating the electric motor **14** (FIG. **1**) and a TMR sensor **300** that is configured to sense a rotational position of a magnetic field of a magnet **302** that is fixedly coupled to the rotor **34**. The TMR sensor **300** and the magnet **302** can optionally be used in place of a conventional encoder or resolver. Significantly, the controller **206** uses direct voltage traces on the various printed circuit boards and/or the electrically conductive leads **272** instead of resistors to determine current flow.

In FIG. **18**, the housing assembly **12** is shown to have a pump mount **310**, a heat exchanger base **312** and a filter mount **314**. The pump **24** can be mounted to the pump mount **310** and can circulate an appropriate fluid about the electric drive module **10** to both lubricate and/or cool various components. In the example provided the fluid is a suitable dielectric fluid, such as automatic transmission fluid. The heat exchanger **26** can be mounted to the heat exchanger base **312** and can be configured to receive a pressurized cooling fluid, such as a water-glycol mixture, from an external source and to facilitate the transfer of heat from the dielectric fluid circulated in the electric drive module **10** to the pressurized cooling fluid. A suitable filer, such as a spin-on oil filter **28**, can be mounted to the filter base **314** and can filter the dielectric fluid that is circulated within the electric drive module.

With reference to FIGS. **19** through **21**, an intake filter or screen **400** can be disposed in a portion of the housing assembly **12** that houses the differential input gear **70**. The intake filter **400** can receive dielectric fluid that can be returned to the low-pressure side of the pump **24**. A windage dam **402** can be integrated into a cover **404** and a main housing portion **406** of the housing assembly **12** to shield the dielectric fluid that is being returned to the intake filter **400** from the differential input gear **70**. More specifically, the windage dam **402** can cause dielectric fluid to accumulate in the vicinity of the intake filter **400** and segregate the accumulated fluid from the (rotating) differential input gear **70**. It will be appreciated that without the windage dam **402**, the rotating differential input gear **70** would tend to pull dielectric fluid away from the intake filter **2400**, which could prevent sufficient dielectric fluid from being returned to the low pressure (intake) side of the pump **24**. It will also be appreciated that segregating the dielectric fluid from the rotating differential input gear **70** can reduce drag losses that would otherwise be incurred from the rotation of the differential input gear through the dielectric fluid. The cover **404** can also include a tubular feed pipe **410**.

With reference to FIGS. **22** and **23**, a deflector **420** can be mounted to the planet carrier PC and can shield the planetary reduction **42** from dielectric fluid that is slung from other rotating components and/or cause dielectric fluid to drain from the planetary reduction **42** in a desired manner.

In FIGS. **24** and **25**, dielectric fluid is received into the intake filter **400** and transmitting to the low pressure (inlet) side of the pump **24**. High pressure dielectric fluid exits the pump **24** and travels through an internal gallery **430** in the housing **12** to an inlet passage of the heat exchanger base **312**, through the heat exchanger **26**, into an outlet passage of the heat exchanger base **312**, into an inlet passage of the filter base **314**, through the filter **28**, into an outlet passage in the filter base **314** and to another internal gallery **432** in the housing **12**.

In FIGS. **26** and **27**, dielectric fluid exiting the internal gallery **432** can travel through a transfer tube **434** through the oil inlet port **296** in the end plate **290** and can enter an annular cavity **440** that is located radially between a tubular central projection **442** on the end plate **290** and the field windings **36**. The central projection **442** can carry a seal that can be sealingly engaged to the central projection **442** and to the field windings **36**. An annular gap **448** is formed between an axial end of the field windings **36** and an annular portion of the end plate **290**. As noted previously, the end plate **290** is fixedly and sealingly coupled to the inverter mount **264**.

In FIG. **28**, the dielectric fluid is shown to flow through the annular gap **448**, through the fins **280** in the heat sinks **274** and into passages **450** formed axially through the stator **32**. While the fins **280** have been depicted herein as perpendicular projections, it will be appreciated that the fins **280** could be shaped differently (for example, as diamond shaped projections) to cause the flow of dielectric fluid passing through the fins **280** to move in both tangential and axial directions. Flow in this manner may be beneficial for rejecting more heat from the heat sinks **274** into the dielectric fluid and/or to produce a desired flow restriction that can aid in the pressure balancing of the cooling flow to the rotor. Accordingly, it will be appreciated that dielectric fluid is introduced to the inverter **204**, passes through fins **280** on heat sinks **274** that are electrically conductively coupled to the electrically conductive leads **272** to thereby cool the inverter **204**, and thereafter enters the passages **450** in the stator **32** to cool the stator **32** as is shown in FIG. **29**.

In FIGS. **30** and **31**, dielectric fluid exiting the stator **32** is collected in an annular cavity **460** on an opposite end of the stator **32** that permits the velocity of the dielectric fluid to slow. A portion of the dielectric fluid is returned to a sump (not shown) in the housing assembly **12**, while other portions of the flow are directed to lubricate various other components. For example, the annular cavity **460** can be in fluid communication with a worm track **464**.

With reference to FIGS. **32** through **34**, the worm track **464** can have an outlet that can discharge the dielectric fluid into a bearing **470**, which can support the differential case **472** for rotation relative to the housing assembly **12**, and/or onto the stub shaft **92**, where the dielectric fluid can migrate to the opposite axial ends of the stub shaft **92** to lubricate the differential gearing and the bearing **94**. Thereafter, the dielectric fluid can drain to the sump where it can flow into the intake filter **400** (FIG. **23**).

In FIGS. **35** and **36**, the annular cavity **460** can be in fluid communication with a passage **480** that provides a flow of the dielectric fluid to a bearing **482** that supports the rotor shaft **38** relative to the housing assembly **12**. Dielectric fluid that is discharged from the bearing **482** can seep between the housing assembly **12** and the rotor shaft **38** and can drain to the sump in the housing assembly **12**.

With reference to FIGS. **27**, **28** and **37**, a portion of the dielectric fluid in the annular cavity **440** can be discharged into a bypass tube **500**. The amount of fluid that is discharged into the bypass tube **500** is based on pressure balancing between the flow that is directed through the bypass tube **500** and the portion of the flow that travels through the inverter **204** and the stator **32**.

FIG. **38** depicts the dielectric fluid as it is discharged from the annular cavity **440** and transferred via the bypass tube **500** to the feed pipe **410** in the cover **404**.

FIG. **39** depicts the bypass flow exiting the bypass tube **500**, traveling through the feed pipe **410** in the cover **404** and being fed into a heat exchanger **506** that is mounted within the rotor shaft **38**. The heat exchanger **506** receives the flow (inflow) of dielectric fluid along its rotational axis, and then turns the flow at the opposite end of the rotor **34** so that the flow of dielectric fluid flows concentrically about the inflow toward the end of the rotor **34** that received the inflow of the dielectric fluid.

In FIGS. **40** and **41**, the outflow of the dielectric fluid that exits the heat exchanger **506** in the rotor shaft **38** can be at least partly employed to lubricate the various components (i.e., bearings, shafts, gear teeth) of the planetary reduction **42**, as well as the bearings **60** that support the shaft **44** of the transmission. Note that the feed pipe **410** in the cover **404** is received through a bore in the shaft **44**. In the example provided, the feed pipe **410** is a discrete component that is assembled to the cover **404**.

FIGS. **42** through **45** show various flows of dielectric fluid being used to lubricate various other components within the electric drive module.

The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

What is claimed is:

1. An electrical assembly comprising:

a stator having a plurality of field windings, each of the field windings having an associated phase leads; and

an inverter having an inverter mount and a plurality of power semiconductor packages, the inverter mount having an annular mounting flange and a plurality of phase lead bosses that are coupled to the annular mounting flange, each of the phase leads being received through a corresponding one of the phase lead bosses, each of the power semiconductor packages having a semiconductor die (**266**), a plurality of electric terminals, and a heat sink, each of the electric terminals being electrically coupled to the semiconductor die (**266**), the heat sink having a base and a plurality of fins, the base being fixedly and electrically coupled to one of the electric terminals, each of the fins extending axially from the base in a direction away from the semiconductor die (**266**), each of the power semiconductor packages being mounted to the inverter mount such that at least a portion of the electric terminals of each of the power semiconductor packages extends through the mounting flange, wherein the power semiconductor packages are arranged in a circumferential spaced apart manner, wherein the fins of each heat sink are arranged in rows, wherein the fins in each row taper such that a radially-inner most one of the fins in each of the rows is shorter than a radially-outer most one of the fins in each of the rows, and wherein a plurality of slots are formed in the base on a radially-inner side of the base, each of the slots extending toward a radially-outer side of the base and intersecting a corresponding one of the rows of fins.

2. The electrical assembly of claim **1**, wherein each row that is intersected by one of the slots has a first quantity of the fins and each row that is not intersected by one of the slots has a second quantity of the fins that is greater than the first quantity.

3. The electrical assembly of claim **1**, wherein each of the fins has a first end which is fixedly coupled to the base, and a second end that is opposite the first end, and wherein each of the fins tapers between the first and second ends.

4. The electrical assembly of claim **1**, wherein the fins in adjacent rows are staggered from one another.

5. The electrical assembly of claim **1**, wherein the base tapers between the radially-inner side of the base and the radially-outer side of the base.

6. The electrical assembly of claim **5**, wherein the radially-inner side of the base is thinner than the radially-outer side of the base.

7. The electrical assembly of claim **1**, wherein the power semiconductor package comprises an insulated gate bipolar transistor (IGBT), a metal oxide silicon field effect transistor (MOSFET), or a junction field effect transistor (JFET).

8. The electrical assembly of claim **1**, wherein the base and the one of the electric terminals are integrally and unitarily formed.

9. The electrical assembly of claim **1**, wherein each heat sink is integrally and unitarily formed.

10. The electrical assembly of claim **1**, wherein the heat sink and the one of the electric terminals are unitarily and integrally formed.

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