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(54) **AIR TURBINE STARTER WITH FLUID DAMPING ASSEMBLY**

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F02C 7/277	(2006.01)
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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,440,456 A *	4/1984	Klusman	F16C 27/045	384/582
4,527,910 A *	7/1985	Fleming	F01D 25/164	384/101
4,669,893 A *	6/1987	Chalaire	F16C 27/045	384/535

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0890781 B1	1/1999
EP	3957841 A1	2/2022

(Continued)

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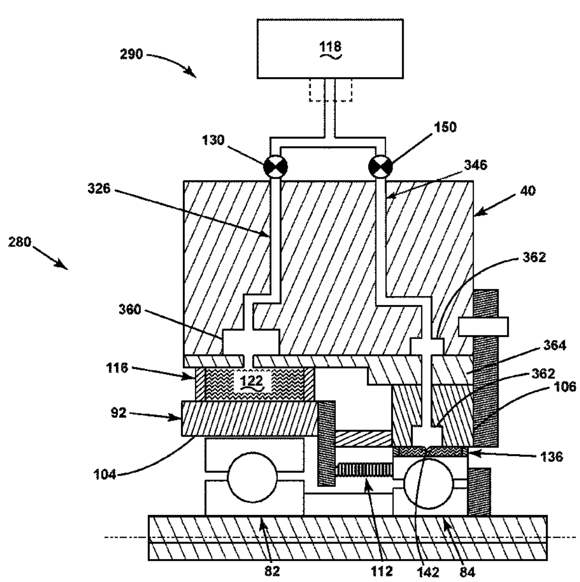
(57) **ABSTRACT**

An air turbine starter for starting an engine having a housing that defines an inlet, an outlet, and an air flow path extending between the inlet and the outlet. The housing includes a seal that defines at least a portion of the air flow path. A drive shaft rotatably coupled to a turbine defines a rotating axis. The turbine includes circumferentially spaced blades at least partially disposed within the air flow path. At least one bearing rotatably supports the drive shaft. A bearing support structure is located between the at least one bearing and the seal. A fluid damping assembly includes one or more conduits that fluidly couple a fluid source to a fluid reservoir.

19 Claims, 4 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,782,919	A *	11/1988	Chalaire	F16F 15/0237 188/266
5,110,257	A *	5/1992	Hibner	F16C 27/045 415/119
6,065,932	A	5/2000	Dodd	
7,384,199	B2	6/2008	Allmon et al.	
8,727,632	B2	5/2014	Do et al.	
9,500,100	B2	11/2016	Carter et al.	
9,599,152	B2	3/2017	Freeman et al.	
9,677,659	B1	6/2017	Niergarth et al.	
9,702,404	B2 *	7/2017	Smedresman	F16C 27/045
9,869,205	B2	1/2018	Ganiger et al.	
10,001,028	B2	6/2018	Ganiger et al.	
10,316,756	B2	6/2019	Gentile et al.	
10,323,541	B2	6/2019	Ganiger et al.	
10,358,942	B2	7/2019	Moniz et al.	
10,794,222	B1 *	10/2020	Ganiger	F16C 27/04
11,193,390	B2	12/2021	Ganiger et al.	
11,203,980	B2	12/2021	Varote et al.	
11,454,134	B2 *	9/2022	Hopper	F01D 25/04
11,661,863	B2	5/2023	Kurvinkop	
2004/0047731	A1 *	3/2004	Hull	F16C 19/52 416/174
2007/0086685	A1 *	4/2007	Klusman	F16C 27/045 384/99
2012/0118103	A1	5/2012	Blewett	
2013/0108440	A1 *	5/2013	Do	F01D 25/164 415/229
2014/0193245	A1 *	7/2014	Morreale	F01D 1/04 415/170.1
2016/0160924	A1 *	6/2016	Meyers	F16C 33/6659 384/474
2017/0122369	A1 *	5/2017	Smedresman	F16C 27/045
2017/0307046	A1 *	10/2017	Steen	F01D 25/164
2017/0363010	A1 *	12/2017	Rodriguez	F16D 41/22
2018/0030900	A1	2/2018	Mathis	
2019/0063261	A1 *	2/2019	Varney	F16C 33/6659
2019/0178104	A1 *	6/2019	Joshi	F01D 25/164
2019/0234239	A1 *	8/2019	Tsujimoto	F02C 7/06
2021/0025290	A1 *	1/2021	Ivakitch	F01D 25/164
2021/0047940	A1 *	2/2021	Ganiger	F01D 25/162
2022/0042423	A1 *	2/2022	Hopper	F01D 25/04
2022/0275831	A1 *	9/2022	Cevik	F16F 15/0237
2024/0052890	A1 *	2/2024	Tripathi	F02C 7/277

FOREIGN PATENT DOCUMENTS

FR	3106622	A1 *	7/2021
GB	927207		5/1963
JP	H09250654	A	9/1997

* cited by examiner

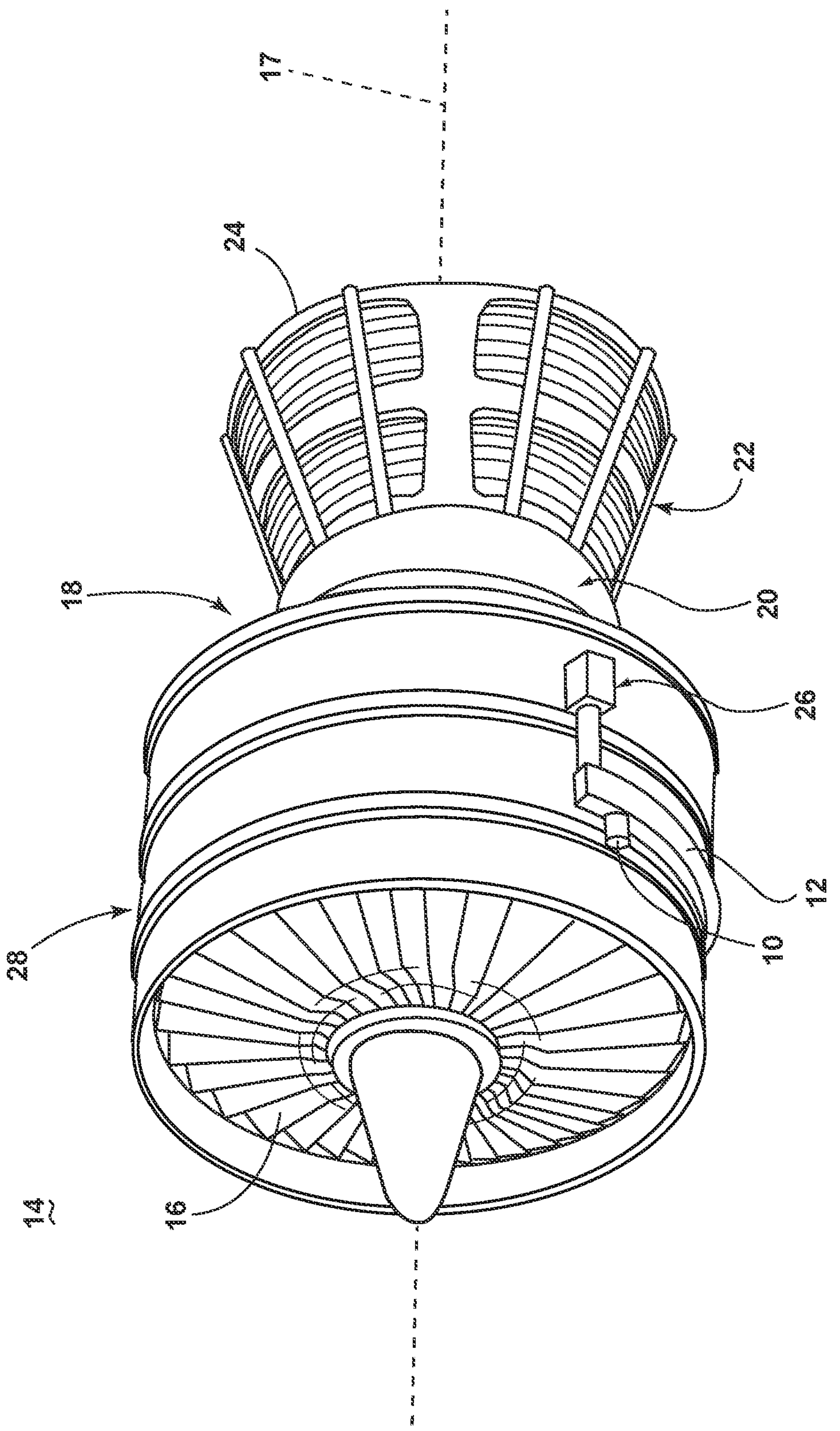


FIG. 1

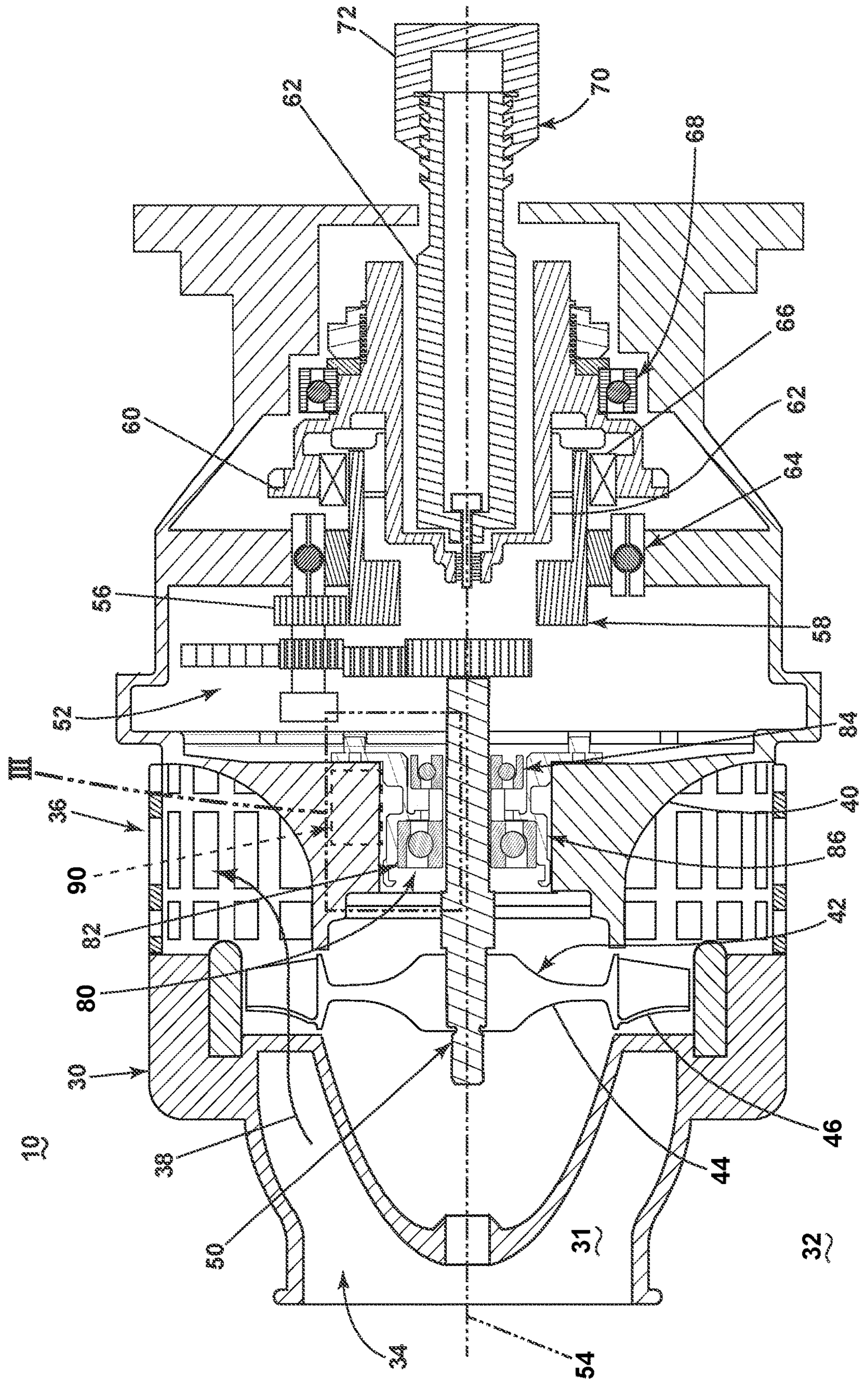

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FIG. 2

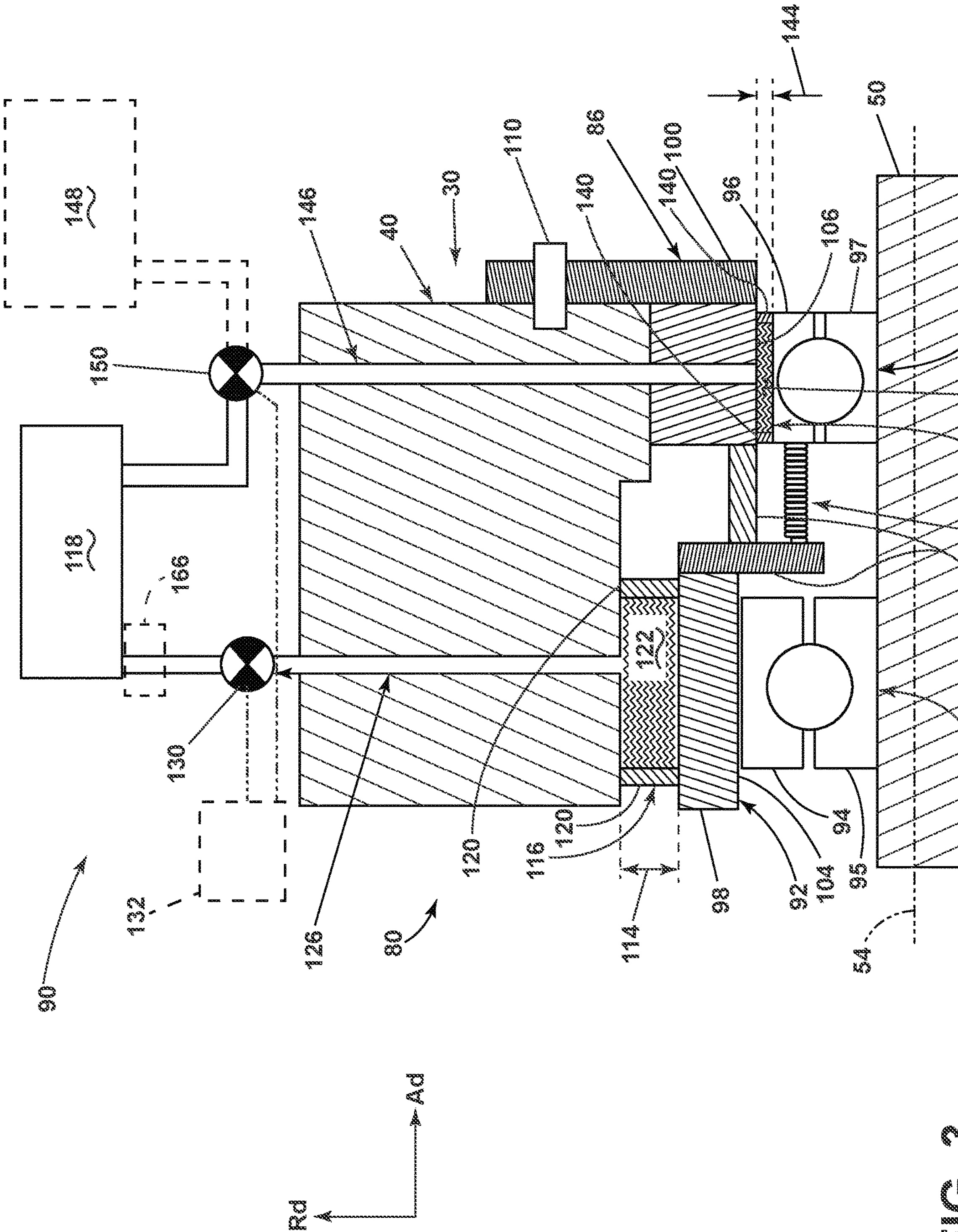
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FIG. 3

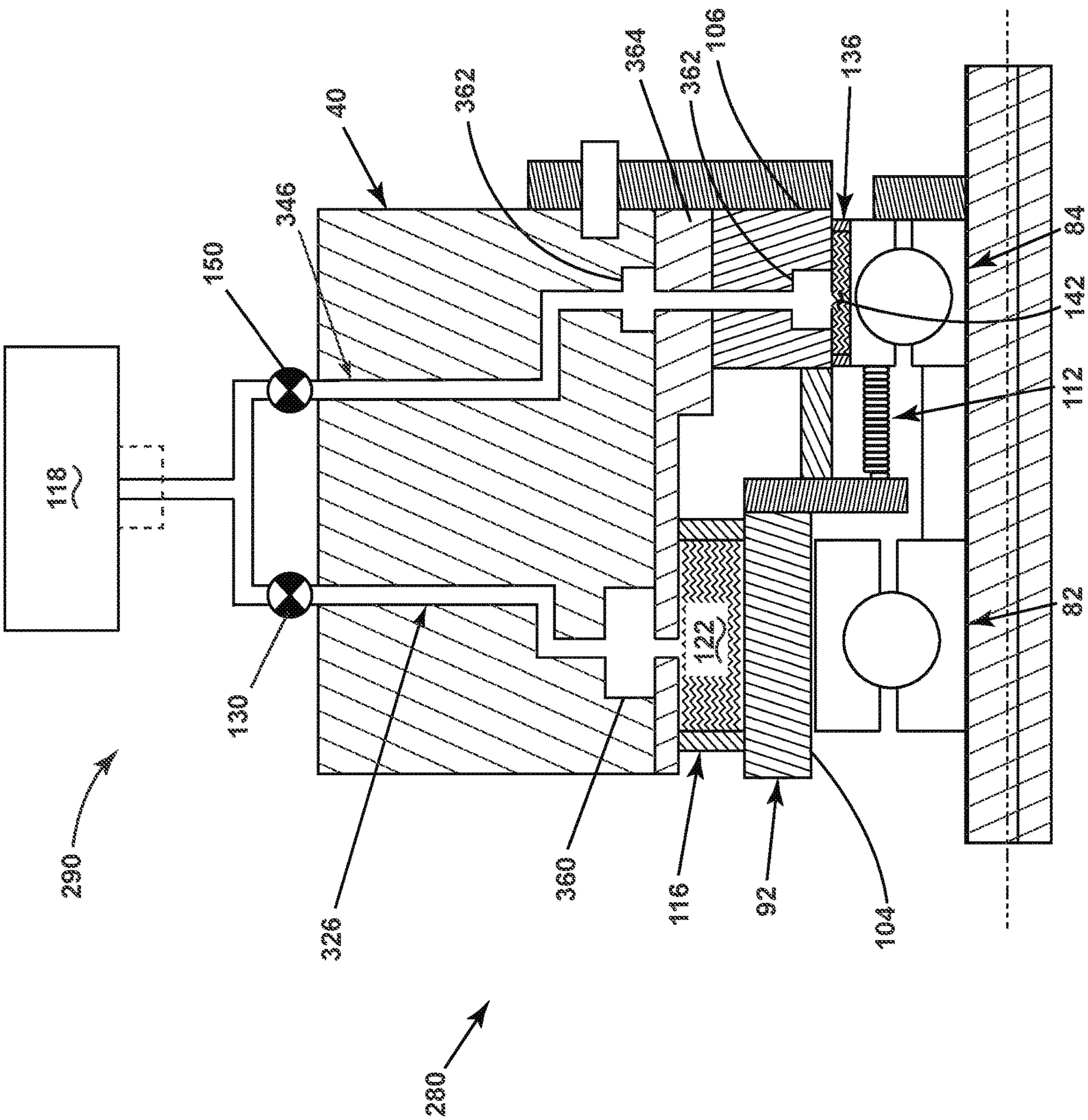

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FIG. 4

AIR TURBINE STARTER WITH FLUID DAMPING ASSEMBLY

TECHNICAL FIELD

The present subject matter relates generally to an air turbine starter, and more specifically to a fluid damping assembly in the air turbine starter.

BACKGROUND

An aircraft engine, for example a gas turbine engine, typically includes an air turbine starter for starting the gas turbine engine. The internal components of the air turbine starter require bearings. In the air turbine starter, the bearings transfer radial and axial loads during rotor operation. The air turbine starter bearings are typically sized and designed based on load input from rotor dynamics and axial thrust. During operation, the air turbine starter bearings typically experience high radial loads caused by rigid mounting.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a schematic illustration of a gas turbine engine with an air turbine starter in accordance with various aspects described herein.

FIG. **2** is a sectional view of the air turbine starter of FIG. **1** with a bearing support structure, in accordance with an exemplary embodiment of the present disclosure.

FIG. **3** is an enlarged cross-sectional view of the bearing support structure from FIG. **2** with a spring-finger structure, in accordance with an exemplary embodiment of the present disclosure.

FIG. **4** is a variation of the bearing support structure of FIG. **3**, in accordance with an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

The present disclosure is related to an air turbine starter ("ATS"), and, more specifically, a bearing support structure for an ATS. An ATS includes a turbine shaft supported by turbine bearings mounted on a turbine exhaust housing. The bearing support structure disclosed herein enables flexibility resulting in lower bearing loads, in turn elongating the life of the bearings and the bearing support structure. The flexibility provided by the bearing support structure disclosed herein can provide a structural flexibility to absorb radial loads, axial loads, or both the radial and axial loads. The ATS can have various applications including starting a gas turbine engine and generating electrical power when the gas turbine engine is in operation. While the exemplary embodiment described herein is directed to a bearing support structure for an ATS, embodiments of the disclosure can be applied to any implementation of support bearings for engine components.

A typical ATS has conventional turbine bearings with bearing sleeves that mount to a turbine housing via an interference fit to support turbine rotors. Turbine bearings transfer radial and axial loads from the turbine rotors during operation. Bearings are sized and designed to accommodate the rotor dynamics and axial thrust loads produced during operation. Due to the rigid mounting, bearings experience high radial loads at critical modes, which in turn influences the bearing life.

To enhance the bearing life, a soft-mount bearing arrangement incorporating flexibility in a bearing load path is described herein. The soft-mount bearing arrangement results in lower radial loads by shifting the critical mode to a lower speed, or revolutions per minute (RPM), for the rotor. The soft-mount bearing arrangement described in more detail herein enables flexibility in the bearing load path by utilizing low stiffness structure between the bearings through implementing flexible connectors. While the axial load does not change, the flexible connectors provide a shift of the natural frequency or critical mode to a portion of the operating range that are passed though rapidly. That is, the flexible connectors provide a shift of the natural frequency or critical mode away from "dwelling ranges," where the term "dwelling ranges" refers to a speed or range of speeds the ATS can pause or remain at during operation. In other words, the natural frequency or critical mode shifts to an operating speed that the ATS passes through rapidly, reducing the number of high reaction load cycles on the bearings. It is contemplated that the flexible connectors can provide a shift of the natural frequency, the critical mode, or at least a portion of the harmonics of the natural frequency beyond current operating ranges.

The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any implementation described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other implementations. Additionally, unless specifically identified otherwise, all embodiments described herein should be considered exemplary.

As used herein, the terms such as "first", "second", and "third" may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components.

The terms "forward" and "aft" refer to relative positions within a gas turbine engine or vehicle, and refer to the normal operational attitude of the gas turbine engine or vehicle. For example, with regard to a gas turbine engine, forward refers to a position closer to an engine inlet and aft refers to a position closer to an engine nozzle or exhaust.

As used herein, the term "upstream" refers to a direction that is opposite the fluid flow direction, and the term "downstream" refers to a direction that is in the same direction as the fluid flow. The term "fore" or "forward" means in front of something and "aft" or "rearward" means behind something. For example, when used in terms of fluid flow, fore/forward can mean upstream and aft/rearward can mean downstream.

Additionally, as used herein, the terms "radial" or "radially" refer to a direction extending towards or away from a common center. For example, in the overall context of a turbine engine, radial refers to a direction along a ray extending between a center longitudinal axis of the turbine engine and an outer engine circumference. Furthermore, as used herein, the term "set" or a "set" of elements can be any number of elements, including only one.

All directional references (e.g., radial, axial, proximal, distal, upper, lower, upward, downward, left, right, lateral, front, back, top, bottom, above, below, vertical, horizontal, clockwise, counterclockwise, upstream, downstream, forward, aft, etc.) are only used for identification purposes to aid the reader's understanding of the present disclosure, and do not create limitations, particularly as to the position, orientation, or use of aspects of the disclosure described herein. Connection references (e.g., attached, coupled, fastened, connected, and joined) are to be construed broadly and can include intermediate structural elements between a collection of elements and relative movement between elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and in fixed relation to one another. The exemplary drawings are for purposes of illustration only and the dimensions, positions, order and relative sizes reflected in the drawings attached hereto can vary.

Referring to FIG. **1**, an air turbine starter motor or air turbine starter (ATS) **10** is coupled to an accessory gear box (AGB) **12**, also known as a transmission housing, and together are schematically illustrated as being mounted to a turbine engine **14**, such as a gas turbine engine. The turbine engine **14** includes an air intake with a fan **16** that supplies air to a compression region having a high-pressure compression region **18**. The fan **16** can define an engine axis of rotation **17**. The air intake with the fan **16** and the compression region collectively are known as the 'cold section' of the turbine engine **14**. The cold section is positioned upstream of a combustion section of the turbine engine **14**. The high-pressure compression region **18** provides a combustion chamber **20** of the combustion section with high-pressure air. In the combustion chamber **20**, the high-pressure air is mixed with fuel and combusted. The hot and pressurized combusted gas passes through a turbine region, illustrated as having a high-pressure turbine region **22** and a low-pressure turbine region **24** before exhausting from the turbine engine **14**. As the pressurized gases pass through a high-pressure turbine (not shown) of the high-pressure turbine region **22** and a low-pressure turbine (not shown) of the low-pressure turbine region **24**, the turbines extract kinetic energy from the flow of the gases passing through the turbine engine **14**. The high-pressure turbine of the high-pressure turbine region **22** can be coupled to the compression mechanism (not shown) of the high-pressure compression region **18** by way of a shaft to power the compression mechanism. The low-pressure turbine can be coupled to the fan **16** of the air intake by way of a shaft to power the fan **16**.

The AGB **12** can be coupled to the turbine engine **14** at one or more of the high-pressure or low-pressure compressor or turbine region **18**, **22**, **24**. The coupling of the AGB **12** to the turbine engine **14** can be by way of a mechanical power take-off **26**. The mechanical power take-off **26** contains multiple gears and means for mechanical coupling of the AGB **12** to the turbine engine **14**. The mechanical power take-off **26** can translate power from the turbine engine **14** to the AGB **12** to power accessories of the aircraft, such as, but not limited to fuel pumps, electrical systems, and cabin environment controls.

The ATS **10** can be located radially outside of a fan casing **28**. That is, the ATS **10** can be located radially outside of the air intake region containing the fan **16**. Alternatively, it is contemplated that in a differing and non-limiting example, the ATS **10** can be located outside of the core near the high-pressure compression region **18**, where the ATS **10** can be coupled to a transfer gear box (not shown) or an accessory gear box (not shown). Further, any location for the ATS **10** is contemplated where the ATS **10** can be coupled to the turbine engine **14**.

FIG. **2** is a schematic cross section of an exemplary ATS **10** that can, for example, be included in FIG. **1**. The ATS **10** includes a housing **30** defining an interior **31** and an exterior **32** of the housing **30**. An inlet **34** and an outlet **36** are also defined by the housing **30**. An air flow path **38** through the interior **31** is illustrated schematically with arrows. The air flow path **38** extends between the inlet **34** and the outlet **36** for communicating a flow of fluid, including, but not limited to gas, compressed air, or the like, therethrough. In one non-limiting example, the fluid is air, such as pressurized air, that is supplied from a pressurized air source, including but not limited to, a ground-operating air cart, an auxiliary power unit, or a cross-bleed start from an engine already operating. The housing **30** can be formed in any suitable manner including, but not limited to, that it can be made up of two or more parts that are joined or otherwise coupled together or can be integrally formed as a single piece.

As shown in FIG. **2**, a seal **40** is coupled to or unitarily formed with the housing **30**. It is contemplated that the seal **40** can divide the interior **31** into a dry portion and a wet portion. In the illustrated example, at least a portion of the seal **40** defines at least a portion of the air flow path **38**. It is further contemplated that the seal **40** can be multiple portions coupled together to define one or more portions of the interior **31**.

While illustrated as the seal **40** separating a "wet" portion of the ATS **10** from a "dry" portion of the housing, it is contemplated that the seal **40** does not have to perform as a seal and can be any portion of the housing **30** or structure coupled to the housing **30**.

A turbine **42** is located within the interior **31** of the housing **30**. At least a portion of the turbine **42** is disposed within the air flow path **38** for rotatably extracting mechanical power from the flow of gas along the air flow path **38**. The turbine **42** includes a rotor portion **44** and a plurality of circumferentially spaced blades **46**.

A drive shaft **50** is coupled to the rotating turbine **42** so that the drive shaft **50** can provide a rotational output. An output gear assembly **52** coupled to the drive shaft **50** allows for the transfer of mechanical power from the turbine **42** to the output gear assembly **52** via the rotational output of the drive shaft **50**. The turbine **42**, the drive shaft **50**, and/or a portion of the output gear assembly **52** can rotate about an axis of rotation **54**.

The output gear assembly **52** can include a gear train **56**. A carrier member **58** can be drivingly coupled with the gear train **56**. A driven member **60** can include a shaft **62** and be rotatably mounted to the carrier member **58**. The carrier member **58** can be supported by carrier bearings **64**.

A clutch **66** can be mounted to the carrier member **58**. The driven member **60** is coupled to the clutch **66** and additionally supported by drive bearings **68**. The driven member **60** is driven by the carrier member **58** which in turn is driven by the gear train **56** which in turn is driven by the turbine **42**.

A decoupler assembly **70** can be disposed within at least a portion of the driven member **60**. An output shaft **72** can be mounted to the shaft **62**. The output shaft **72** is operably coupled to the turbine engine **14** (FIG. **1**) such that the output shaft **72** can rotate a portion of the turbine engine **14**. It is contemplated that the output shaft **72** is operably coupled to one or more portions of the compression region or the turbine region. That is, the output shaft **72** can rotate one or more portions of the compression region or the turbine region.

A bearing assembly **80** rotatably supports the drive shaft **50** and, thus, also rotatably supports the turbine **42**. The bearing assembly **80** includes at least one bearing, illustrated as a first bearing **82** and a second bearing **84**, a bearing support structure **86**, and a fluid damping assembly **90**. The bearing support structure **86** is radially located, at least in part, by way of example, between the seal **40** and the drive shaft **50**. While illustrated as axially forward of the output gear assembly **52**, the bearing assembly **80** can be located axially aft of the output gear assembly **52**.

The bearing assembly **80** can be located anywhere in the ATS **10**. It is contemplated, in a different and non-limiting example, that the carrier bearings **64** or the drive bearings **68** are part of one or more bearing assemblies similar to the bearing assembly **80**, having at least one bearing, a bearing support structure, and a fluid damping assembly.

FIG. **3** is an enlarged cross-sectional view of section III from FIG. **2** illustrating the bearing assembly **80**. The first bearing **82** and the second bearing **84** can be ball bearings as illustrated, or any type of bearing including cylindrical roller bearings, tapered roller bearings and needle bearings. The first bearing **82** and the second bearing **84** can operate as parallel bearings. The first bearing **82** can be a thrust bearing or a primary load bearing, while the second bearing **84** can be a preload bearing that can maintain the ball angular load angle of the first bearing **82**.

The bearing support structure **86** is a flexible bearing support structure that includes one or more flexible portions that absorb or dampen relative movement between the seal **40** or the housing **30** and the first bearing **82** or the second bearing **84**. That is, one or more portions of the bearing support structure **86** can dissipate energy and/or transfer load. It is contemplated that the bearing support structure **86** can function like a shock absorber.

The bearing support structure **86** is illustrated, by way of example, as including a spring-finger structure **92** disposed between the seal **40** or the housing **30** and one or more of the first bearing **82** or the second bearing **84**. More specifically, the spring-finger structure **92** is located between a portion of the seal **40** and a first outer race **94** of the first bearing **82** and a second outer race **96** of the second bearing **84**.

The spring-finger structure **92** extends axially between a first end **98** and a second end **100**. The spring-finger structure **92** includes a first bearing support **104** that receives or supports a portion of the first bearing **82** and a second bearing support **106** that receives or supports a portion of the second bearing **84**.

The spring-finger structure **92** can include at least one flexible connector **108** to connect the first bearing support **104** to the second bearing support **106**. The spring-finger structure **92** can be mounted to the seal **40** with any suitable fastener **110**, such as, but not limited to, a bolt. The at least one flexible connector **108** can be formed from a shape memory alloy (denoted "SMA") material. It is further contemplated that the entire spring-finger structure **92** is formed from an SMA material.

A spring **112** or other known spacer or damping element can be disposed between the first bearing **82** and the second bearing **84**. As illustrated, by way of example the spring **112** can extend between one of the flexible connectors **108** and the second outer race **96** of the second bearing **84**. The spring **112** and the at least one flexible connector **108** contribute to the flexible movement of the spring-finger structure **92**. The spring **112** can absorb or reduce the axial load on the second bearing **84**, through at least preloading of the second outer race **96** of the second bearing **84**.

A first inner race **95** of the first bearing **82** and a second inner race **97** of the second bearing **84** can rotatably support the drive shaft **50**. The first bearing **82** and the second bearing **84** can be axially spaced with respect to the axis of rotation **54**. The spring-finger structure **92** can include the first bearing support **104** and the second bearing support **106** for accommodating the first bearing **82** and the second bearing **84** respectively.

The first bearing support **104** and the second bearing support **106** of the spring-finger structure **92** can be formed to have two different axial/thrust (AT) load capabilities. The first bearing support **104** (and optionally surrounding structures) can be formed to have a first AT value (AT1) while the second bearing support **106** (and optionally surrounding structures) can be formed to have a second AT value (AT2) that is, for example, less than the value of AT1. In other words, the first bearing support **104** is more flexible in the axial direction than the second bearing support **106**, as the first bearing support **104** has an AT value that is greater than the AT value of the second bearing support **106**.

Likewise, the first bearing support **104** and the second bearing support **106** of the spring-finger structure **92** can be formed to have two different radial load/stiffness (K) capabilities. Stiffness (K) can be determined as the force applied to stretch, compress, or deflect an object, divided by the distance that the object gets longer, shorter, or deflects. For example, an object A having value lower K value than an object B indicates that object A is easier to stretch/compress or is less stiff than object B.

The first bearing support **104** (and optionally surrounding structures) can be formed to have a first K value (K1) while the second bearing support **106** (and optionally surrounding structures) can be formed to have a second K value (K2) that is, for example, greater than the value of K1. In other words, the first bearing support **104** can have a higher AT and a lower K than the second bearing support **106**. Therefore, the spring-finger structure **92** can define a dual differential thrust rated bearing system where the second bearing **84** can be an "axial bearing" that is moveable or easier to flex in the axial direction (Ad) while the first bearing **82** can be a "radial bearing" that is moveable or easier to flex in the radial direction (Rd). It is further contemplated that the first bearing **82** is an axial bearing and the second bearing **84** is a radial bearing. In other words, the dual differential thrust rated bearing system has one bearing that is axially stiffer and radially softer while the other bearing is axially softer and radially stiffer.

To reduce radial loads on the first bearing **82**, the first bearing support **104** has a low K value and is spaced from the seal **40** a distance **114**. The fluid damping assembly **90** further reduces the radial load on the first bearing **82**. The fluid damping assembly **90** can include a first fluid reservoir **116** and a fluid source **118**.

The first fluid reservoir **116** is located between the first bearing support **104** and the seal **40**. The first fluid reservoir **116** includes a portion of the first bearing support **104**, a portion of the seal **40**, and a fluid dam, illustrated as sidewalls **120** that define a first fluid cavity **122**. The sidewalls **120** can be made of a flexible or shape memory material that allows for flexing or bending of the first bearing support **104** toward the seal **40**. The sidewalls **120** can trap, seal, bind, or otherwise limit or restrict the flow of liquid from the first fluid cavity **122** to the region between the seal **40** and the spring-finger structure **92**. The sidewalls **120** can include a material that is non-absorbing. Alternatively, in a different and non-limiting example, the sidewalls **120** can include a material that absorbs, for example, oil. The first fluid cavity **122** can be a variable volume cavity used to dampen the radial motion of the first bearing **82**.

One or more of the sidewalls **120** can be located between or press fit between the first bearing support **104** and the seal **40**. As used herein, the term "press fit" is an interference fit in which the coupling of two parts is achieved by normal force, friction, or cold welding. That is, prior to locating the sidewalls **120** between the seal **40** and the spring-finger structure **92**, at least one dimension of the sidewalls **120** is greater than the distance **114** between the seal **40** and the spring-finger structure **92**. It is contemplated that the sidewalls **120** can maintain oil volume in the first fluid cavity **122**.

Alternatively, in another non-limiting example, the sidewalls **120** can couple to the first bearing support **104**, the seal **40**, or the first bearing support **104** and the seal **40**. By way of non-limiting example, the sidewalls **120** or fluid dam can be a piston ring. Alternatively, in another different and non-limiting example, the sidewalls **120** can be a series of structures that limit the flow of fluid from the first fluid cavity **122** to the region between the first bearing support **104** and the seal **40**. By way of non-limiting example, the series of structures can include one or more structures coupled to the first bearing support **104**, the seal **40**, or the first bearing support **104** and the seal **40**.

The fluid source **118** is fluidly coupled to the first fluid reservoir **116** by one or more first conduits **126**. The fluid source **118** can be journaled, housed within, defined, supported, or otherwise coupled to the seal **40** or housing **30** (FIG. **2**).

A flow regulation device illustrated as a first valve **130** can control the volume or flow rate of fluid between the fluid source **118** and the first fluid reservoir **116**. The flow regulation device illustrated as a first valve **130** can be coupled to or located within the one or more first conduits **126**. Alternatively, in a different and non-limiting example, the first valve **130** can be located at an outlet of the fluid source **118**.

The first valve **130** can be active (actively controlled) or powered. It is contemplated that the first valve **130** can be coupled to a controller and/or power source **132**. Alternatively, in a different and non-limiting example, the first valve **130** can be passive, unpowered, and responsive to internal pressure. The first valve **130** can allow flow from the fluid source **118** to the first fluid reservoir **116** or allow flow from the first fluid reservoir **116** to the fluid source **118**. While illustrated as located radially between the fluid source **118** and the first fluid reservoir **116**, any location of the first valve **130** is contemplated, where the first valve **130** can control the flow of fluid between the fluid source **118** and the first fluid reservoir **116**.

When the first bearing support **104** flexes in the radial direction (Rd) towards the seal **40**, the distance **114** can decrease by 0% to 100%. More specifically, the distance **114** can decrease by 0% to 50%. Still more specifically, the distance **114** can decrease by 0% to 20%.

The spring **112** and material selected for the second bearing support **106** can absorb or reduce the axial load on the second bearing **84**, through at least preloading of the spring-finger structure **92**.

The fluid damping assembly **90** can include a second fluid reservoir **136**. The second fluid reservoir **136** can be located between the second bearing support **106** and the second bearing **84**. Alternatively, in a different and non-limiting example, the second fluid reservoir **136** can be located between the second bearing support **106** and the seal **40**.

The second fluid reservoir **136** includes a portion of the second bearing support **106**, a portion of the second bearing **84**, and a fluid dam, illustrated as sidewalls **140** that define a second fluid cavity **142**. The flexibility of the sidewalls **140** of the second fluid reservoir **136** can be similar to the sidewalls **120** of the first fluid reservoir **116**. The sidewalls **140** of the second fluid reservoir **136** can be made of a flexible or shape memory material that allows for flexing or bending of the first bearing support **104** toward the seal **40**. In a different and non-limiting example, the flexibility of the sidewalls **140** of the second fluid reservoir **136** can be different in the radial direction (Rd) than the sidewalls **120** of the first fluid reservoir **116**. It is further contemplated that the sidewalls **140** of the second fluid reservoir **136** can have a flexibility in the axial direction Ad different than the sidewalls **120** of the first fluid reservoir **116**.

The sidewalls **140** of the second fluid reservoir **136** can trap, seal, bind, or otherwise limit or restrict the flow of liquid from the second fluid cavity **142** to the region between the second bearing **84** and the spring-finger structure **92**. One or more of the sidewalls **140** can be located between or press fit between the second bearing support **106** and the second bearing **84**. The second fluid cavity **142** can be a variable volume cavity used to dampen the radial motion of the second bearing support **106** or the second bearing **84**.

A second bearing distance **144** can be measured between the second outer race **96** of the second bearing **84** to the spring-finger structure **92**. The second bearing distance **144** can be less than the distance **114** between the first bearing support **104** and the seal **40**. The second bearing distance **144** can be between 5% and 50% of the distance **114** between the first bearing support **104** and the seal **40**.

The fluid source **118** can be fluidly coupled to the second fluid reservoir **136** by one or more second conduits **146**. Alternatively, in a different and non-limiting example, the second fluid reservoir **136** can be fluidly coupled via the second conduits **146** to another fluid source **148**, separate and/or spaced from the fluid source **118**.

A second valve **150** can control the volume or flow rate of fluid between the fluid source **118** or the other fluid source **148** and the second fluid reservoir **136**. The flow regulation device illustrated as the second valve **150** can be coupled to or located within the one or more second conduits **146**. Alternatively, in a different and non-limiting example, the second valve **150** can be located at an outlet of the fluid source **118** or another fluid source **148**.

The second valve **150** can be active or powered. Optionally, it is contemplated that the second valve **150** can be coupled to the controller and/or power source **132**. Alternatively, in a different and non-limiting example, the second valve **150** can be passive, unpowered, and responsive to internal pressure. The second valve **150** can allow the flow of fluid into or out of the second fluid cavity **142**. The second valve **150** can allow the flow of fluid into or out of the second fluid cavity **142**.

When the second bearing support **106** flexes in the radial direction (Rd) towards the seal **40**, the second bearing distance **144** can decrease by 0% to 100%. More specifically, the second bearing distance **144** can decrease by 0% to 50%. Still more specifically, the second bearing distance **144** can decrease by 0% to 20%.

Flexibility in the radial direction (Rd) of the second fluid reservoir **136** can increase the capability or load bearing ability of the second bearing **84**. Radial flexibility in the second bearing **84** results in an increase in radial flexibility of the first bearing **82**. As the first bearing **82** is allowed to radially flex, the drive shaft **50** can apply a load or "push into" the second bearing **84**. Therefore, an increase in flexibility of the second bearing **84** allows for a greater "push into" or load to be applied to the second bearing **84**.

Although flexibility increases the radial load on the second bearing **84**, the second fluid reservoir **136** (and optionally the material selected for the second bearing support **106**) can dampen, dissipate, distribute, transfer, reduce the radial reaction, or otherwise reduce the radial load on the second bearing **84**.

The second bearing support **106** is illustrated, by way of example, as in contact with the seal **40** and spaced from the second outer race **96** of the second bearing **84**. However, it is contemplated in different and non-limiting examples that a gap can be located between the second bearing support **106** and the seal **40** or the second bearing support **106** can be in contact with at least a portion of the second outer race **96**.

While illustrated as having a first bearing support and second bearing support, any number, including one, of bearing supports can be formed by the spring-finger structure **92**.

Optionally, the fluid damping assembly **90** can include one or more flow control elements **166**. While illustrated between the first valve **130** and the fluid source **118**, it is contemplated that the one or more flow control elements **166** can be fluidly or operably coupled to any portion of the fluid damping assembly **90**. The one or more flow control elements **166** can include, but are not limited to, one or more of a pump, a flow sensor, a pressure sensor, additional valves, filters, or bleed line.

In operation, during the start-up of the turbine engine **14** (FIG. **1**) via the ATS **10** (FIG. **2**), compressed air is provided at the inlet **34** (FIG. **2**) of the ATS **10** (FIG. **2**). The compressed air is directed by the seal **40** (FIG. **2**) through the air flow path **38** (FIG. **2**). The turbine **42** (FIG. **2**) in the air flow path **38** rotates in response to the compressed air flow. The turbine **42** (FIG. **2**) is operably coupled to the drive shaft **50**, which provides rotational output that will result in starting the turbine engine **14** (FIG. **2**). The drive shaft **50** is rotatably supported by the first bearing **82** and the second bearing **84**.

During start-up, pressurized fluid such as, but not limited to, pressurized oil is provided to the first fluid reservoir **116**, the second fluid reservoir **136**, or both the first fluid reservoir **116** and the second fluid reservoir **136**. The oil pressure and volume in the first fluid reservoir **116** or the second fluid reservoir **136** is controlled by the first valve **130** or the second valve **150**, or both the first valve **130** and the second valve **150**.

The axial, radial, or axial and radial forces or loads are dissipated or distributed with the spring-finger structure **92** which supports the first bearing **82** with the first bearing support **104** and the second bearing **84** with the second bearing support **106**.

The axial load on the first bearing **82** can be absorbed by the first bearing support **104** and/or transferred to the seal **40** or the housing **30** by the at least one flexible connector **108**.

The radial load on the first bearing **82** can be damped, dissipated, distributed, or otherwise reduced by the first bearing support **104** and/or the first fluid reservoir **116**, as the first bearing support **104** deflects towards the seal **40**. The first valve **130** controls the fluid flow between the first fluid reservoir **116** and the fluid source **118**. Control of the fluid flow in and out of the first fluid reservoir **116** allows for control of the amount of radial flex or damping provided by the first fluid reservoir **116**. Further, at least a portion of the radial load on the first bearing **82** can be transferred to the second bearing **84** by allowing radial flexibility of the first bearing **82**.

The second bearing support **106** can absorb, distribute, transfer, or otherwise reduce the axial load on the second bearing **84**. By way of non-limiting example, the spring **112** can absorb or reduce the axial load on the second bearing **84**, through at least preloading of the second outer race **96** of the second bearing **84**. The second bearing support **106** can be made of a material that can dissipate axial load and/or transfer the axial load on the second bearing **84** to one or more portions of the seal **40** or housing **30**.

The increased radial load on the second bearing **84** (due to increased flexibility of the first bearing **82**) can be damped by control of the second fluid reservoir **136**.

The second valve **150** controls the fluid flow between the second fluid reservoir **136** and the fluid source **118** or another fluid source **148**. Control of the fluid flow in and out of the second fluid reservoir **136** allows for control of the amount of radial flex or damping provided by the second fluid reservoir **136**.

Further, in addition to the second fluid reservoir **136**, portions of the radial load on the second bearing **84** can be transferred and/or dampened by the material chosen for the second bearing support **106**.

Damping the axial and radial load or movement of the first bearing **82** and the second bearing **84** can lengthen the life of the ATS **10** and/or allow the drive shaft **50** to rotate at a higher speed. More specifically, increasing the radial load of the second bearing **84** decreases the radial load of the first bearing **82**, improving the length of life of the first bearing **82**. The increased radial load on the second bearing **84** is dampened, transferred, or otherwise reduced by at least the second fluid reservoir **136** to improve the length of life of the second bearing **84**. That is, the increase in radial load is defused or offset by the second fluid reservoir **136** and/or the spring-finger structure **92**.

Once the turbine engine **14** is started or self-sustaining, the clutch **66** can disconnect the shaft **62** from the carrier member **58**. Further, once the turbine engine **14** has started, the pressurized fluid provided to the first fluid reservoir **116** or the second fluid reservoir **136** to enhance the damping of spring-finger structure **92** can stop or otherwise be allowed to reach an unpowered equilibrium.

In the event of a backdrive, the ATS **10** can be disconnected from the AGB **12** via the decoupler assembly **70**.

FIG. **4** illustrates a cross section of a bearing assembly **280** with a fluid damping assembly **290** similar to the bearing assembly **80** and the fluid damping assembly **90** of FIG. **3**, therefore, like parts will be identified with like numerals increased by 200, with it being understood that the description of the like parts of bearing assembly **80** and the fluid damping assembly **90** applies to the bearing assembly **280** and the fluid damping assembly **290** unless otherwise noted.

The fluid damping assembly **290** can include the first fluid reservoir **116** located between the spring-finger structure **92** and the first bearing support **104**, the second fluid reservoir **136** located between the second bearing **84** and the second bearing support **106**, and at least one fluid source, illustrated as the fluid source **118**. The fluid damping assembly **290** can further include auxiliary fluid reservoirs illustrated as a first auxiliary fluid reservoir **360** and a set of second auxiliary fluid reservoirs **362**. The first auxiliary fluid reservoir **360** or the set of second auxiliary fluid reservoirs **362** can be coupled to the fluid source **118** by one or more first or second conduits **326**, **346**.

The first auxiliary fluid reservoir **360** can be journaled, housed within, defined, supported, or otherwise coupled to the seal **40** or housing **30** (FIG. **2**). The first auxiliary fluid reservoir **360** is fluidly coupled between the fluid source **118** and the first fluid reservoir **116**. The first auxiliary fluid reservoir **360** provides additional control of the pressurized fluid in the fluid damping assembly **290** that is between the fluid source **118** and the first fluid cavity **122**. That is, instead of controlling flow or pressure with just the first valve **130**, the flow or pressure can be controlled using the first valve **130** and the first auxiliary fluid reservoir **360**. While other locations are contemplated, the first auxiliary fluid reservoir **360** can be located radially between the first valve **130** and the first fluid cavity **122**.

The set of second auxiliary fluid reservoirs **362** can be journaled, housed within, defined, supported, or otherwise coupled to the seal **40** or housing **30** (FIG. **2**). The set of second auxiliary fluid reservoirs **362** are fluidly coupled between the fluid source **118** and the second fluid reservoir **136**. The set of second auxiliary fluid reservoirs **362** provides additional control of the pressurized fluid in the fluid damping assembly **290** that is between the fluid source **118** and the second fluid cavity **142**. That is, instead of controlling flow or pressure with just the second valve **150**, the flow or pressure can be controlled using the second valve **150** and the set of second auxiliary fluid reservoirs **362**.

One or more support portions **364** can be coupled to or unitarily formed within the seal **40** that at least partially define the first auxiliary fluid reservoir **360** or one or more of the set of second auxiliary fluid reservoirs **362**.

As illustrated, by way of example, one or more of the set of second auxiliary fluid reservoirs **362** can be defined by the second bearing support **106** of the spring-finger structure **92**.

Benefits associated with the spring-finger structure and fluid damping assembly described herein allow for a longer life of the ATS bearing. Further, with the dissipating, damping, and otherwise controlling the axial and radial forces on the bearings equates with better lubrication which allows for more robust operations, such as allowing for faster rotation of the drive shaft.

The spring-finger structure combined with the fluid damping assembly provides reduced radial loads and axial loads on the bearings, which results in longer bearing life.

The flexibility provided by the finger structure combined with the fluid damping assembly allows for a decrease in the traditional radial load on the first bearing and an increase in radial load on the second bearing. Aspects such as the second fluid reservoir and/or the second bearing support can defuse, transfer, or otherwise reduce any increase in the radial load of the second bearing.

Further, the fluid damping assembly, having the first fluid reservoir and the second fluid reservoir, can provide differential damping to each of the two bearings. That is, the flow rate, volume, or pressure of the fluid/oil provided to the first fluid cavity is independently controlled from the flow rate, volume, or pressure of the fluid/oil provided to the second fluid cavity.

To the extent not already described, the different features and structures of the various embodiments can be used in combination, or in substitution with each other as desired. That one feature is not illustrated in all of the embodiments is not meant to be construed that it cannot be so illustrated, but is done for brevity of description. Thus, the various features of the different embodiments can be mixed and matched as desired to form new embodiments, whether or not the new embodiments are expressly described. All combinations or permutations of features described herein are covered by this disclosure.

This written description uses examples to describe aspects of the disclosure described herein, including the best mode, and also to enable any person skilled in the art to practice aspects of the disclosure, including making and using any devices or circuits and performing any incorporated methods. The patentable scope of aspects of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

Further aspects are provided by the subject matter of the following clauses:

An air turbine starter for starting an engine, comprising a housing having an inlet, an outlet, and an air flow path extending between the and the outlet, wherein the housing includes a seal that defines at least a portion of the air flow path, a drive shaft rotatably coupled to a turbine defining an axis of rotation and having circumferentially spaced blades at least partially disposed within the air flow path, at least one bearing rotatably supporting the drive shaft, a bearing support structure located, at least in part, between the at least one bearing and the seal, and a fluid damping assembly comprising one or more conduits that fluidly couple a fluid source to a fluid reservoir, wherein the fluid reservoir includes a fluid cavity at least partially defined by a portion of the bearing support structure.

The air turbine starter of any preceding clause, wherein the fluid damping assembly further comprises a flow regulation device coupled to or located within the one or more conduits.

The air turbine starter of any preceding clause, wherein the flow regulation device is a valve coupled to a controller or a power source.

The air turbine starter of any preceding clause, wherein the flow regulation device is a passive valve.

The air turbine starter of any preceding clause, wherein the flow regulation device is located radially between the fluid source and the fluid reservoir.

The air turbine starter of any preceding clause, wherein the flow regulation device provides pressurized fluid to the fluid reservoir.

The air turbine starter of any preceding clause, wherein the pressurized fluid is pressurized oil.

The air turbine starter of any preceding clause, wherein the fluid source provides pressurized fluid to the fluid reservoir.

The air turbine starter of any preceding clause, wherein the pressurized fluid is pressurized oil.

The air turbine starter of any preceding clause, wherein the fluid cavity is defined by the portion of the bearing support structure, a portion of the seal, and sidewalls.

The air turbine starter of any preceding clause, wherein the sidewalls are press fit between the bearing support structure and the portion of the seal.

The air turbine starter of claim **8**, further comprising an auxiliary fluid reservoir fluidly connected to and located radially between the fluid source and the fluid reservoir.

The air turbine starter of any preceding clause, wherein the auxiliary fluid reservoir is a set of auxiliary fluid reservoirs located radially between the fluid source and the fluid reservoir, wherein each reservoir of the set of auxiliary fluid reservoirs is radially spaced from another reservoir of the set of auxiliary fluid reservoirs.

The air turbine starter of any preceding clause, wherein the bearing is a first bearing, the air turbine starting including a second bearing, and the bearing support structure includes a first bearing support adjacent the first bearing and a second bearing support adjacent the second bearing.

The air turbine starter of any preceding clause, wherein the bearing support structure includes a spring-finger structure defined by the first bearing support, the second bearing support, and at least one flexible connector.

The air turbine starter of any preceding clause, wherein a spring is axially located between one of the at least one flexible connector and the second bearing.

The air turbine starter of any preceding clause, wherein the fluid reservoir of the fluid damping assembly is a first fluid reservoir, the fluid damping assembly including a second fluid reservoir, wherein the first fluid reservoir located between the first bearing support and the seal, and the second fluid reservoir axially spaced from the first fluid reservoir and located between the second bearing support and the portion of the second bearing.

The air turbine starter of any preceding clause, further comprising a first valve and a second valve, wherein the first valve is located between the fluid source and the first fluid reservoir, and the second valve is located between the fluid source and the second fluid reservoir.

The air turbine starter of any preceding clause, further comprising one or more of a pump, a flow sensor, a pressure sensor, a valve, a filter, or a bleed line.

The air turbine starter of any preceding clause, wherein the fluid cavity is defined by the portion of the bearing support structure, a portion of the bearing, and sidewalls.

The air turbine starter of any preceding clause, wherein the sidewalls are press fit between the portion of the bearing support structure and the portion of the bearing.

The air turbine starter of any preceding clause, further comprising an auxiliary fluid reservoir fluidly connected to and located radially between a valve located in the one or more conduits and the fluid reservoir.

The air turbine starter of any preceding clause, wherein the fluid reservoir defines a fluid cavity that is a variable volume cavity that dampens the radial motion of the bearing.

The air turbine starter of any preceding clause, wherein the fluid reservoir defines a fluid cavity that is a variable volume cavity that dampens the radial motion of the bearing support structure.

The air turbine starter of any preceding clause, wherein the first fluid reservoir defines a first fluid cavity that is a variable volume cavity that dampens the radial motion of the first bearing, and the second fluid reservoir defines a second fluid cavity that is a variable volume cavity that dampens the radial motion of the second bearing support structure.

The air turbine starter of any preceding clause, wherein the set of flexible connectors define a load path between the first bearing support and the second bearing support.

The air turbine starter of any preceding clause, wherein the first bearing and the second bearing are axially spaced with respect to the rotating axis.

The air turbine starter of any preceding clause, wherein the first or second bearing is a radial bearing and the second or first bearing is an axial bearing.

What is claimed is:

1. An air turbine starter for starting an engine, comprising:

a housing having an inlet, an outlet, and an air flow path extending between the inlet and the outlet, wherein the housing includes a seal that defines at least a portion of the air flow path;

a drive shaft rotatably coupled to a turbine defining an axis of rotation, the turbine having circumferentially spaced blades at least partially disposed within the air flow path;

a first bearing and a second bearing rotatably supporting the drive shaft;

a bearing support structure located, at least in part, between the first and second bearings and the seal, the bearing support structure comprising:

a first bearing support structure located between the first bearing and the seal;

a second bearing support structure located between the second bearing and the seal; and

at least one flexible connector coupling the first bearing support structure to the second bearing support structure;

a fluid damping assembly comprising one or more conduits that fluidly couple a fluid source to a fluid reservoir, wherein the fluid reservoir includes a fluid cavity at least partially defined by a portion of the bearing support structure; and

an output shaft operably coupled to the turbine by an output gear assembly, wherein the output shaft is selectively operably coupled to the engine, to rotate a portion of the engine.

2. The air turbine starter of claim **1**, wherein the fluid damping assembly further comprises a valve coupled to or located within the one or more conduits.

3. The air turbine starter of claim **2**, wherein the valve is coupled to a controller or a power source.

4. The air turbine starter of claim **2**, wherein the valve is located radially between the fluid source and the fluid reservoir.

5. The air turbine starter of claim **2**, wherein the valve provides pressurized fluid to the fluid reservoir.

6. The air turbine starter of claim **1**, wherein the fluid source provides pressurized fluid to the fluid reservoir.

7. The air turbine starter of claim **6**, wherein the pressurized fluid is pressurized oil.

8. The air turbine starter of claim **1**, wherein the fluid cavity is at least partially defined by the portion of the bearing support structure and sidewalls.

9. The air turbine starter of claim **8**, wherein the sidewalls are press fit between the bearing support structure and the portion of the seal.

10. The air turbine starter of claim **8**, further comprising an auxiliary fluid reservoir fluidly connected to and located radially between the fluid source and the fluid reservoir.

11. The air turbine starter of claim **10**, wherein the auxiliary fluid reservoir is a set of auxiliary fluid reservoirs, wherein at least one auxiliary fluid reservoir is located radially between the fluid source and the fluid reservoir, wherein each reservoir of the set of auxiliary fluid reservoirs is radially spaced from another reservoir of the set of auxiliary fluid reservoirs.

12. The air turbine starter of claim **1**, wherein the bearing support structure includes a spring-finger structure defined by the first bearing support structure, the second bearing support structure, and the at least one flexible connector.

13. The air turbine starter of claim **12**, wherein a spring is axially located between one of the at least one flexible connector and the second bearing.

14. The air turbine starter of claim **12**, wherein the fluid reservoir of the fluid damping assembly is a first fluid reservoir, the fluid damping assembly including a second fluid reservoir, wherein the first fluid reservoir is located between the first bearing support and the seal, and the second fluid reservoir is axially spaced from the first fluid reservoir and located between the second bearing support and a portion of the second bearing.

15. The air turbine starter of claim **14**, further comprising a first valve and a second valve, wherein the first valve is located between the fluid source and the first fluid reservoir, and the second valve is located between the fluid source and the second fluid reservoir.

16. The air turbine starter of claim **15**, further comprising one or more of a pump, a flow sensor, a pressure sensor, a filter, or a bleed line.

17. The air turbine starter of claim **1**, wherein the fluid cavity is defined by the portion of the bearing support structure, a portion of the second bearing, and sidewalls.

18. The air turbine starter of claim **17**, wherein the sidewalls are press fit between the portion of the bearing support structure and the portion of the second bearing.

19. The air turbine starter of claim **17**, further comprising an auxiliary fluid reservoir fluidly connected to and located radially between a valve located in the one or more conduits and the fluid reservoir.

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