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Hydraulically supported face seal

Abstract

A hydraulically supported seal including a seal plate operatively coupled with a seal, the seal being supported by a seal carrier within a housing; a piston having a piston shaft, the piston being in operative communication with the seal opposite the seal plate, the piston shaft being disposed through the housing through a piston receiver formed in the housing; a cylinder operatively coupled to the piston opposite the seal; and wherein the piston is hydraulically biased by a hydraulic fluid within the cylinder.

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Background/Summary

BACKGROUND

- (1) The present disclosure is directed to a high pressure cylinder integrated into a housing for a face seal to improve sealing with use of a very high pressure CO2 working fluid system.
- (2) Waste heat recovery systems are configured to capture the thermal energy in the engine exhaust and transfer the thermal energy to a working fluid, such as supercritical CO2 or air. The working fluid is then sent through a thermodynamic cycle to produce power in the form of electricity or mechanical motion. This power is used to supplement engine thrust.
- (3) The use of supercritical CO2 as a working fluid in the waste heat recovery system requires very high pressure systems and resultant pressure differentials across sealing surfaces (1,000 psi).
- (4) As seen in FIGS. 1 to 3 typical face seals include a seal plate interacting with a carbon seal supported by a carbon carrier in a housing. FIG. 1 shows a bearing compartment with a face seal highlighted. FIG. 2 and FIG. 3 show a seal plate A proximate a low pressure P_{low} section. A

carbon seal B is adjacent the seal plate A on the high pressure P.sub.high section. A carbon carrier C supports the carbon seal B. A damper D is coupled to a biasing member or spring S. The carbon seal B is biased by the mechanical spring S, such as a bellows spring or coil spring. The forces mustered by the bellows spring have a fixed limited range (100-150 psi) and can degrade over time. (5) What is needed is an improved face seal system capable of withstanding very high pressure differentials.

SUMMARY

(6) In accordance with the present disclosure, there is provided a hydraulically supported seal comprising a seal plate operatively coupled with a seal, the seal being supported by a seal carrier within a housing; a piston having a piston shaft, the piston being in operative communication with the seal opposite the seal plate, the piston shaft being disposed through the housing through a piston receiver formed in the housing; a cylinder operatively coupled to the piston opposite the seal; and wherein the piston is hydraulically biased by a hydraulic fluid within the cylinder.

(7) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the seal plate is between a high-pressure section and a low-pressure section opposite the high-pressure section.

(8) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the seal is adjacent the seal plate on the low-pressure side of the seal plate.

(9) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the piston shaft within the piston receiver is sealed by a non-rotating secondary seal.

(10) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the hydraulically supported seal further comprising a hydraulic circuit fluidly coupled to the cylinder, the hydraulic circuit configured to pressurize the cylinder.

(11) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include secondary seals seal the piston and the cylinder interface.

(12) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the hydraulically supported seal further comprising a controller employed to maintain the hydraulic circuit pressure which maintains a seal face integrity.

(13) In accordance with the present disclosure, there is provided a system for hydraulically supporting a seal in a supercritical carbon dioxide (sCO₂) turbomachine comprising a supercritical carbon dioxide turbomachine seal plate operatively coupled with a seal, the seal being supported by a seal carrier within a housing located in the supercritical carbon dioxide turbomachine; a piston having a piston shaft, the piston being in operative communication with the seal opposite the seal plate, the piston shaft being disposed through the housing through a piston receiver formed in the housing; a cylinder operatively coupled to the piston opposite the seal; and

(14) a hydraulic circuit containing a hydraulic fluid fluidly coupled to the cylinder, the hydraulic circuit configured to pressurize the cylinder, wherein the piston is hydraulically biased by the hydraulic fluid within the cylinder.

(15) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the system for hydraulically supporting a seal in a supercritical carbon dioxide turbomachine, further comprising a controller employed to maintain the hydraulic circuit pressure which maintains a seal face integrity.

(16) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the seal plate is between a high-pressure section and a low-pressure section.

(17) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the hydraulic circuit can be pressurized by a pump.

(18) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the system for hydraulically supporting a seal in a supercritical carbon dioxide turbomachine, further comprising a variable restrictor fluidly coupled to the hydraulic circuit and

employed to regulate pressure in the hydraulic circuit.

(19) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the system for hydraulically supporting a seal in a supercritical carbon dioxide turbomachine, further comprising a controller operatively coupled to the hydraulic circuit and employed to maintain the hydraulic circuit pressure which maintains a sealing force.

(20) In accordance with the present disclosure, there is provided a process for hydraulically supporting a seal comprising operatively coupling a seal plate with a seal; supporting the seal with a seal carrier within a housing; providing a piston having a piston shaft, the piston being in operative communication with the seal opposite the seal plate, disposing the piston shaft through a piston receiver formed in the housing; operatively coupling a cylinder to the piston opposite the seal; fluidly coupling a hydraulic circuit containing a hydraulic fluid to the cylinder; and hydraulically biasing the piston with the hydraulic fluid within the cylinder.

(21) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising operatively coupling a controller with the hydraulic circuit; and employing the controller to maintain the hydraulic circuit pressure which maintains a seal face integrity.

(22) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising sealing the interface between the piston and the cylinder with secondary seals.

(23) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising fluidly coupling a variable restrictor to the hydraulic circuit; and employing the variable restrictor to regulate pressure in the hydraulic circuit.

(24) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising pressurizing the hydraulic circuit with a pump.

(25) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include wherein the controller can be in communication with a supervisory controller.

(26) A further embodiment of any of the foregoing embodiments may additionally and/or alternatively include the process further comprising providing engine operational conditions as control input to the hydraulic circuit to maintain the sealing forces acting on the carbon seal throughout at least one engine operating cycle.

(27) Other details of the hydraulically supported seal are set forth in the following detailed description and the accompanying drawings wherein like reference numerals depict like elements.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 is a schematic exemplary bearing compartment.

(2) FIG. 2 is a partial cross section view of a face seal.

(3) FIG. 3 is a cross section view of the face seal.

(4) FIG. 4 is a cross section view of an exemplary gas turbine engine.

(5) FIG. 5 is a cross section schematic of an exemplary face seal with hydraulically supported seal.

DETAILED DESCRIPTION

(6) FIG. 4 schematically illustrates a gas turbine engine **20**. The gas turbine engine **20** is disclosed herein as a two-spool turbopump that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. The fan section **22** may include a single-stage fan **42** having a plurality of fan blades **43**. The fan blades **43** may have a fixed stagger angle or may have a variable pitch to direct incoming airflow from an engine inlet. The fan **42** drives air along a bypass flow path B in a bypass duct **13** defined within a housing **15** such as a fan case or nacelle, and also drives air along a core flow path C for compression and communication into the

combustor section **26** then expansion through the turbine section **28**. A splitter **29** aft of the fan **42** divides the air between the bypass flow path B and the core flow path C. The housing **15** may surround the fan **42** to establish an outer diameter of the bypass duct **13**. The splitter **29** may establish an inner diameter of the bypass duct **13**. Although depicted as a two-spool turboprop engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turboprops as the teachings may be applied to other types of turbine engines including three-spool architectures.

(7) The exemplary engine **20** generally includes a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, and the location of bearing systems **38** may be varied as appropriate to the application.

(8) The low speed spool **30** generally includes an inner shaft **40** that interconnects, a first (or low) pressure compressor **44** and a first (or low) pressure turbine **46**. The inner shaft **40** is connected to the fan **42** through a speed change mechanism, which in the exemplary gas turbine engine **20** is illustrated as a geared architecture **48** to drive the fan **42** at a lower speed than the low speed spool **30**. The inner shaft **40** may interconnect the low pressure compressor **44** and low pressure turbine **46** such that the low pressure compressor **44** and low pressure turbine **46** are rotatable at a common speed and in a common direction. In other embodiments, the low pressure turbine **46** drives both the fan **42** and low pressure compressor **44** through the geared architecture **48** such that the fan **42** and low pressure compressor **44** are rotatable at a common speed. Although this application discloses geared architecture **48**, its teaching may benefit direct drive engines having no geared architecture. The high speed spool **32** includes an outer shaft **50** that interconnects a second (or high) pressure compressor **52** and a second (or high) pressure turbine **54**. A combustor **56** is arranged in the exemplary gas turbine **20** between the high pressure compressor **52** and the high pressure turbine **54**. A mid-turbine frame **57** of the engine static structure **36** may be arranged generally between the high pressure turbine **54** and the low pressure turbine **46**. The mid-turbine frame **57** further supports bearing systems **38** in the turbine section **28**. The inner shaft **40** and the outer shaft **50** are concentric and rotate via bearing systems **38** about the engine central longitudinal axis A which is collinear with their longitudinal axes.

(9) Airflow in the core flow path C is compressed by the low pressure compressor **44** then the high pressure compressor **52**, mixed and burned with fuel in the combustor **56**, then expanded through the high pressure turbine **54** and low pressure turbine **46**. The mid-turbine frame **57** includes airfoils **59** which are in the core flow path C. The turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion. It will be appreciated that each of the positions of the fan section **22**, compressor section **24**, combustor section **26**, turbine section **28**, and fan drive gear system **48** may be varied. For example, gear system **48** may be located aft of the low pressure compressor, or aft of the combustor section **26** or even aft of turbine section **28**, and fan **42** may be positioned forward or aft of the location of gear system **48**.

(10) The low pressure compressor **44**, high pressure compressor **52**, high pressure turbine **54** and low pressure turbine **46** each include one or more stages having a row of rotatable airfoils. Each stage may include a row of static vanes adjacent the rotatable airfoils. The rotatable airfoils and vanes are schematically indicated at **47** and **49**.

(11) The engine **20** may be a high-bypass geared aircraft engine. The bypass ratio can be greater than or equal to 10.0 and less than or equal to about 18.0, or more narrowly can be less than or equal to 16.0. The geared architecture **48** may be an epicyclic gear train, such as a planetary gear system or a star gear system. The epicyclic gear train may include a sun gear, a ring gear, a plurality of intermediate gears meshing with the sun gear and ring gear, and a carrier that supports the intermediate gears. The sun gear may provide an input to the gear train. The ring gear (e.g., star gear system) or carrier (e.g., planetary gear system) may provide an output of the gear train to drive

the fan **42**. A gear reduction ratio may be greater than or equal to 2.3, or more narrowly greater than or equal to 3.0, and in some embodiments the gear reduction ratio is greater than or equal to 3.4. The gear reduction ratio may be less than or equal to 4.0. The fan diameter is significantly larger than that of the low pressure compressor **44**. The low pressure turbine **46** can have a pressure ratio that is greater than or equal to 8.0 and in some embodiments is greater than or equal to 10.0. The low pressure turbine pressure ratio can be less than or equal to 13.0, or more narrowly less than or equal to 12.0. Low pressure turbine **46** pressure ratio is pressure measured prior to an inlet of low pressure turbine **46** as related to the pressure at the outlet of the low pressure turbine **46** prior to an exhaust nozzle. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present invention is applicable to other gas turbine engines including direct drive turbofans. All of these parameters are measured at the cruise condition described below.

(12) A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section **22** of the engine **20** is designed for a particular flight condition—typically cruise at about 0.8 Mach and about 35,000 feet (10,668 meters). The flight condition of 0.8 Mach and 35,000 ft (10,668 meters), with the engine at its best fuel consumption—also known as “bucket cruise Thrust Specific Fuel Consumption (‘TSFC’)”—is the industry standard parameter of pounds-mass per hour lbm/hr of fuel flow rate being burned divided by pounds-force lbf of thrust the engine produces at that minimum point. The engine parameters described above, and those in the next paragraph are measured at this condition unless otherwise specified.

(13) “Low fan pressure ratio” is the pressure ratio across the fan blade **43** alone, without a Fan Exit Guide Vane (“FEGV”) system. A distance is established in a radial direction between the inner and outer diameters of the bypass duct **13** at an axial position corresponding to a leading edge of the splitter **29** relative to the engine central longitudinal axis A. The low fan pressure ratio is a spanwise average of the pressure ratios measured across the fan blade **43** alone over radial positions corresponding to the distance. The low fan pressure ratio can be less than or equal to 1.45, or more narrowly greater than or equal to 1.25, such as between 1.30 and 1.40. “LOW corrected fan tip speed” is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(T_{\text{Tram}} / 518.7^{\circ}\text{R})]^{\text{sup.}0.5}$. The “low corrected fan tip speed” can be less than or equal to 1150.0 ft/second (350.5 meters/second), and greater than or equal to 1000.0 ft/second (304.8 meters/second).

(14) Referring now to FIG. 5, there is illustrated an exemplary hydraulically supported seal **100**. The hydraulically supported seal **10** includes a seal plate **12**. The seal plate **112** is proximate a high pressure section $P_{\text{sub.high}}$. On the opposite side of the high pressure section $P_{\text{sub.high}}$ is a low pressure section P_{low} such as ambient pressure. The pressure differential between $P_{\text{sub.high}}$ and P_{low} can be one thousand pounds per square inch (1,000 psi). A seal **114** is adjacent the seal plate **112** on the low pressure side of the seal plate **112**. A seal carrier **116** is coupled to the seal **114** and supporting the seal **114** within a housing **118**.

(15) A piston **120** is in operative communication with the seal **114**. The piston **120** includes a shaft **121** that is disposed through the housing **118** through a piston receiver **122**. The piston receiver **122** can be sealed by a non-rotating secondary seal **124**. The piston **120** is coupled to a cylinder **126** opposite the seal **114**. Secondary seals **124** can also seal the piston **120** and cylinder **126** interface.

(16) The piston **120** is hydraulically biased by a hydraulic fluid **128** within the cylinder **126**. The cylinder **126** can be pressurized by a regulated hydraulic circuit **130**.

(17) The hydraulic circuit **130** can be pressurized by a variety of pumps **132**, such as a gearbox driven pump, variable speed pump, variable displacement pump, and the like. In an exemplary embodiment, a variable restrictor **134** can be employed to regulate pressure in the hydraulic circuit **130**.

(18) A controller **136** can be employed to maintain the hydraulic circuit **130** pressure which then maintains the seal face integrity. The controller **136** can be in communication with a supervisory

controller **138** such as a Full Authority Digital Engine Controller (FADEC). Engine operational conditions can provide control input to the hydraulic circuit **130** to maintain the sealing forces **140** acting on the carbon seal **114** operational throughout the various engine operating cycles. In an exemplary embodiment, a supercritical carbon dioxide (sCO₂) turbomachine can be employed along with the disclosed hydraulically supported seal.

(19) A technical advantage of the disclosed hydraulically supported seal includes the capacity to increase or decrease the sealing forces to maintain a balanced seal.

(20) Another technical advantage of the disclosed hydraulically supported seal includes the capacity to apply high sealing forces to the seal to maintain seal integrity.

(21) Another technical advantage of the disclosed hydraulically supported seal includes separation of the high-pressure supercritical CO₂ from hydraulic fluid, thus eliminating cross-contamination.

(22) There has been provided a hydraulically supported seal. While the hydraulically supported seal has been described in the context of specific embodiments thereof, other unforeseen alternatives, modifications, and variations may become apparent to those skilled in the art having read the foregoing description. Accordingly, it is intended to embrace those alternatives, modifications, and variations which fall within the broad scope of the appended claims.

Claims

1. A gas turbine engine with a hydraulically supported seal, the seal comprising: a seal plate operatively coupled with a seal, the seal being supported by a seal carrier within a housing; a piston having a piston shaft, the piston being in operative communication with the seal opposite the seal plate, the piston shaft being disposed through the housing through a piston receiver formed in the housing; a cylinder operatively coupled to the piston opposite the seal; wherein the piston is hydraulically biased by a hydraulic fluid within the cylinder; a hydraulic circuit fluidly coupled to the cylinder, the hydraulic circuit configured to pressurize the cylinder; and a controller employed to maintain a hydraulic circuit pressure which maintains a contact between the seal plate and the seal, wherein the controller is in operative communication with a supervisory controller comprising a Full Authority Digital Engine Controller; wherein gas turbine engine operational conditions provide control input to the hydraulic circuit to maintain sealing forces acting on the seal throughout gas turbine engine operating cycles.
 2. The hydraulically supported seal according to claim 1, wherein the seal plate is between a high pressure section and a low pressure section opposite the high pressure section.
 3. The hydraulically supported seal according to claim 2, wherein the seal is adjacent the seal plate on a low pressure side of the seal plate.
 4. The hydraulically supported seal according to claim 1, wherein the piston shaft within the piston receiver is sealed by a non-rotating secondary seal.
 5. The hydraulically supported seal according to claim 1, wherein secondary seals seal the piston and the cylinder interface.
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