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United States Patent	12395044
Kind Code	B2
Date of Patent	August 19, 2025
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CAC motor auxiliary water cooling system

Abstract

A system for cooling a cabin air compressor (CAC) motor includes a water separator which extracts water from airflow through a turbine and/or a fuel cell, and a CAC motor including cooling channels connected to an inlet and an outlet. The inlet of the CAC motor receives water from the water separator. The steam at the outlet of the CAC motor can be repurposed for warming utilities in an aircraft cabin, or for de-icing or increasing enthalpy of the turbine. The cooling water flow can be directed to the CAC motor in response to a predicted temperature of the CAC motor exceeding a threshold. The predicted temperature can be generated by feeding inputs including CAC motor input power measured by a power sensor, differential pressure measured by a pressure sensor, and a temperature at an air cooling inlet measured by a temperature sensor to a processor which generates a map model.

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Appl. No.: 18/169180

Filed: February 14, 2023

Prior Publication Data

Document Identifier	Publication Date
US 20240275241 A1	Aug. 15, 2024

Publication Classification

Int. Cl.: H02K9/20 (20060101); B33Y80/00 (20150101); B64D13/02 (20060101); F04D29/58 (20060101); H02K5/20 (20060101); H02K7/14 (20060101)

U.S. Cl.:

CPC H02K9/20 (20130101); B64D13/02 (20130101); H02K5/203 (20210101); H02K7/14 (20130101); B33Y80/00 (20141201); F04D29/5806 (20130101)

Field of Classification Search

CPC: B33Y (80/00); B64D (13/02); B64D (13/06); B64D (2013/0618); B64D (2013/0644); F04D (29/5806); H02K (5/203); H02K (7/14); H02K (9/20)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
7633193	12/2008	Masoudipour et al.	N/A	N/A
9469023	12/2015	Pal	N/A	N/A
9729020	12/2016	Pal	N/A	N/A
10807722	12/2019	Himmelmann	N/A	N/A
2001/0004837	12/2000	Sauterleute	62/402	B64D 13/06
2015/0035392	12/2014	Pal	N/A	N/A
2018/0331599	12/2017	Parlante	N/A	H02K 9/04
2019/0291873	12/2018	Connell	N/A	B64D 13/06
2022/0194597	12/2021	Merritt et al.	N/A	N/A
2022/0194601	12/2021	Merritt et al.	N/A	N/A
2023/0399112	12/2022	Army	N/A	F04D 17/10

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2407380	12/2011	EP	N/A
3401223	12/2017	EP	N/A
4019784	12/2021	EP	N/A
4019785	12/2021	EP	N/A

OTHER PUBLICATIONS

Extended European Search Report for European Patent No. 24157358.3, Dated Jul. 5, 2024, 6 Pages. cited by applicant

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Background/Summary

BACKGROUND

(1) Electric motors can be used within aircraft to drive compressors which compress air for delivery to an air cycle machine (ACM). Such an electric motor can be, for example, a cabin air compressor (CAC) motor. CAC motors can generate a high level of heat when used to drive the compressor. Thus, cooling of the CAC motor is necessary. Existing cooling solutions, such as using ram air, can create undesirable drag and can also fail to achieve enough cooling. Therefore, additional cooling of the CAC motor is desirable.

SUMMARY

(2) A system for cooling a cabin air compressor (CAC) motor includes a turbine including a turbine outlet. The system further includes a water separator including a separator inlet fluidly connected to the turbine outlet of the turbine, and a first separator outlet. The water separator collects cooling water from the turbine. The system further includes a CAC motor including a motor housing, a first CAC inlet, and a first CAC outlet. The first CAC inlet is fluidly connected to the first separator outlet, such that the cooling water can flow from the first separator outlet to the first CAC inlet. The CAC motor housing includes a plurality of first cooling channels fluidly connected to the first CAC inlet such that the cooling water can flow from the first CAC inlet through the plurality of first cooling channels. The first CAC outlet is fluidly connected to the plurality of first cooling channels, such that the cooling water that is evaporated into steam within the first cooling channels exits through the first CAC outlet.

(3) A method for cooling a motor includes directing fluid from a turbine, via a turbine outlet, to a water separator via a separator inlet. The method further includes separating cooling water from the fluid, via the water separator. The method further includes directing the cooling water from a first separator outlet of the water separator to a first cabin air compressor (CAC) inlet of a CAC motor. The method further includes directing the cooling water from the first CAC inlet through a plurality of cooling channels of the CAC motor. The method further includes directing the cooling water in the plurality of cooling channels to a CAC outlet of the CAC motor. The method further includes directing steam in the plurality of cooling channels that arises from evaporation of the cooling to the CAC outlet of the CAC motor.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) FIG. 1 is a schematic diagram depicting a CAC motor cooling system.
- (2) FIG. 2 is a schematic diagram depicting an alternative embodiment of the CAC motor cooling system.
- (3) FIG. 3 is a cross-sectional view of a CAC motor with a plurality of cooling channels.
- (4) FIG. 4 is a cross-sectional view of a CAC motor with a plurality of cooling channels.
- (5) FIG. 5 is a diagram depicting cooling across a stator of a CAC motor.
- (6) FIG. 6 is a flowchart depicting a method of turning on a CAC motor cooling system in response to high temperatures.
- (7) FIG. 7 is a diagram depicting a system for turning on a CAC motor cooling system in response to high temperatures.
- (8) FIG. 8 is a flowchart depicting a method of cooling a CAC motor.

DETAILED DESCRIPTION

(9) According to the techniques of this disclosure, a cooling system can be used for water cooling of a motor. In particular, a cabin air compressor (CAC) motor can be connected within an air cycle machine (ACM). A turbine within the ACM can deliver air to a water separator, which in turn can direct cooling water to a CAC motor. The CAC motor can have a plurality of cooling channels through which the cooling water can flow to cool the CAC motor. The resulting steam from the

cooling process of the CAC motor can be ejected outside the aircraft, directed to the cabin for utility purposes, or directed back to the turbine for increased enthalpy and/or de-icing. A processor can be used to predict the temperature of the CAC motor based on a mapping model, and the cooling process can be configured to begin when a predetermined predicted temperature threshold is exceeded.

(10) FIG. 1 is a schematic diagram depicting CAC motor cooling system **100**. CAC motor cooling system includes compressor **102**, turbine **104**, water separator **106**, ram air duct **108**, CAC motor **116**, fuel cell **122**, and sprayer **152**. Ram air duct **108** includes diffuser **110**, primary heat exchanger **112**, secondary heat exchanger **114**, fan **118**, and nozzle **120**. Primary heat exchanger **112** includes primary heat exchanger inlet **124** and primary heat exchanger outlet **126**. Secondary heat exchanger **114** includes secondary heat exchanger inlet **132** and secondary heat exchanger outlet **134**.

Compressor **102** includes compressor inlet **128** and compressor outlet **130**. Turbine **104** includes turbine inlet **136** and turbine outlet **138**. Water separator **106** includes separator inlet **148**, first separator outlet **140**, and second separator outlet **142**. CAC motor **116** includes first CAC inlet **144**, second CAC inlet **146**, and CAC outlet **150**. CAC motor **116** also includes air inlet **160** and air outlet **162**.

(11) In motor cooling system **100**, primary heat exchanger **112** is connected to an external air supply (not shown) via primary heat exchanger inlet **124**. Primary heat exchanger outlet **126** is fluidly connected to compressor inlet **128**. Compressor outlet **130** is fluidly connected to secondary heat exchanger inlet **132**. Secondary heat exchanger outlet **134** is fluidly connected to turbine inlet **136**. Turbine **104**, compressor **102**, fan **118**, and CAC motor **116** are connected to shaft **148** such that one or more turbine rotors, one or more compressor rotors, and fan **118** will all rotate in response to the rotation of shaft **148**. Turbine outlet **138** is fluidly connected to separator inlet **148**. Water separator **106**, as depicted, has two outlet paths. First separator outlet **140** is fluidly connected to sprayer **152**. Second separator outlet **142** is fluidly connected to first CAC inlet **144**. Second CAC inlet **146** is fluidly connected to fuel cell **122**. CAC outlet **150** is fluidly connected to nozzle **120**.

(12) Motor cooling system **100** operates by first receiving air in through primary heat exchanger inlet **124**. As shown in FIG. 1, primary heat exchanger inlet **124** is located within ram air duct **108** between nozzle **120** and diffuser **110**. The air entering primary heat exchanger inlet **124** can be ambient air that is drawn from a source exterior to the aircraft, such as atmosphere. The air can also be drawn from other sources including but not limited to the aircraft cabin. Air flows through primary heat exchanger **112** to be cooled by ram air flowing through ram air duct **108**. Ram air is cooling air sourced from outside the aircraft. Ram air can flow through diffuser **110** as air is forced into ram air duct **108** while the aircraft is in motion. Ram air can also flow into ram air duct **108** while the aircraft is stationary via the operation of fan **118**. Ram air flow across primary heat exchanger **112** to cool air flowing through primary heat exchanger **112**. Ram air exits the aircraft through nozzle **120** after flowing over both primary heat exchanger **112** and secondary heat exchanger **114**.

(13) The air in primary heat exchanger **112** continues to flow through primary heat exchanger outlet **126** after cooling within primary heat exchanger **112**. The air then flows into compressor **128** via compressor inlet **128**. Rotors within compressor **128** compress the air such that the pressure of the air is increased. The compressed air then flows out of compressor **128** via compressor outlet **130** and into secondary heat exchanger **114** via secondary heat exchanger inlet **132**. The compressed air is further cooled in secondary heat exchanger **114**. Secondary heat exchanger **114** is also located within ram air duct **108** between primary heat exchanger **114** and diffuser **110** such that ram air flows across secondary heat exchanger **114** to cool the air flowing through secondary heat exchanger **114**. As described with respect to primary heat exchanger **112**, ram air flows across secondary heat exchanger **114** as the ram air flows through ram air duct **108** and exits through nozzle **120**.

(14) The compressed air then flows out of secondary heat exchanger **114** via secondary heat exchanger outlet **134** and into turbine **104** via turbine inlet **136**. In some ACM embodiments, the compressed air may instead flow through a reheater and through a condenser prior to flowing into turbine **104** via turbine inlet **136**. In still other embodiments, there may be a second turbine wherein the air flows through a first turbine, through a condenser, and through a second turbine. In the depicted embodiment, the air that was compressed by compressor **102** enters turbine **104** and expands, causing the air to rotate turbine rotors within turbine **104** and energize turbine **104**. The rotation of the turbine rotors is used to drive and rotate shaft **148** such that the compressor rotors of compressor **102** and fan **118** are rotated and driven as shaft **148** is driven and rotated by turbine **104**.

(15) After passing through turbine **104**, the air is then directed out of turbine **104** via turbine outlet **138** and into water separator **106** via separator inlet **148**. Water separator **106** collects water out of the air. In one embodiment, water separator **106** uses a mechanical spinner to direct the air in a spiral direction, thereby separating the air and water using centrifugal force. In other embodiments, any air-water separator known in the art can be used. The water from water separator **106** is directed along two flow paths. The first flow path utilizes first separator outlet **140**. In the first flow path, cooling water is directed through first separator outlet **140** and is directed to sprayer **152**. Sprayer **152** sprays cooling water through diffuser **110** and into ram air duct **108** to provide additional cooling to primary heat exchanger **112** and secondary heat exchanger **114**. The second flow path of water separator **106** utilizes second separator outlet **142**. In the second flow path, cooling water flows from second operator outlet **142** to first CAC inlet **144**. After passing through first CAC inlet **144**, the cooling water is then directed through CAC motor **116** to provide cooling to CAC motor **116**. The structure of CAC motor **116** that directs the cooling water through CAC motor **116** will be described below with reference to FIGS. **3** and **4**.

(16) In addition to directing cooling water from water separator **106** to CAC motor **116** for cooling of CAC motor **116**, a cooling fluid can be directed from fuel cell **122** to CAC motor **116**. In some embodiments, the cooling fluid sourced from fuel cell **122** to CAC motor **116** can be excess cooling water within fuel cell **122**. In such an embodiment, excess cooling water from fuel cell **122** can enter the cooling channels of CAC motor **116** via second CAC inlet **146**. Thus, in the depicted embodiment of FIG. **1**, cooling water directed to first CAC inlet **144** by system **100** can come from water extracted from air exiting turbine **104** and cooling water directed to second CAC inlet **146** by system **100** can come from water extracted from fuel cell **122**. In other embodiments, the cooling water passing through CAC motor **116** can come only from fuel cell **122** or only from turbine **104**. Water traveling through CAC motor **116** can be converted to steam due to high temperatures within CAC motor **116**. Excess water and/or steam can exit CAC motor **116** through CAC outlet **150** and can be ejected out of the aircraft through nozzle **120** to aid in aircraft propulsion.

(17) In addition to the water cooling described with reference to FIG. **1**, air cooling can also be used as an additional cooling source for CAC motor **116**. Cooling air flow can come from ambient air exterior to the aircraft, turbine **104**, the aircraft cabin, or other cooling air sources. In one example, cooling airflow from an aircraft cabin can be directed through air inlet **160** to CAC motor **116**. The cooling airflow through the air inlet **160** can be directed through air cooling channels, as described below with reference to FIGS. **3** and **4**. The cooling airflow can then exit CAC motor **116** through air outlet **162** and be released through nozzle **120**, where it can be ejected with used ram air. The described example is merely one embodiment of how cooling air can flow through CAC motor **116** to provide cooling in addition to the water cooling.

(18) FIG. **2** is a schematic depicting an alternative embodiment of system **100** depicted in FIG. **1**. FIG. **2** depicts CAC motor cooling system **180**. The parts of CAC motor cooling system **180** are largely similar to system **100**. System **180**, however, differs from system **100** in the fluid connections of CAC motor **116**. CAC motor **116** includes CAC inlet **144**, first CAC outlet **154** and second CAC outlet **156**. CAC inlet **144** is connected as described in system **100** of FIG. **1**. The

depicted embodiment of system **180** does not contain a fuel cell or a second inlet for CAC motor **116**. First CAC outlet **154** is fluidly connected to an aircraft cabin (not shown). Second CAC outlet **156** is fluidly connected to turbine **104** via second turbine inlet **158**.

(19) In operation, system **180** operates similarly to system **100**. Air travels through primary heat exchanger **112**, compressor **102**, secondary heat exchanger **114**, turbine **104**, and water separator **106** in the same manner as system **100**. Water separator **106** again has two outlet paths. A first outlet path sprays water via sprayer **152** through diffuser **110** for additional cooling across primary heat exchanger **112** and secondary heat exchanger **114**. A second outlet path delivers cooling water flow through CAC inlet **144** and into cooling channels within CAC motor **116**. As described above with respect to FIG. **1**, CAC motor **116** can also undergo air cooling via air entering through air inlet **160**, flowing through air cooling channels within CAC motor **116**, and exiting the air cooling channels through air outlet **162**.

(20) In the embodiment of system **180** shown in FIG. **2**, the water traveling through CAC motor **116** can be converted to steam due to high temperatures within CAC motor **116**. Excess water and/or steam can be directed through first CAC outlet **154** and/or second CAC outlet **156**. Excess water/steam directed through first CAC outlet **154** can flow to the aircraft cabin. In the aircraft cabin, the heated water or steam can be used for utility applications such as hot water for food warming or lavatories. Excess water/steam directed through second CAC outlet **156** can flow to turbine **104** via second turbine inlet **158**. The steam at second turbine inlet **158** can increase the enthalpy of turbine **104**, thereby increasing the power generated by turbine **104**. The steam at second turbine inlet **158** can also be used to help control icing on or within turbine **104**. In the depicted embodiment, both first CAC outlet **154** and second CAC outlet **156** are used simultaneously such that steam and/or water is directed through both paths. In other embodiments, system **180** can exclusively use first CAC outlet **154** or system **180** can exclusively use second CAC outlet **156**. In other embodiments, system **180** can selectively use first CAC outlet **154** or selectively use second CAC outlet **156** via a valve.

(21) The described embodiments of system **100** and system **180** in FIGS. **1** and **2** are intended to be illustrations and to be non-limiting. Various combinations of the outlet paths and inlet paths of CAC motor **116** can be applied. For example, in an additional embodiment of system **180**, fuel cell **122** can be connected to CAC motor **116** via an additional CAC inlet. Further, in an additional embodiment of system **180**, a third CAC outlet may connect to nozzle **120** to eject excess water/steam to atmosphere. Thus, the described embodiments are non-limiting and can be used in isolation or in combination.

(22) Systems **100** and **180** provide the advantage of cooling for CAC motor **116**. The cooling arises from the outgoing cooled air from turbine **104**. Using the air exhausted by turbine **104** as a cooling source allows for increased efficiency as the airflow from turbine **104** is repurposed for cooling CAC motor **116**. Additional cooling drawn from fuel cell **122** is also advantageous as an efficient method of cooling CAC motor **116**. Additional sources of cooling water are contemplated by this disclosure, including cooling water arising from a vapor cycle system. The output of hot water/steam from CAC motor **116** is also advantageous because the hot water/steam can be repurposed in various ways. The hot water/steam can be recirculated in the cycle, including directing hot water/steam to primary heat exchanger inlet **124**. Further, the hot water/steam can be used for cabin utilities and/or increasing enthalpy or de-icing of turbine **104**. In the case that the hot water/steam cannot be repurposed, there is still an outlet for exhausting the excess hot water/steam overboard via nozzle **120**.

(23) FIG. **3** depicts a cross-sectional view of CAC motor assembly **200** in a plane parallel to center axis **224**. FIG. **4** depicts a cross-sectional view of CAC motor assembly **200** in a plane perpendicular to center axis **224** of CAC motor assembly **200**. FIGS. **3** and **4** will be discussed together. CAC motor assembly **200** includes housing **202**, compressor **226**, compressor **228**, fins **230**, air cooling channels **212**, water cooling channels **216**, air cooling inlet **204**, air cooling outlet

206, water cooling inlet **218**, water cooling outlet **220**, rotor **222**, stator **208**, and stator core **210**.

(24) Air cooling inlet **204** and air cooling outlet **206** extend from housing **202**. Similarly, water cooling inlet **218** and water cooling outlet **220** also extend from housing **202**. Rotor **222** is contained within housing **202** and is configured to rotate compressor **226** and compressor **228**. Stator **208** contains stator core **210** and is positioned adjacent to air cooling channels **212**, such that both stator **208** and air cooling channels **212** are contained within housing **202**. Stator **208** contains fins **230** extending from stator core **210**. Fins **230** can create air cooling channels **212** such that cooling air flows therein. Air cooling channels **212** extend within housing **202** to fluidically connect air cooling inlet **204** with air cooling outlet **206**. Water cooling channels **216** are positioned adjacent to air cooling channels **212** and are also contained within housing **202**. In some CAC motor applications, air cooling channels **212** may already exist and be contained within housing **202**, while water cooling channels **216** do not. In such a case, water cooling channels **216** may be produced within housing **202** via additive manufacturing. Additive manufacturing can also be used to produce water cooling inlet **218** and water cooling outlet **220** within housing **202**.

(25) CAC motor assembly **200** is cooled both by air cooling and water cooling in the depicted embodiments. Cooling air flow can come from ambient air exterior to the aircraft, turbine **104**, the aircraft cabin, or other cooling air sources. Cooling air flow enters through air cooling inlet **204**, flows through air cooling channels **212**, and exits through air cooling outlet **206**. Cooling water flow enters through water cooling inlet **218**, flows through water cooling channels **216**, and exits through water cooling outlet **220**. Water cooling channels are necessarily fluidly isolated from air cooling channels **212**, rotor **222**, and stator **208**. Cooling water may contain impurities, rendering the water electrically conductive. In such a case, isolating the electrically conductive water from rotor **222** and stator **208** is desirable.

(26) Water cooling flow through water cooling channels **216** can come from a variety of sources. As described in FIG. 1, cooling water flow can come from turbine **104** via water separator **106** and into water cooling inlet **218**. Cooling water flow can also come from fuel cell **122** into water cooling inlet **218**. In the case that cooling water flow is obtained from both fuel cell **122** and turbine **104**, CAC motor assembly **200** may have two water cooling inlets that are fluidly connected to water cooling channels **216**. In other embodiments, CAC motor assembly **200** may receive both sources of cooling water flow through water cooling inlet **218**.

(27) Water cooling outlet **220** can also be connected to various downstream components. As described in FIG. 1, water cooling outlet **220** can be fluidly connected to nozzle **120** such that excess water or steam is ejected overboard, outside of the aircraft. As described in FIG. 2, excess water or steam can also be directed to the aircraft cabin for utility purposes, or back to turbine **104** for de-icing or increased enthalpy.

(28) The configuration of CAC motor assembly **200** provides the advantage of providing for two stages of cooling, air cooling and water cooling. Thus, a greater amount of heat generated by the CAC motor can be mitigated when both cooling sources are used. Further, the upstream connection of water cooling inlet **218** to turbine **104** and the downstream connections of water cooling outlet **220** to the aircraft cabin and/or turbine **104** also provide advantages described above with respect to FIGS. 1 and 2.

(29) FIG. 5 depicts air cooled stator **300(a)** and air and water cooled stator **300(b)**. Included in the depiction of stator **300(a)** is air cooling inlet **204**, air cooling outlet **206**, and air cooling channels **212** (only one of which is shown in FIG. 5). Included in the depiction of stator **300(b)** is air cooling inlet **204**, air cooling outlet **206**, air cooling channels **212**, water cooling inlet **216**, water cooling outlet **218**, and water cooling channels **220**.

(30) In FIG. 5, air cooled stator **300(a)** and air and water cooled stator **300(b)** are both placed in a similar environment and are under similar operating conditions and loads of a CAC motor. Temperature measurements are shown on stators **300(a)** and **300(b)** to show and compare temperature gradients across stators **300(a)** and **300(b)** during operation. In stator **300(a)**, wherein

only air cooling is applied, the temperature of stator **300(a)** near air cooling inlet **204** is 210° C. the temperature near the center of stator **300(a)** is 198° C., and the temperature of stator **300(a)** near air cooling outlet **206** is 195° C. Stator **300(b)**, where water cooling is applied in addition to the air cooling, shows improved cooling over stator **300(a)**. In the example testing environment of FIG. 5, the water entering water cooling inlet **216** is near or at the vaporization point of 100° C. As depicted in stator **300(b)**, the temperature of stator **300(b)** near air cooling inlet **204** is 170° C. the temperature of stator **300(b)** near the center of stator **300(b)** is 166° C., and the temperature of stator **300(b)** near air cooling outlet **206** is 163° C. Thus, the addition of the water cooling channel provides the advantage of increased cooling capability when used in combination with existing air cooling.

(31) The present application does not require an excessive amount of water to ensure cooling is accomplished as described. Sample heat transfer characteristics can be used to determine how much water flow is required to accomplish the cooling. The heat transfer from water cooling can be calculated using Equation 1 below.

(32) $Q = (m * c * \Delta T) + (m * h_{fg})$ Equation 1

(33) In the Equation 1, Q is the heat absorbed by the water from the motor, m is the mass flow rate of water, c is the specific heat of water, ΔT is the increase in temperature of the water from the inlet to the outlet, and h_{fg} is the latent heat of evaporation. Table 1 shown below was generated from Equation 1 with boiling set at 1 bar.

(34) TABLE-US-00001 TABLE 1 Heat Transfer With Boiling Set at 1 Bar Water Water flow Heat transfer from flow rate rate (m) h_{fg} water cooling (Q) lbm/min kg/s kJ/kg kW
0.1 0.00075599 2258 1.707
0.2 0.00151198 2258 3.416

(35) As shown in Table 1, a desired heat transfer of 1.707 kW requires a flow rate of 0.1 lbm/min. Additionally, increasing the flow rate to 0.2 lbm/min provides a heat transfer Q value of 3.416 kW. Thus, sufficient heat transfer can be achieved with water cooling without the need for excessive water flow through water cooling channels **220**.

(36) The stator cooling depicted in FIG. 5 demonstrates the advantage of water cooling in addition to air cooling. As shown in Table 1, additional cooling in the range of 40° C. can be obtained by adding water cooling to a CAC motor. Further, the calculations shown in Table 1 demonstrate that such cooling does not require a high flow rate of water. Thus, in addition to the efficiencies described in FIGS. 1 and 2, the present disclosure is an improvement over existing cooling of a CAC motor.

(37) FIG. 6 depicts method **400** which is a method of turning on the CAC motor cooling system in response to high temperatures. Due to the heat arising out of the CAC motor, mounting a device for sensing temperature within the CAC motor is not a feasible solution for determining when additional cooling is required. Thus, a model can be mapped based on known parameters to calculate a predicted temperature of the stator windings within the CAC motor.

(38) In the embodiment depicted in method **400**, map model **408** takes input power **402**, differential pressure **404**, and inlet air temperature **406** as inputs to a processor in order to calculate the predicted temperature of the stator windings. Input power **402** is the input power to a common motor start controller (CMSC), which is used to power the CAC motor. The input power can be a constant value required to power CAC motor that is known by the processor. In other embodiments, there can be a power sensor at the input of the CAC motor which detects the value of the input power to the CAC motor and transmits the value of the input power to the processor. Differential pressure **404** is the differential pressure across the CAC motor. The value of the differential pressure across the CAC motor can be measured by a differential pressure sensor, and transmitted to the processor. The inlet air temperature is the air temperature measured at the air cooling inlet of the CAC motor such as air cooling inlet **204** of FIG. 3. The inlet air temperature can be measured by a temperature sensor mounted near air cooling inlet **204** and transmitted to the

processor. Transmission of the parameters including input power, differential pressure, and inlet air temperature can be through electrical connections or through wireless connections with the processor. Once the parameters are received from the respective sensors, the processor can create map model **408** wherein predicted temperature outputs are generated based on the input parameters. The temperature outputs in map model **408** are predicted temperatures of the stator windings.

(39) In response to the predicted temperature from map model **408** exceeding a temperature threshold, water cooling can be activated. For example, the temperature threshold can be set at 175° C., such that the water cooling is turned on when the predicted stator winding temperature exceeds 175° C. The water separator is configured to direct water through a separator outlet such as second separator outlet **142** of FIG. 1, to a CAC inlet, such as the first CAC inlet **144** of FIG. 1.

(40) FIG. 7 depicts water cooling system **420** in which water cooling is turned on in response to high temperatures. System **420** includes power sensor **422** which can be a sensor at the input of the CAC motor configured to detect the value of the input power to the CAC motor and transmits the value of the input power to the processor. System **420** also includes pressure sensor **424** which can be a differential pressure sensor configured to sense the pressure across the CAC motor. System **420** also includes temperature sensor **426**, which can be a temperature sensor located near an air cooling inlet, such as air cooling inlet **204** of FIG. 3.

(41) Power sensor **422**, pressure sensor **424** and temperature sensor **426** all transmit their respective measurements to processor **428**. Processor **428** can then generate map model **408** of FIG. 6, and produce a predicted temperature. If the predicted temperature exceeds a temperature threshold, processor **428** can send a signal to valve **430**, where valve **430** is included within a water separator, such as water separator **106** of FIGS. 1 and 2. Valve **430** can be configured to open in response to a signal from processor **428** indicating that the predicted temperature exceeds the temperature threshold. Valve **430** can be configured to close in response to a signal from processor **428** indicating that the predicted temperature does not exceed the temperature threshold.

(42) System **420** is one embodiment of a water cooling system in which water cooling is turned on in response to high temperatures. In other embodiments, water is directed by operation of a pump instead of the opening or closing of a valve. Additionally, the valve or pump can be located, for example, at the outlet of a turbine such as turbine **104** of FIGS. 1 and 2. The valve or pump can also be located, for example, at the inlet of the CAC motor, such that cooling water flow does not enter cooling channels within the CAC motor until the processor indicates that the valve can be opened or the pump can be activated.

(43) In other embodiments, water can be directed continuously through the cooling channels of the CAC motor without relying on the map model. In still other embodiments, the flow of water conducted through the cooling channels can be continuous, but the flow rate of the water can increase in response to the predicted stator winding temperature exceeding a temperature threshold. Further, a higher flow rate can be permitted through the CAC winding depending on the quantity of the difference between the predicted temperature and the temperature threshold. Thus, for example, a higher flow rate of water can travel through the cooling channels at a predicted temperature of 210° C. as compared to the flow rate when the temperature is 180° C.

(44) Method **400** and system **420** provides the advantage of regulating water flow through the CAC motor for cooling as well as determining predicted temperatures without the need for mounting a temperature sensor within the CAC motor. As described with respect to Table 1 above, excessive amounts of water are not required to accomplish cooling of the motor. Using the method **400** and system **420** described with respect to FIGS. 6 and 7, additional conservation of water can be achieved as water can be stored and saved until the temperature threshold is exceeded.

(45) FIG. 8 is a flowchart depicting method of cooling a CAC motor **500**. Method **500** begins at step **502** with calculating, via a processor, a predicted temperature of one or more windings of the CAC motor based upon an input power to the CAC motor, a differential pressure across the CAC motor, and a temperature at an air cooling inlet of the CAC motor. The input power to the CAC

motor can be a power directed to the motor from a common motor start controller (CMSC). The predicted temperature can be obtained via map model **408** described above in the description of FIGS. **6** and **7**.

(46) At step **504**, water cooling is turned on in response to the predicted temperature exceeding a temperature threshold. Turning on water cooling can involve opening a valve at a water collector or starting the operation of a pump from the water collector. Water cooling involves the steps of **506-514** described below.

(47) At step **506**, fluid is directed from a turbine, via a turbine outlet, to a water separator via a separator inlet. The fluid directed from the turbine can be cooling airflow that contains a mixture of air and cooling water. At step **508** water is collected from the cooling airflow via the water separator. The water separator is configured to separate the water from the airflow that passes through the turbine and arrives at the water separator.

(48) At step **510**, water from the first separator outlet of the water separator is directed to a first CAC inlet of a CAC motor. In some embodiments, an additional step of method **500** can also include receiving cooling water at a second CAC inlet. The second source of cooling water can be, for example, from fuel cell **122** shown in FIG. **1**.

(49) At step **512**, water is directed from the first CAC inlet through a plurality of cooling channels of the CAC motor. In some embodiments, there is a first plurality of cooling channels and second plurality of cooling channels. The first plurality of cooling channels is used for air cooling and the second plurality of cooling channels is used for water cooling. In such an embodiment, water cooling and air cooling together provide cooling to the CAC motor.

(50) At step **514**, the cooling water from the plurality of cooling channels of the CAC motor can be directed to a CAC outlet of the CAC motor. The CAC outlet can also output steam that arises from evaporation of the cooling water flowing through the plurality of cooling channels. The steam can then be repurposed for a variety of uses including cabin utilities, turbine enthalpy, and/or turbine de-icing, or can be disposed of by ejection through a nozzle.

(51) The techniques of this disclosure demonstrate the advantages of water cooling in addition to air cooling of a CAC motor. As described above, airflow from a turbine can be efficiently repurposed, via a water separator, to provide cooling water flow through cooling channels of a CAC motor. Water extracted from a fuel cell can also be used to provide cooling water flow through said cooling channels. Further, the cooling water flow can be activated in response to a temperature threshold of the CAC motor being met. The temperature of the CAC motor can be predicted based on input parameters to a map model. Such a prediction allows for cooling water flow to be conducted when necessary.

Discussion of Possible Embodiments

(52) The following are non-exclusive descriptions of possible embodiments of the present invention.

(53) A system for cooling a cabin air compressor (CAC) motor includes a turbine including a turbine outlet. The system further includes a water separator comprising a separator inlet fluidly connected to the turbine outlet of the turbine, and a first separator outlet. The water separator collects cooling water from the turbine. The system further includes a CAC motor comprising a motor housing, a first CAC inlet, and a first CAC outlet. The first CAC inlet is fluidly connected to the first separator outlet, such that the cooling water can flow from the first separator outlet to the first CAC inlet. The CAC motor housing includes a plurality of first cooling channels fluidly connected to the first CAC inlet such that the cooling water can flow from the first CAC inlet through the plurality of first cooling channels. The first CAC outlet is fluidly connected to the plurality of first cooling channels, such that the cooling water that is evaporated into steam within the first cooling channels exits through the first CAC outlet.

(54) The system of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional

components:

- (55) A further embodiment of the foregoing system, further comprising a processor configured to calculate a predicted temperature of one or more windings of the CAC motor based upon an input power to the CAC motor, a differential pressure across the CAC motor, and a temperature at the first CAC inlet.
- (56) A further embodiment of any of the foregoing systems, wherein the water separator is configured to open a separator valve to direct water through the first separator outlet to the first CAC inlet when the processor indicates the predicted temperature exceeds a temperature threshold.
- (57) A further embodiment of any of the foregoing systems, wherein the water separator comprises a second separator outlet fluidly connected to a diffuser.
- (58) A further embodiment of any of the foregoing systems, wherein a heat exchanger is downstream from the diffuser such that the diffuser diffuses water from the water separator onto an external side of the heat exchanger.
- (59) A further embodiment of any of the foregoing systems, wherein the first CAC outlet is fluidly connected to atmosphere by a nozzle.
- (60) A further embodiment of any of the foregoing systems, wherein the CAC motor further comprises a second CAC inlet, wherein the second CAC inlet is fluidly connected to a fuel cell outlet.
- (61) A further embodiment of any of the foregoing systems, wherein the fuel cell outlet is fluidly connected to the second CAC inlet.
- (62) A further embodiment of any of the foregoing systems, wherein the first CAC outlet is fluidly coupled to a cabin inlet of an aircraft cabin.
- (63) A further embodiment of any of the foregoing systems, wherein the first CAC outlet is fluidly coupled to a turbine inlet of the turbine.
- (64) A further embodiment of any of the foregoing systems, wherein the CAC motor further comprises a second CAC outlet fluidly connected to the plurality of first cooling channels.
- (65) A further embodiment of any of the foregoing systems, wherein the first CAC outlet is fluidly coupled to a cabin inlet of an aircraft cabin and the second CAC outlet is fluidly coupled to a turbine inlet of the turbine.
- (66) A further embodiment of any of the foregoing systems, wherein the motor housing with the plurality of first cooling channels is additively manufactured.
- (67) A further embodiment of any of the foregoing systems, wherein the CAC motor further comprises a plurality of second cooling channels.
- (68) A further embodiment of any of the foregoing systems, wherein the plurality of second cooling channels are formed between a stator of the CAC motor and the motor housing.
- (69) A method for cooling a motor includes directing fluid from a turbine, via a turbine outlet, to a water separator via a separator inlet. The method further includes separating cooling water from the fluid, via the water separator. The method further includes directing the cooling water from a first separator outlet of the water separator to a first cabin air compressor (CAC) inlet of a CAC motor. The method further includes directing the cooling water from the first CAC inlet through a plurality of cooling channels of the CAC motor. The method further includes directing the cooling water in the plurality of cooling channels to a CAC outlet of the CAC motor. The method further includes directing steam in the plurality of cooling channels that arises from evaporation of the cooling to the CAC outlet of the CAC motor.
- (70) A further embodiment of any of the foregoing methods, further including calculating, via a processor, a predicted temperature of one or more windings of the CAC motor based upon an input power of the CAC motor received from a power sensor, a differential pressure across the CAC motor received from a pressure sensor, and a temperature at the first CAC inlet received from a temperature sensor. The method further includes performing the steps of directing the fluid from the turbine, separating the cooling water from the fluid via the water separator, directing the

cooling water from the first separator outlet to the first CAC inlet, directing the cooling water from the first CAC inlet through the plurality of cooling channels, and directing the cooling water in the plurality of cooling channels to the CAC outlet in response to the predicted temperature exceeding a temperature threshold.

(71) A further embodiment of any of the foregoing methods, further including directing water from a second separator outlet of the water separator to a diffuser.

(72) A further embodiment of any of the foregoing methods, further including diffusing water from the water separator, via the diffuser, onto an external side of a heat exchanger.

(73) A further embodiment of any of the foregoing methods, further including directing steam from the first CAC outlet to atmosphere by a nozzle.

(74) While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A system for cooling a cabin air compressor (CAC) motor, comprising: a turbine comprising a turbine outlet; a water separator comprising a separator inlet fluidly connected to the turbine outlet of the turbine, and a first separator outlet, wherein the water separator collects cooling water from the turbine; the CAC motor comprising a motor housing, a first CAC inlet, and a first CAC outlet, wherein: the first CAC inlet is fluidly connected to the first separator outlet, such that the cooling water can flow from the first separator outlet to the first CAC inlet; the CAC motor housing comprises a plurality of first cooling channels fluidly connected to the first CAC inlet such that the cooling water can flow from the first CAC inlet through the plurality of first cooling channels; and the first CAC outlet is fluidly connected to the plurality of first cooling channels, such that the cooling water that is evaporated into steam within the first cooling channels exits through the first CAC outlet.
2. The system of claim 1, further comprising a processor configured to calculate a predicted temperature of one or more windings of the CAC motor based upon an input power to the CAC motor, a differential pressure across the CAC motor, and a temperature at the first CAC inlet.
3. The system of claim 2, wherein the water separator is configured to open a separator valve to direct water through the first separator outlet to the first CAC inlet when the processor indicates the predicted temperature exceeds a temperature threshold.
4. The system of claim 1, wherein the water separator comprises a second separator outlet fluidly connected to a diffuser.
5. The system of claim 4, wherein a heat exchanger is downstream from the diffuser such that the diffuser diffuses water from the water separator onto an external side of the heat exchanger.
6. The system of claim 1, wherein the first CAC outlet is fluidly connected to atmosphere by a nozzle.
7. The system of claim 1, wherein the CAC motor further comprises a second CAC inlet, wherein the second CAC inlet is fluidly connected to a fuel cell outlet.
8. The system of claim 1, wherein the first CAC outlet is fluidly coupled to a cabin inlet of an aircraft cabin.
9. The system of claim 1, wherein the first CAC outlet is fluidly coupled to a turbine inlet of the turbine.
10. The system of claim 1, wherein the CAC motor further comprises a second CAC outlet fluidly

connected to the plurality of first cooling channels.

11. The system of claim 10, wherein the first CAC outlet is fluidly coupled to a cabin inlet of an aircraft cabin and the second CAC outlet is fluidly coupled to a turbine inlet of the turbine.

12. The system of claim 1, wherein the motor housing with the plurality of first cooling channels is additively manufactured.

13. The system of claim 1, wherein the CAC motor further comprises a plurality of second cooling channels.

14. The system of claim 13, wherein the plurality of second cooling channels are formed between a stator of the CAC motor and the motor housing.

15. A method for cooling a motor, comprising: directing fluid from a turbine, via a turbine outlet, to a water separator via a separator inlet; separating cooling water from the fluid, via the water separator; directing the cooling water from a first separator outlet of the water separator to a first cabin air compressor (CAC) inlet of a CAC motor; directing the cooling water from the first CAC inlet through a plurality of cooling channels of the CAC motor; directing the cooling water in the plurality of cooling channels to a CAC outlet of the CAC motor; and directing steam in the plurality of cooling channels that arises from evaporation of the cooling to the CAC outlet of the CAC motor.

16. The method of claim 15, further comprising: calculating, via a processor, a predicted temperature of one or more windings of the CAC motor based upon an input power of the CAC motor measured by a power sensor, a differential pressure across the CAC motor measured by a pressure sensor, and a temperature at an air cooling inlet of the CAC motor measured by a temperature sensor; and performing the steps of directing the fluid from the turbine, separating the cooling water from the fluid via the water separator, directing the cooling water from the first separator outlet to the first CAC inlet, directing the cooling water from the first CAC inlet through the plurality of cooling channels, and directing the cooling water in the plurality of cooling channels to the CAC outlet in response to the predicted temperature exceeding a temperature threshold.

17. The method of claim 15, further comprising: directing water from a second separator outlet of the water separator to a diffuser.

18. The method of claim 17, further comprising: diffusing water from the water separator, via the diffuser, onto an external side of a heat exchanger.

19. The method of claim 15, further comprising: directing steam from the first CAC outlet to atmosphere by a nozzle.
