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Brushless Motor Winding Termination Switchable Between Star and Delta Configurations Automatically Keyed to a Detected Operating Medium for a Transmedium Air-and-Water Vehicle

Promising · 74.2/100 | 12 claims

TECHNICAL FIELD

Electric propulsion control for transmedium unmanned vehicles, specifically automatic reconfiguration of a brushless DC motor winding termination as a function of the surrounding fluid medium.

ABSTRACT

A propulsion controller for an unmanned vehicle that operates both in air and submerged in water reconfigures the termination of a brushless DC (BLDC) motor between a star (wye) and a delta connection in response to a signal indicating the detected operating medium. A medium-detection subsystem (for example a conductivity probe, an immersion sensor, a pressure sensor, or a data-fusion estimator) classifies the surrounding fluid as air or water. When air is detected the controller commands a delta termination to favour high rotational speed for aerial flight; when water is detected the controller commands a star termination to favour high torque for higher-density submerged propulsion through a common or mechanically coupled propulsor. Switching is gated by interlocks that enforce a safe rotor state and bounded transition current. The arrangement allows a single motor and propulsor set, or a coupled set, to serve two fluid media that impose very different load characteristics, improving range and efficiency in both regimes. Star-delta switching is itself known; the disclosed advance is its automatic keying to a detected air-or-water medium in a transmedium vehicle.

BACKGROUND

Aerial rotorcraft and submerged thrusters impose opposite demands on an electric propulsor. Air is a low-density medium that rewards high propeller rotational speed, while water is roughly eight hundred times denser and rewards high torque at low speed. A motor wound and terminated for one medium is poorly matched to the other, so a vehicle that must fly and then dive either carries two separate propulsion systems, adding mass and drag, or accepts a compromise that is inefficient in both media. Reconfigurable star-delta (wye-delta) winding termination is well known as a means of trading torque for speed: industrial soft-start uses it, and switchable star-delta motor windings are described in prior art such as US5675222 and EP2421143. However, those teachings switch in response to commanded speed, load, or a manual selection. The prior art does not key the star-delta selection to an automatically detected change of operating fluid medium between air and water, because the prior art is not concerned with a vehicle that transitions between flight and submerged propulsion. As a result, no prior art uses medium classification to drive a torque-versus-speed winding reconfiguration for a transmedium drone. There remains a need for a propulsion controller that senses whether the vehicle is in air or water and automatically selects the winding termination best suited to that medium, with safe switching interlocks, so that a shared or coupled propulsor can serve both regimes efficiently.

SUMMARY OF THE INVENTION

The invention provides a method and a controller that select a BLDC winding termination as a function of a detected operating medium. A medium-detection subsystem classifies the surrounding fluid as air or water using one or more of conductivity, immersion, pressure, and fused motion or acoustic data. A switching network of contactors or solid-state switches reconfigures the motor phases between a delta connection, selected for air to favour speed, and a star connection, selected for water to favour torque. A safety interlock conditions any reconfiguration on a permitted rotor state (for example reduced or zero current, or a bounded electrical angle) and limits transition inrush. The reconfiguration may apply to a single common propulsor used in both media or to mechanically coupled air and water propulsors driven by the shared motor. Hysteresis and a confirmation dwell prevent chattering at the air-water

interface. The result is improved efficiency, thrust margin, and range in each medium from a shared electrical machine, without manual mode selection by the operator.

DETAILED DESCRIPTION

FIG. 1 is a schematic of the transmedium vehicle showing a BLDC motor (10), a propulsor (12) which may be a common air-and-water propulsor or one of a mechanically coupled pair, a switching network (14), a medium-detection subsystem (16), and a propulsion controller (18). FIG. 2 is a wiring diagram of the switching network (14) showing the three motor phase windings and the contactor or solid-state switch set that selectively forms a star (wye) node or closes the phases into a delta loop. FIG. 3 is a torque-speed map illustrating the delta characteristic (higher speed, lower torque) overlaid with the star characteristic (lower speed, higher torque) and the operating envelopes for air and water. FIG. 4 is a flowchart of the medium-keyed switching method. FIG. 5 is a section view of an immersion and conductivity sensor (20) mounted in the airframe. FIG. 6 is a state diagram of the switching interlock. In operation, the medium-detection subsystem (16) samples one or more inputs. A conductivity probe distinguishes the high electrical conductivity of seawater from air; an immersion or wetness sensor confirms contact with liquid; a pressure sensor confirms depth consistent with submersion; and a fusion estimator (18) combines these with inertial and acoustic cues to reject spray and rain. The estimator outputs a classified medium state of AIR or WATER with a confidence value. The controller (18) requires the confidence to exceed a threshold and the state to persist for a confirmation dwell before commanding a change, providing hysteresis at the interface. When AIR is confirmed, the controller commands the switching network (14) to the delta termination so the motor (10) develops high rotational speed suitable for aerial thrust. When WATER is confirmed, the controller commands the star termination so the same or coupled propulsor develops high torque suitable for the denser medium. Before any reconfiguration, the interlock of FIG. 6 brings the motor to a permitted rotor state, for example commanding a current reduction or a brief freewheel so that switches operate within rated transition current. The controller then ramps current back up in the new termination. In an embodiment the switching network uses make-before-break sequencing on solid-state devices to bound transient torque. In a further embodiment the star or delta selection is additionally trimmed by commanded thrust so that, within a medium, the controller may bias the termination, while the primary selection key remains the detected medium.

DRAWINGS

FIG. 1 is a schematic of the transmedium vehicle showing the BLDC motor, propulsor, switching network, medium-detection subsystem, and propulsion controller; FIG. 2 is a wiring diagram of the switching network forming a selectable star node or delta loop; FIG. 3 is a torque-speed map overlaying the delta and star characteristics with the air and water operating envelopes; FIG. 4 is a flowchart of the medium-keyed switching method; FIG. 5 is a section view of an immersion and conductivity sensor in the airframe; FIG. 6 is a state diagram of the switching interlock enforcing a permitted rotor state and bounded transition current.

CLAIMS

1. A method of controlling electric propulsion of an unmanned vehicle configured to operate in air and submerged in water, the method comprising: detecting an operating medium surrounding the vehicle and classifying the operating medium as air or water; and in response to the classified operating medium, automatically selecting a termination of a polyphase brushless motor between a star connection and a delta connection, wherein the delta connection is selected when the operating medium is classified as air and the star connection is selected when the operating medium is classified as water, such that the motor drives a propulsor with a higher-speed characteristic in air and a higher-torque characteristic in water.

2. A propulsion system for a transmedium unmanned vehicle configured to operate in air and submerged in water, the system comprising: a polyphase brushless motor coupled to at least one propulsor; a switching network operable to terminate windings of the motor selectively in a star connection or a delta connection; a medium-detection subsystem arranged to classify a fluid medium surrounding the vehicle as air or water; and a controller configured to command the switching network to the delta connection responsive to the medium being classified as air and to the star connection responsive to the medium being classified as water.

3. The method of claim 1, wherein detecting the operating medium comprises measuring an electrical conductivity of fluid in contact with the vehicle and classifying the medium as water when the conductivity exceeds a threshold.

4. The method of claim 1, wherein classifying the operating medium comprises fusing two or more of a conductivity signal, an immersion signal, a pressure signal, an inertial signal, and an acoustic signal to reject spray and precipitation.

5. The method of claim 1, further comprising requiring the classified operating medium to persist for a confirmation dwell time and to exceed a confidence threshold before changing the selected termination, thereby providing hysteresis at an air-water interface.

6. The method of claim 1, further comprising, before changing the selected termination, commanding the motor to a permitted rotor state in which a switching current is bounded below a rated transition current of the switching network.

7. The method of claim 6, wherein commanding the permitted rotor state comprises one of reducing motor current and commanding a freewheel interval, and wherein the termination is changed using a make-before-break sequence of solid-state switches.

8. The method of claim 1, wherein the propulsor comprises a common propulsor that is driven in both air and water, or a pair of mechanically coupled air and water propulsors driven by the motor.

9. The method of claim 1, further comprising, within a classified medium, trimming the selected termination as a function of a commanded thrust, wherein the classified operating medium remains a primary selection key for the termination.

10. The system of claim 2, wherein the switching network comprises solid-state switches and the controller is configured to apply a make-before-break sequence bounding a transient torque during reconfiguration.

11. The system of claim 2, wherein the medium-detection subsystem comprises at least one of a conductivity probe, an immersion sensor, and a pressure sensor mounted to an airframe of the vehicle.

12. The system of claim 2, wherein the controller is configured to apply a confirmation dwell and a confidence threshold to the classification before commanding the switching network, providing hysteresis at an air-water interface.

PATENTABILITY SELF-ASSESSMENT (30-FACTOR)

Patentability	86.0%
Prior-art position	64.0%
Technical merit	64.0%
Commercial	74.0%
Composite genius score	**74.2/100 (Promising)**

FILING ROUTES

United Kingdom (UK IPO)
GB national application at UK IPO with combined search and examination requested early; keystone filing intended to anchor a later PCT international application claiming UK priority.

Ireland (IPOI / Irish PATO)
Parallel IE filing at IPOI; a 10-year short-term Irish patent may be used as a fast keystone if quick certainty is wanted, then EPO or PCT for full-term protection claiming priority.

PRIOR-ART VERIFICATION (LIVE SEARCHES)

UK IPO patent search (Ipsum)
UK national register and file inspection
https://www.search-for-intellectual-property.service.gov.uk/SearchByNumber

Espacenet (EPO)
European/worldwide prior-art search
https://worldwide.espacenet.com/patent/search?q=medium%20keyed%20star%20delta%20winding

Google Patents
Full-text + family view
https://patents.google.com/?q=(medium%20keyed%20star%20delta%20winding%20drone%20UAV%20transmedium)&type=PATENT

IPOI (Irish Patents Office)
Irish national filing route (short-term + full-term)
https://www.ipoi.gov.ie/en/types-of-ip/patents/

EPO CPC B64U (UAS)
Unmanned-aircraft classification
https://worldwide.espacenet.com/patent/search?q=cpc%3DB64U