

CLAIMS

1. An apparatus (100) for controlling propulsion of a marine vessel (102), comprising:
- a vessel interface (506) couplable with a vessel control system (106);
 - 5 a control interface (508) to control a foil wheel propulsion system (104), which foil wheel propulsion system (104) comprises a rotatable wheel (204) powered by a wheel motor (202) and controlled by a wheel controller (200), a plurality of rotatable foils (214A, 214B, 214C, 214D) attached perpendicularly to the wheel (204), each foil (214A, 214B, 214C, 214D) powered by a foil motor (212A, 212B, 212C, 212D) and controlled by a foil drive (210A, 210B, 210C, 210D),
10 a wheel sensor (206) to measure an actual angular wheel position of the wheel (204), and a plurality of foil sensors (216A, 216B, 216C, 216D) to measure an actual angular foil position of each foil (214A, 214B, 214C, 214D);
 - one or more memories (502) including computer program code (504);
 - 15 and
 - one or more processors (500) to execute the computer program code (504) to cause the apparatus (100) to perform at least the following:
 - receiving (602) a wheel operation status (520) from the wheel controller (200);
 - 20 receiving (604) a plurality of foil operation statuses (522) from a plurality of foil drives (210A, 210B, 210C, 210D);
 - receiving (606) a command (524) from the vessel control system (106);
 - generating (608) wheel control data (528) for the wheel controller (200) to control a foil pitch function (532) of the foil wheel propulsion system (104) based on the command (524) in view of the wheel operation status (520);
 - 25 and
 - generating (610) foil control data (530) for the plurality of the foil drives (210A, 210B, 210C, 210D) to further control the foil pitch function (532) of the foil wheel propulsion system (104) based on the command (524) in view of the
 - 30 wheel operation status (520) and the plurality of foil operation statuses (522), wherein a reference torque of the foil control data for each foil drive (210A, 210B, 210C, 210D) is generated (612) using a foil feedforward model.
 - 2. The apparatus of claim 1, wherein the apparatus (100) is caused to perform:
 - 35 receiving (620) the actual angular wheel position as a part of the wheel operation status (520);

receiving (622) an actual wheel speed as a part of the wheel operation status (520), or generating (630) the actual wheel speed based on a plurality of actual angular wheel positions;

receiving (624) a reference angular foil position for each foil (214A, 214B, 214C, 214D) as a part of the foil operation status (522);

receiving (626) a reference foil speed for each foil (214A, 214B, 214C, 214D) as a part of the foil operation status (522);

receiving (628) a reference foil acceleration for each foil (214A, 214B, 214C, 214D) as a part of the foil operation status (522); and

generating (612) the reference torque of the foil control data (530) for each foil drive (210A, 210B, 210C, 210D) using the feedforward model, whose inputs are the actual angular wheel position, the reference angular foil position, the actual wheel speed, the reference foil speed, and the reference foil acceleration, and the reference torque is modified by a position feedback torque describing a difference in torque between the reference angular foil position and the actual angular foil position, and by a speed feedback torque describing a difference in torque between the reference foil speed and the actual foil speed.

3. The apparatus of claim 1, wherein the apparatus (100) is caused to perform:

receiving (620) the actual angular wheel position as a part of the wheel operation status (520);

receiving (632) the actual angular foil position for each foil (214A, 214B, 214C, 214D) as a part of the foil operation status (522);

receiving (634) an actual foil speed as a part of the foil operation status (522), or generating (636) the actual foil speed based on a plurality of actual angular foil positions;

receiving (638) an actual foil torque for each foil (214A, 214B, 214C, 214D) as a part of the foil operation status (522);

receiving (640) one or more parameters from the foil pitch function (532);

generating (642, 644, 646) a reference foil speed (810), a reference angular foil position (812), and a reference foil acceleration (814) for each foil (214A, 214B, 214C, 214D) based on the actual angular wheel position and the one or more parameters;

generating (612) the reference torque (820) for each foil (214A, 214B, 214C, 214D) based on the reference foil speed (810), the reference angular foil

position (812), and the reference foil acceleration (814) for each foil (214A, 214B, 214C, 214D); and

adjusting (648) the reference torque (820) for each foil (214A, 214B, 214C, 214D) based on the the actual foil torque (822) of each foil (214A, 214B, 5 214C, 214D).

4. The apparatus of claim 3, wherein the apparatus (100) is caused to perform:

adjusting (650) the reference foil speed (810) for each foil (214A, 214B, 214C, 214D) based on the actual foil speed (816) of each foil (214A, 214B, 214C, 10 214D);

adjusting (652) the reference angular foil position (812) for each foil (214A, 214B, 214C, 214D) based on the actual angular foil position (818) of each foil (214A, 214B, 214C, 214D); and

adjusting (654) the reference foil acceleration (814) for each foil (214A, 15 214B, 214C, 214D) using an acceleration feedforward model (804).

5. The apparatus of claim 1, wherein the apparatus (100) is caused to perform:

applying (656) a second order derivative (900) on the foil pitch function (532) to generate a torque compensation command (910); and

20 multiplying (658) the torque compensation command with a torque compensation constant to generate the reference torque (910) of the foil control data (530) for each foil drive (210A, 210B, 210C, 210D).

6. The apparatus of claim 1, wherein the apparatus (100) is caused to perform:

25 receiving (660) a steering command from the vessel control system (106) instructing the foil wheel propulsion system (104) to steer the marine vessel (102); and

generating (608, 610), based on the steering command, wheel control data (528) for the wheel controller (200) and foil control data (530) for the 30 plurality of the foil drives (210A, 210B, 210C, 210D).

7. The apparatus of any preceding claim 1 to 6, wherein the wheel motor (202) is an electric motor, and the wheel controller (200) is a wheel drive configured to control electric energy sent to the electric motor (202).

8. The apparatus of any preceding claim 1 to 6, wherein the wheel motor 35 (202) is an engine (114), and the wheel controller (200) is configured to electrically control the engine.

9. A method for controlling propulsion of a marine vessel, the propulsion being at least partly implemented by a foil wheel propulsion system, which foil wheel propulsion system comprises a rotatable wheel powered by a wheel motor and controlled by a wheel drive, a plurality of rotatable foils attached perpendicularly to the wheel, each foil powered by a foil motor and controlled by a foil drive, a wheel sensor to measure an actual angular wheel position of the wheel, and a plurality of foil sensors to measure an actual angular foil position of each foil, the method comprising:
- receiving (602) a wheel operation status from the wheel drive;
 - receiving (604) a plurality of foil operation statuses from a plurality of foil drives;
 - receiving (606) a command from the vessel control system;
 - generating (608) wheel control data for the wheel drive to control a foil pitch function of the foil wheel propulsion system based on the command in view of the wheel operation status; and
 - generating (610) foil control data for the plurality of the foil drives to further control the foil pitch function of the foil wheel propulsion system based on the command in view of the wheel operation status and the plurality of foil operation statuses, wherein a reference torque of the foil control data for each foil drive is generated (612) using a foil feedforward model.
10. The method of claim 9, further comprising:
- receiving (620) the actual angular wheel position as a part of the wheel operation status;
 - receiving (622) an actual wheel speed as a part of the wheel operation status, or generating (630) the actual wheel speed based on a plurality of actual angular wheel positions;
 - receiving (624) a reference angular foil position for each foil as a part of the foil operation status;
 - receiving (626) a reference foil speed for each foil as a part of the foil operation status;
 - receiving (628) a reference foil acceleration for each foil as a part of the foil operation status; and
 - generating (612) the reference torque of the foil control data for each foil drive using the feedforward model, whose inputs are the actual angular wheel position, the reference angular foil position, the actual wheel speed, the reference foil speed, and the reference foil acceleration, and the reference torque is modified

by a position feedback torque describing a difference in torque between the reference angular foil position and the actual angular foil position, and by a speed feedback torque describing a difference in torque between the reference foil speed and the actual foil speed.

- 5 11. The method of claim 9, further comprising:
 receiving (620) the actual angular wheel position as a part of the wheel operation status;
 receiving (632) the actual angular foil position for each foil as a part of the foil operation status;
10 receiving (634) an actual foil speed as a part of the foil operation status, or generating (636) the actual foil speed based on a plurality of actual angular foil positions;
 receiving (638) an actual foil torque for each foil as a part of the foil operation status;
15 receiving (640) one or more parameters from the foil pitch function;
 generating (642, 644, 646) a reference foil speed, a reference angular foil position, and a reference foil acceleration for each foil based on the actual angular wheel position and the one or more parameters;
 generating (612) the reference torque for each foil based on the reference foil speed, the reference angular foil position, and the reference foil acceleration for each foil; and
20 adjusting (648) the reference torque for each foil based on the the actual foil torque of each foil.
12. The method of claim 11, further comprising:
25 adjusting (650) the reference foil speed for each foil based on the actual foil speed of each foil;
 adjusting (652) the reference angular foil position for each foil based on the actual angular foil position of each foil; and
 adjusting (654) the reference foil acceleration for each foil using an acceleration feedforward model.
30 13. The method of claim 9, further comprising:
 applying (656) a second order derivative on the foil pitch function to generate a torque compensation command; and
 multiplying (658) the torque compensation command with a torque compensation constant to generate the reference torque of the foil control data for
35 each foil drive.

14. The method of claim 9, further comprising:

receiving (660) a steering command from the vessel control system
instructing the foil wheel propulsion system to steer the marine vessel; and

generating (608, 610), based on the steering command, wheel control
5 data for the wheel drive and foil control data for the plurality of the foil drives.

15. A computer-readable medium comprising computer program code,
which, when executed by one or more processors, causes performance of a method
for controlling propulsion of a marine vessel, the propulsion being at least partly
implemented by a foil wheel propulsion system, which foil wheel propulsion
10 system comprises a rotatable wheel powered by a wheel motor and controlled by
a wheel drive, a plurality of rotatable foils attached perpendicularly to the wheel,
each foil powered by a foil motor and controlled by a foil drive, a wheel sensor to
measure an actual angular wheel position of the wheel, and a plurality of foil
sensors to measure an actual angular foil position of each foil, the method
15 comprising:

receiving (604) a plurality of foil operation statuses from a plurality of
foil drives;

receiving (606) a command from the vessel control system;

generating (608) wheel control data for the wheel drive to control a foil
20 pitch function of the foil wheel propulsion system based on the command in view
of the wheel operation status; and

generating (610) foil control data for the plurality of the foil drives to
further control the foil pitch function of the foil wheel propulsion system based on
the command in view of the wheel operation status and the plurality of foil
25 operation statuses, wherein a reference torque of the foil control data for each foil
drive is generated (612) using a foil feedforward model.