JP10175587A discloses a method wherein small air bubbles are fed in a boundary layer so as to reduce the generation of frictional resistance of a hull. The bubbles are blown out of a porous plate in which a number of small ports are formed at given pitches.

CN2652812Y discloses a micro bubble generator used for drag reduction comprising a cavity, a connection pipeline, a pressure air power machine and a porous silicon plate

However, even though the above prior art systems disclose the generation of bubbles by means of bubble generators which can be fitted to a ship's hull, it remains a problem to provide a method for generating micro-bubbles for efficiently reducing the drag or frictional resistance of a ship's hull during different operational conditions, e.g. different speeds, water temperature, draught, and/or the like.

Summary

According to a first aspect, there is provided an apparatus for generating bubbles of a fluid for reducing drag on a hull of a ship, wherein the bubble generating device is attachable to an outer surface of the hull, and wherein the apparatus comprises one or more micro-fluidic devices for generating said bubbles, wherein the apparatus comprises a layered structure comprising two or more layers, wherein at least one of the layers comprises a microstructure forming at least a part of the one or more micro-fluidic device, and wherein at least one of the layers comprises a supply channel that connects to the one or more microfluidic devices for feeding compressed air into the micro-fluidic devices.

According to a second aspect, there is provided a hull for a ship comprising a device comprising micro fluidic means, where the device has a plurality of openings connected to a source of fluid, said plurality of openings being arranged such that the fluid can be ejected through said openings so as to form bubbles in the boundary layer of a water towards the hull when the fluid flows along said hull, wherein a fluidic oscillator or a separate fluidic amplifier is connected between said source of air under pressure and each of said

plurality of openings, each of said fluid oscillators or fluidic amplifiers being controllable such that the bubble size of the bubbles ejected from the opening can be varied, wherein the apparatus comprises a layered structure comprising two or more layers, wherein at least one of the layers comprises a microstructure forming at least a part of the one or more micro-fluidic device, and wherein at least one of the layers comprises a supply channel that connects to the one or more microfluidic devices for feeding compressed air into the micro-fluidic devices.

According to a third aspect, there is provided the use of a device according to the first aspect comprising micro fluidic means, adapted to be attached to the exterior of a ship for generating micro-bubbles for reducing drag on a ship hole.

According to a fourth aspect, there is provided a method of reducing drag on a hull of a ship, the method comprising

- attaching an apparatus as defined in the first aspect to an outer surface of the hull;
- generating bubbles of a bubble-generating fluid at a boundary between the hull and water surrounding the hull by discharging said bubble-generating fluid through exhaust nozzles of the apparatus into the water;
- controlling a size of the generated bubbles by providing a flow of a bubble-forming fluid which flow varies over time.

Disclosed herein is an apparatus for generating bubbles for reducing drag of a hull of a ship, wherein the bubble generating device is attachable to an outer surface of the hull, and wherein the apparatus comprises a micro-fluidic device for generating bubbles of a well-defined bubble size of the generated bubbles. The bubbles are formed in a boundary layer of the water surrounding the hull, i.e. at the interface between the hull and the surrounding water.

The bubble size of the generated bubbles may be controllable by means of a micro fluidic device, e.g. by controlling a flow of the bubble-forming fluid, whereby an efficient control of the bubble size is provided, which in turn allows an efficient and controllable drag reduction even at different operational conditions.

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~~Reducing drag of a hull of a ship~~

Claims:

1. An apparatus for generating bubbles of a fluid for reducing drag on a hull of a ship, wherein the bubble generating device is attachable to an outer surface of the hull, and wherein the apparatus comprises one or more micro-fluidic device for generating said bubbles, wherein the apparatus comprises a layered structure comprising two or more layers, wherein at least one of the layers comprises a microstructure forming at least a part of the one or more micro-fluidic device, and wherein at least one of the layers comprises a supply channel that connects to the one or more microfluidic devices for feeding compressed air into the micro-fluidic devices.

2. An apparatus according to claim 1, wherein the micro-fluidic device is adapted to control a bubble size of the generated bubbles.

3. An apparatus according to claim 1 or 2; wherein the at least one micro-fluidic device comprises:

- an inlet port for supplying a flow of the fluid;
-a first channel comprising a first nozzle for generating bubbles of the fluid for reducing drag on a hull of a ship, said first channel being in fluidic communication with said inlet port through a central chamber ; and
-a first control channel comprising a first control inlet configured to control the flow through said first nozzle, said first control inlet being in fluidic communication with said inlet port and said first channel through said central chamber.

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4. An apparatus according to claim 1 through 3, wherein the at least one micro-fluidic device further comprises

- a second channel comprising a second nozzle for generating bubbles of the fluid for reducing drag on a hull of a ship, said second channel being in fluidic communication with said inlet port and said first control inlet through said central chamber, and wherein said first control inlet is further configured to control the flow through said second nozzle.

5. An apparatus according to any one of claims 3 through 4, wherein the at least one micro-fluidic device is configured to increase the total flow resistance from said inlet port to said first nozzle by providing a first control flow through said first control inlet into said central chamber.

6. An apparatus according to claim 4 or 5, wherein the at least one micro-fluidic device is configured to shift a flow running through said first channel to said second channel by providing a first control flow running through said first control inlet into said central chamber, whereby at least 50% of the flow that would have ran through said first channel is redirected to run through said second channel.

7. An apparatus according to any one of claims 4 through 6, wherein said at least one micro-fluidic device further comprises

--a second control channel comprising a second control inlet for controlling the flow through said first nozzle and said second nozzle, said second control inlet being in fluidic communication with said inlet port, said first nozzle, said second nozzle, and said first control inlet through said central chamber.

8. An apparatus according to any one of claims 4 through 7, wherein the at least one micro-fluidic device is configured to shift a flow running through

said second channel to said first channel by providing a second control flow running through said second control inlet into said central chamber, whereby at least 50% of the flow that would have ran through said second channel is redirected to run through said first channel.

9. An apparatus according to any one of claims 7 through 8, wherein said at least one micro-fluidic device further comprises a feed-back channel connecting said first control channel and said second control channel, whereby said first control outlet and said second control outlet is in direct fluid communication.

10. An apparatus according to any one of claims 3 through 9, wherein the first control channel and/or the second control channel is in fluid communication with a control system configured to generate control flows through the first control channel and/or the second control channel.

11. An apparatus according to any one of claims 1 through 10, wherein the device comprises a plurality of micro-fluidic devices as specified in any one of claims 1 through 10.

12. An apparatus according to any one of claims 1 through 11, adapted to generate bubbles of a controllable bubble size by providing a flow of a bubble-forming fluid which flow varies over time.

13. An apparatus according to any one of claims 1 through 12, wherein the micro-fluidic device comprises a micro-fluidic oscillator and/or a micro-fluidic oscillator flip-flop and/or a micro-fluidic amplifier and/or a micro-fluidic switch.

14. An apparatus according to any one of claims 1 through 13, wherein the apparatus is a retro-fittable device attachable to an existing ship.

15. An apparatus according to any one of claims 1 through 14, comprising a plurality of exhaust nozzles for outputting a fluid in the form of bubbles.

16. An apparatus according to any one of the preceding claims, comprising a plurality of sets of micro-fluidic devices, wherein the micro-fluidic devices of each set are adapted to generate bubbles having a respective bubble size, and wherein the apparatus comprises a flow selector for selectively directing a supply flow of the bubble-forming fluid to one or a subset of the sets micro-fluidic devices different from the frequency.

17. An apparatus according to claim 16, wherein the micro-fluidic devices of each set are adapted to generate bubbles at a respective predetermined frequency.

18. An apparatus according to any one of the preceding claims, wherein the fluid is a gas such as air.

19. An apparatus according to claim 1, wherein the at least one of the layers comprises a micro-structured surface forming at least a part of the one or more micro-fluidic device.

20. An apparatus according to any one of the preceding claims, wherein the apparatus comprises a bonding surface for bonding the apparatus to the hull of a ship and a convex outer surface opposite the bonding surface.

21. An apparatus according to any one of the preceding claims, comprising a plurality of exhaust nozzles for outputting the fluid; wherein a surface area surrounding each exhaust nozzle is provided with a hydrophilic surface.

22. An apparatus according to any one of the preceding claims, wherein each of the one or more micro-fluidic devices is formed as a planar system of channels and/or chambers.

23. A hull for a ship comprising a device comprising micro fluidic means, where the device has a plurality of openings connected to a source of fluid, said plurality of openings being arranged such that the fluid can be ejected through said openings so as to form bubbles in the boundary layer of a water towards the hull when the fluid flows along said hull, wherein a fluidic oscillator or a separate fluidic amplifier is connected between said source of air under pressure and each of said plurality of openings, each of said fluid oscillators or fluidic amplifiers being controllable such that the bubble size of the bubbles ejected from the opening can be varied, wherein the apparatus comprises a layered structure comprising two or more layers, wherein at least one of the layers comprises a microstructure forming at least a part of the one or more micro-fluidic device, and wherein at least one of the layers comprises a supply channel that connects to the one or more microfluidic devices for feeding compressed air into the micro-fluidic devices..

24. Use of a device according to any of claims 1 to 22 comprising micro fluidic means, adapted to be attached to the exterior of a ship for generating micro-bubbles for reducing drag on a ship hole.

25. A method of reducing drag on a hull of a ship, the method comprising

- attaching an apparatus as defined in any one of claims 1 through 22 to an outer surface of the hull;
- generating bubbles of a bubble-generating fluid at a boundary between the hull and water surrounding the hull by discharging said bubble-generating fluid through exhaust nozzles of the apparatus into the water.
- controlling a size of the generated bubbles by providing a flow of a bubble-forming fluid which flow varies over time.