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A PROPULSION SYSTEMTechnical Field

This disclosure is directed towards a propulsion system
5 suitable for work machines. In one embodiment the propulsion
system comprises a power unit which provides power to a
transmission via a mechanical and/or alternate route and the
transmission provides a power output. In another embodiment
the propulsion system comprises a power unit which drives a
10 planetary gearbox. The propulsion system is particularly
applicable to marine vessels.

Background

Propulsion systems for work machines typically comprise
15 one or more power units, such as gas turbines and engines.
Such work machines include vehicles, such as marine vessels,
aircraft or land vehicles. The power output from the power
units may, for example, provide the required loads to house
loads, operator quarters or work tools. Exemplary work tools
20 include cranes, drills, bow or stern thrusters, grapples,
buckets and backhoes. If the work machine is a vehicle, the
power may provide a thrust to move the vehicle.

The range of potential power output from the power unit
25 may be selected in order to meet the expected loads required
in the operating profiles of the work machine. There are
also environmental and cost reduction benefits in operating
such power units efficiently. In particular, the power unit
may be selected to operate at maximum efficiency at the
30 vehicle cruising speed, which is the speed at which the
vehicle moves for the majority of the time it is
operational.

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By way of example, marine tankers have an operating profile in which the majority of time is spent at cruising speed. Such tankers may not include a transmission, or may
5 have a relatively simple transmission, provided by a shaft transferring power between the power unit and propeller. It may therefore be fairly simple to select an appropriately sized power unit to operate efficiently at cruising speed. However, it may not be possible to operate the power unit at
10 maximum efficiency if the vessel's operating profile is relatively varied.

As another example, the operating profile of a tugboat includes substantial time spent manoeuvring, which requires
15 low power; substantial time spent travelling at medium speed, which requires medium power; and substantial time spent pushing or towing other ships, which requires high power. It has been found that tugboats can spend the majority of their operating time at below 20% of the rated
20 load of the power unit providing thrust.

Marine vessels typically comprise either a mechanical or an electrical propulsion system. An electrical propulsion system may comprise a one or more power unit(s) driving an
25 electric generator, which feeds power to at least one electric motor to drive one or more propeller(s). Figure 1 illustrates a prior art ship 10, in this case an anchor handling tug supply vessel, comprising a mechanical propulsion system 11. The mechanical propulsion system
30 typically comprises a power unit 12, such as a diesel engine, rotating a drive shaft 13. The drive shaft 13 supplies power to a gearbox 14, the output of which is

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connected to a propeller shaft 15. A propeller 16, which in this example is a fixed propeller, is connected to the propeller shaft 15 to provide a thrust to the ship 10. The power unit 12 may also supply power to an electric
5 generator, which may be used to provide power to the operator quarters 17, bow thrusters 18, stern thrusters 19 and crane 20.

As illustrated in Figure 2, the gearbox 14 is typically
10 relatively simple and may comprise an input gear 21 attached to the drive shaft 13 and an output gear 22 attached to the propeller shaft 15. The input and output gears 21, 22 may interlock in a countershaft arrangement. The output gear diameter 23 may depend upon the gear ratio required of the
15 gearbox 14. Therefore, if a large reduction in rotational speed between the drive shaft 13 and propeller shaft 15 is required, the output gear diameter 23 may be relatively large. As the output gear 22 is typically located in a keel 24 of the ship 10, the keel 24 may have to be relatively
20 wide to accommodate the output gear 22. A relatively wide keel 24, however, may have a negative impact upon the operational efficiency of the ship 10 due to, for example, increased drag. If the gearbox 14 has a high reduction gear ratio, the width of the keel 24 will depend upon the largest
25 output gear diameter 23.

Marine vessels may also comprise variable pitch
propellers, rather than fixed pitch propellers, to improve operational efficiency. The power unit may be run at a more
30 efficient power output whilst the propeller pitch is varied in order to change the ship speed. However, such variable pitch propellers may have drawbacks, for example high cost

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and complexity, in comparison with fixed pitch propellers. Furthermore, when a hydraulic actuation mechanism is utilised to vary the propeller pitch, oil from the actuation mechanism may cause water pollution. For example, the

5 variable pitch propeller may require a larger hub to house the actuation mechanism which results in an increase in drag in comparison to fixed pitch propellers. In addition, the efficiency of the variable pitch propeller may only be at an optimum at a certain pitch angle and may reduce

10 significantly as the pitch angle is varied. Also, it is not possible to effectively fit a shroud or duct around a variable pitch propeller due to the variation in propeller diameter as the pitch is varied. Shrouded or ducted fixed pitch propellers may have significant efficiency advantages

15 in some applications. Shrouds may be used to improve propeller output efficiency by reducing radial losses and improving axial thrust. However, it may be difficult to provide the same flexibility as provided by a variable pitch propeller, whilst including a shroud.

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A hybrid propulsion system may be utilised to improve flexibility, redundancy and efficiency. US-A-2010/0144219 discloses a marine vessel hybrid propulsion system comprising multiple internal combustion engines, multiple

25 electrical generators, multiple electrical motors and multiple propellers. The engines may provide power to the generators and/or to the propellers. The generators may provide energy to be stored in a battery or directed to the motors. The motors may provide energy to the propellers.

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However, US-A-2010/0144219 does not disclose how the outputs of the motors and engines can be combined to provide

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output to a single propeller. Furthermore it does not disclose how the speed of the propeller is controlled. This prior art system also does not provide means for the engines to supply power to the generators whilst both the engines and motors supply power to the propellers. Therefore, the battery may run out of energy to drive the motors. The system also does not provide flexibility in the propeller speed when the engine is run at full operational speed. Furthermore, no means are provided for increasing the propeller speed beyond the speed at which the motor and engines are providing maximum power to the propellers.

Summary

The present disclosure provides a propulsion system for providing a power output; said propulsion system comprising; a transmission configured to provide the power output; at least one first energy conversion machine; at least one power unit operable to selectively drive the transmission and/or the at least one first energy conversion machine; at least one second energy conversion machine operable to selectively drive or be driven by the transmission; and a power transfer arrangement for transferring power between the first and second energy conversion machines.

The present disclosure further provides a method of operating a propulsion system, said propulsion system comprising; a transmission configured to provide the power output; at least one first energy conversion machine; at least one power unit operable to selectively drive the transmission and/or the at least one first energy conversion machine; at least one second energy conversion machine operable to selectively drive or be driven by the

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transmission; and a power transfer arrangement for transferring power between the first and second energy conversion machines; said method comprising; connecting the power unit to drive the transmission; or connecting the power unit to drive the at least one first energy conversion machine; or connecting the power unit to drive the transmission and the at least one first energy conversion machine.

10 The present disclosure further provides a marine vessel comprising a propulsion system for providing propulsion to the ship, said propulsion system comprising; a power unit providing a rotational output to a power unit output shaft; a first kinematic connection element attached to the power unit output shaft; and at least one planetary gearbox providing a rotational output to a transmission output shaft, said transmission output shaft being connected to a propulsion element; wherein the first kinematic connection element is operably connected to the at least one planetary gearbox.

25 The present disclosure further provides a propulsion system comprising; first and second power units; a transmission configured to transmit power to a transmission shaft; at least one first energy conversion machine; and a power unit transmission; wherein said power unit transmission comprises; a plurality of transmission shafts operably connecting the power unit transmission to the first and second power units, the transmission and the at least one first energy conversion machine; a first torque coupling for selectively operably connecting the second power unit to the power unit transmission; and a second torque coupling

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for selectively operably connecting the transmission to the power unit transmission.

By way of example only, embodiments of a propulsion
5 system are now described with reference to, and as shown in, the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a side elevation of a ship of the prior
10 art;

Figure 2 is a front view of an exemplary transmission arrangement used in the ship of Figure 1;

Figure 3 is a schematic of a propulsion system of the present disclosure;

15 Figure 4 is a schematic of a transmission of the present disclosure;

Figure 5 is a schematic of a transmission of the present disclosure comprising a plurality of planetary gearboxes;

20 Figure 6 is a schematic of a further propulsion system of the present disclosure;

Figure 7 is a schematic of a further propulsion system of the present disclosure;

Figure 8 is a schematic of the propulsion system of
25 Figure 3 with a mechanical operating mode shown;

Figure 9 is a schematic of the propulsion system of Figure 3 with an alternate operating mode shown;

Figure 10 is a schematic of the propulsion system of Figure 3 with a combined operating mode shown;

30 Figure 11 is a schematic of the propulsion system of Figure 3 with a reverse operating mode shown; and

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Figures 12 to 16 are nomographs illustrating the operation of the propulsion system of Figure 3 through a sequential increase in system output speed.

5 Detailed Description

The present disclosure is generally directed towards a propulsion system comprising at least one power unit operably connected to a transmission via a mechanical route and/or via an alternate route, such as hydraulic or
10 electrical route. The present disclosure is also directed towards a propulsion system wherein a power unit drives or provides power to a planetary gearbox. The present disclosure is also directed towards a propulsion system comprising two power units and a power unit transmission
15 suitable to distribute the power output of two power units via a mechanical route and/or via an alternate route. The propulsion systems are particularly applicable to marine vessels.

20 In the description below, the term "operably connected" means that one component drives another component, for example by using coupling means. The coupling means may comprise engaged gears, connected shafts, torque converters, clutches, transmissions and any other suitable means for
25 transferring power.

The following exemplary embodiments specifically refer to the use of the propulsion system in marine vessels such as ships. However, the propulsion system may be used in any
30 other form of work machine, such as land vehicles.

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Figure 3 illustrates an exemplary propulsion system 25 comprising a power unit 26, a first energy conversion machine 27, a second energy conversion machine 28 and a transmission 29. The power unit 26 may be of any suitable type, for example an internal combustion engine or a gas turbine. The power unit 26 may be capable of providing a variable power output at a range of speeds. For example, the power unit 26 may be a diesel engine. A plurality of power units 26 may be provided and operably connected in parallel as described below.

The power unit 26 is operably connected to the first energy conversion machine 27 and to the transmission 29. The operable connection enables power to be transferred in any direction between the power unit 26, the first energy conversion machine 27 and the transmission 29. The operable connection may be a mechanical connection as shown. The power unit 26 may comprise a rotatable power unit output shaft 30.

The power unit output shaft 30 may be operably connected to the first energy conversion machine 27 and transmission 29 via interlocking gears. A first gear 31 may be mounted on the power unit output shaft 30. The first gear 31 may interlock (mesh) with a second gear 32 mounted on a shaft (not shown) providing an input to, or output from, the transmission 29. A third gear 33 may be mounted on the power unit output shaft 30. The third gear 33 may interlock with a fourth gear 34 mounted on a first machine shaft 35 providing an input to or output from the first energy conversion machine 27. Alternatively, the second and fourth

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gears 32, 34 may interlock with a single gear mounted on the power unit output shaft 30.

Alternatively, any suitable kinematic connection
5 elements may be provided instead of the first, second, third and fourth gears 31, 32, 33 and 34 to operably connect the power unit output shaft 30 to the transmission 29 and/or the first energy conversion machine 27. For example, the kinematic connection elements may comprise belts, chains
10 and/or gears.

Alternatively, the power unit 26 may comprise one or more power outputs. The power unit 26 may be operably connected to the first energy conversion machine 27 via a
15 first output shaft and to the transmission 29 via a second output shaft. The first output may comprise a main drive output shaft. The second output may comprise an auxiliary power take-off shaft.

20 A transmission coupling 36 may also be provided to enable the power unit 26 to be selectively operably connected to the first energy conversion machine 27 and/or to the transmission 29. As shown in Figure 1, the transmission coupling 36 may comprise a clutch located in the power unit
25 output shaft 30 between the first and third gears 31, 33. Further couplings may also be provided in the power unit output shaft 30, for example between the power unit 26 and the third gear 33. The coupling(s) may be mechanical or fluid couplings and may comprise any apparatus suitable for
30 selectively transferring torque.

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The first and second energy conversion machines 27, 28 may comprise any suitable means for reversibly converting or transferring energy. In particular, the first and second energy conversion machines 27, 28 may be suitable for
5 converting one form of energy, particularly mechanical, into another, particularly electric or fluid, and vice-versa. For example, the first and second energy conversion machines 27, 28 may be reversible hydraulic machines (i.e. pump/motors) or reversible electric machines (i.e. motor/generators).
10 Alternatively, the first and second energy conversion machines 27, 28 may comprise reversible mechanical machines which enable the transfer of mechanical energy. A plurality of each of the first and second energy conversion machines may be provided and may be connected in parallel as
15 described below.

The first and second energy conversion machines 27, 28 are operably connected to one another to enable power to be supplied to, or received from one another. The operable
20 connection may be provided by a power transfer arrangement 37. The power transfer arrangement 37 may also enable the power transferred between the first and second energy conversion machines 27, 28 to be controlled. For example, the power transfer may be controlled such that the input
25 speed to the first energy conversion machine 27 may be different to the output speed of the second energy conversion machine 28.

The first and second energy conversion machines 27, 28
30 and the power transfer arrangement 37 may together form a variator. In particular, the variator may enable the stepless variation of the ratio between input and output.

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The variator may be bi-directional, such that the power input may be to the first energy conversion machine 27 and the power output may be from the second energy conversion machine 28 or vice-versa.

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The first and second energy conversion machines 27, 28 may be reversible hydraulic machines, such as variable displacement hydraulic motors and the like. Reversible hydraulic machines convert mechanical energy from a rotating shaft into fluid energy and vice-versa. Alternatively, the first and second energy conversion machines 27, 28 may each comprise a hydraulic pump and a hydraulic motor arranged in parallel such that each can act independently. The power transfer arrangement 37 may comprise a hydraulic system for transferring hydraulic fluid, and thereby energy or power, between the first and second reversible hydraulic machines. The hydraulic system may comprise any suitable arrangement known in the art, for example comprising hoses, pumps, motors, valves, reservoirs, filters, accumulators, seals, connections, charge pumps, charge circuits and/or the like. Exemplary arrangements of the hydraulic system are disclosed below.

Alternatively, the first and second energy conversion machines 27, 28 may be reversible electric machines, such as a reversible electric motor or generator and the like. Reversible electric machines convert mechanical energy from a rotating shaft into electric energy and vice-versa. The reversible electric machines may be DC or AC and may be of any suitable type, for example asynchronous, synchronous, switch reluctance and variable frequency induction motors.

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The power transfer arrangement 37 may comprise an electrical system for transferring electric current, and thereby energy or power, between the first and second reversible electric machines. The electrical system may be
5 of any suitable arrangement known in the art, for example comprising inverters, rectifiers, cables, isolators, batteries, power control electronics and the like. The power transfer arrangement may provide power to a house load, operator quarters, a work tool and/or the like. Exemplary
10 arrangements of the electrical system are disclosed below.

The transmission 29 receives power from the power unit 26 and/or the second energy conversion machine 28 and may supply power to a transmission output 38. As shown, the
15 transmission output 38 may comprise or be operably connected to a transmission output shaft 39 to which a propulsion element 40 may be attached. The propulsion element 40 may comprise one or more propellers, thrusters, wheels and other forms of moving a vehicle. Therefore, the transmission 29
20 may have at least three input and/or output shafts. Any route of power transfer may be provided by the transmission 29, for example power from the power unit 26 may be directed to the second energy conversion machine 28 and to the transmission output 38.

25

The transmission 29 may be of any suitable type known in the art, for example planetary, automatic, continuously variable and the like. As shown in Figures 3 and 4, the transmission 29 may be a planetary system comprising a
30 plurality of rotatable gears that transfer power in the same plane. As described below, the transmission may comprise multiple planetary gearboxes arranged in series.

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In particular, the transmission 29 may comprise a sun gear 41 encircled by a ring gear 42. The ring gear 42 may comprise inward facing teeth around the inner edge of an annular disc. A plurality of planetary gears 43 may be located between and interlock with the sun gear 41 and ring gear 42. The plurality of planetary gears 43 may be attached about their axles to a carrier 44. A transmission lock 45, for example in the form of a clutch, may be provided to prevent the carrier 44 from rotating. Alternatively, any two of the sun gear, 41, plurality of planetary gears 43, carrier 44 and ring gear 42 may be locked together by the transmission lock 45.

The second energy conversion machine 28 may be operably connected to the sun gear 41, for example via a second machine shaft 46. A second machine coupling (not shown), for example a clutch or torque converter, may be provided in the second machine shaft 46 between the sun gear 41 and second energy conversion machine 28. The second machine coupling may enable the operable connection between the sun gear 41 and second energy conversion machine 28 to be disengaged. Alternatively, the operable connection may be disengaged by switching the second energy conversion machine 28 such that no power is transmitted from the power transfer arrangement to the sun gear 41 and vice versa. For example, if the second energy conversion machine 28 is a variable displacement hydraulic motor a swash plate contained therein may be rotated such that power is not transferred.

30

The carrier 44 may be operably connected to the power unit 26 via the power unit output shaft 30, the transmission

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coupling 36, the first gear 31 and the second gear 32. The carrier 44 may be in a countershaft arrangement with the second gear 32. The transmission 29 may have a gearbox width 47, which may be the width of the planetary gearbox.

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The ring gear 42 may provide the transmission output 38 that is operably connected to the transmission output shaft 39. In particular, an outer gear may be provided on the outer edge of the ring gear 42 and the outer gear may
10 interlock with a further gear attached to the transmission output shaft 39.

The transmission 29 may comprise a plurality of planetary gearboxes arranged in series. As illustrated in
15 Figure 5, first, second and third planetary gearboxes 48, 49, 50 may be arranged in series. The second planetary gearbox 49 is arranged in a similar manner to the planetary system described previously herein. The first and third
20 planetary gearboxes 48, 50 are arranged on either side of the second planetary gearbox 49 to provide a reduction or increase in gear ratio from the second machine shaft 46 to the transmission output shaft 39.

Each of the first, second and third planetary gearboxes
25 48, 49, 50 may comprise a sun gear 51, 52, 53, a carrier (not shown), a plurality of planetary gears 54, 55, 56 and a ring gear 57, 58, 59. The ring gears 57, 59 of the first and third planetary gearboxes 48, 50 may be fixed such that they are unable to rotate. The ring gear 58 of the second
30 planetary gearbox 49 may be rotatable.

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A second machine coupling 60 may be provided in the second machine shaft 46, which is operably connected to the sun gear 51 of the first planetary gearbox 48. The carrier of the first planetary gearbox 48 may be operably connected
5 to the sun gear 52 of the second planetary gearbox 49, for example via a shaft 61. The carrier of the second planetary gearbox 49 may be operably connected to the power unit 26 via the first and second gears 19, 20 and the power unit output shaft 30. A transmission lock 62 may be provided to
10 selectively prevent the carrier of the second planetary gearbox 49 from rotating. The ring gear 58 of the second planetary gearbox 49 may be operably connected to the sun gear 53 of the third planetary gearbox 50, for example via a shaft 63. The carrier of the third planetary gearbox 50 may
15 be operably connected to the transmission output shaft 39.

A plurality of power units 26 may be provided and operably connected in parallel. Figure 6 illustrates a propulsion system 64 of the present disclosure comprising
20 first and second power units 65, 66, first and second reversible hydraulic machines 67, 68 and an electrical generator 69 providing power to an electrical system 70. The electrical system 70 may provide power to work tools, thrusters, a hotel load and the like. The transmission 29 is
25 the same as shown in Figure 5 and the equivalent reference numerals are shown in Figure 6.

In Figure 6 the power transfer arrangement 37 comprises hydraulic lines 71, 72 that transfer fluid, and therefore
30 energy, from the first reversible hydraulic machine 67 to the second reversible hydraulic machine 68 and vice-versa.

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The power transfer arrangement 37 may comprise other hydraulic components, such as reservoirs and charge pumps.

The power units 65, 66 may be operable to provide power
5 to the transmission 29, first reversible hydraulic machine
67 and electrical generator 69 via a power unit transmission
73. The power unit transmission 73 may comprise first,
second, third, fourth and fifth transmission shafts 74, 75,
76, 77, 78, first and second torque couplings 79, 80 and
10 first, second, third, fourth and fifth transmission gears
81, 82, 83, 84, 85.

The first transmission shaft 74 may be operably
connected to the first power unit 65 and to the first torque
15 coupling 79. The first torque coupling 79 may be operably
connected to the fourth transmission shaft 77, upon which
may be mounted the first and fourth transmission gears 81,
84. The fourth transmission shaft 77 may be operably
connected to the first reversible hydraulic machine 67. The
20 first transmission gear 81 may interlock with the second
transmission gear 82, which may be mounted on the second
transmission shaft 75. The second transmission shaft 75 may
be operably connected to the electrical generator 69. The
second transmission gear 82 may also interlock with the
25 third transmission gear 83, which may be mounted upon the
third transmission shaft 76. The third transmission shaft 76
may be operably connected to the second power unit 66 and to
the second torque coupling 80. The second torque coupling 80
may be operably connected to the fifth transmission shaft
30 78, upon which the first gear 31 may be mounted. The fifth
transmission gear 85 may either be mounted on the third
transmission shaft 76 or the third transmission shaft 76

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side of the second torque coupling 80 and may interlock with the fourth transmission gear 84.

The first torque coupling 79 may selectively engage the first transmission shaft 74 with the fourth transmission shaft 77. The second torque coupling 80 may selectively engage the third transmission shaft 76 with the fifth transmission shaft 78. The first and second torque couplings 79, 80 may be any suitable apparatus for selectively transmitting torque, for example a clutch or torque converter. The first torque coupling 79 may enable the power unit 65 to be selectively engaged with the power unit transmission 73. The second torque coupling 80 may enable the fifth transmission shaft 78 to be selectively engaged with the rest of the power unit transmission 73. The second torque coupling 80 may operate along similar lines to the transmission coupling 36 described previously herein.

Figure 7 illustrates a propulsion system 86 of the present disclosure that is substantially similar to the propulsion system 64 of Figure 6. In the propulsion system 86 the second transmission shaft 75 may be operably connected to the first energy conversion machine 27, which may comprise first and second reversible electrical machines 87, 88 connected to one another in series. The second machine shaft 46 may be operably connected to the second energy conversion machine 28, which may comprise third and fourth reversible electrical machines 89, 90. In particular, the fourth reversible electrical machine 90 may be directly connected to the second machine shaft 46. The third reversible electrical machine 89 may provide an output to a gear 91 which interlocks with another gear 92 mounted on the

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second machine shaft 46. The first, second, third and fourth reversible electrical machines 87, 88, 89, 90 may be selectively operably connected to the second machine shaft 46 or second transmission shaft 75.

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The power transfer arrangement 37 may comprise a first conductor 93 for transferring variable frequency AC current between a first inverter/rectifier 94 and the first and second reversible electrical machines 87, 88. A second
10 conductor 95 may be provided for transferring variable frequency AC current between a second inverter/rectifier 96 and the third and fourth reversible electrical machines 89, 90. The first and second inverter/rectifiers 94, 96 may exchange power with a main DC bus 97. The main DC bus 97 may
15 also supply power to an inverter/isolator 98 for providing a fixed frequency AC current to an electrical propulsion system 99. The electrical propulsion system 99 may comprise a hotel load, thrusters, batteries, a work tool and/or the like. A second propulsion system 86 may also feed into/out
20 of the main DC bus 97.

The propulsion system 25, 64, 86 may comprise any number of power units 26, 65, 66, each of which may be selectively operably connected to the transmission 29 and/or
25 the first energy conversion machine 27.

Industrial Applicability

The propulsion system 25 may have at least four modes of operation. The modes are described hereinbelow with
30 reference to the propulsion system 25 of Figure 3, but may also be engaged in the propulsion systems 64, 86 of Figures 6 and 7.

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MECHANICAL MODE

As shown in Figure 8, in a mechanical mode 100 a mechanical route is utilised for transferring power from the power unit 26 to the transmission output shaft 39. The transmission coupling 36 may be engaged such that power is transferred from the power unit 26 to the transmission 29 via the power unit output shaft 30. The transmission 29 receives no power from the second energy conversion machine 28. However, in the mechanical mode 100 power may be transferred from the power unit 26 to the first energy conversion machine 27 to provide power to the power transfer arrangement 37. This power may be transferred to a house load, operator quarter, work tool and/or the like.

In particular, the rotating power unit output shaft 30 may rotate the first gear 31 and thereby rotate the second gear 32. The rotating second gear 32 may rotate the carrier 44. The transmission lock 45 may be disengaged to enable the carrier 44 to rotate. As the carrier 44 rotates, the plurality of planetary gears 43 may also rotate and thereby rotate the ring gear 42. The rotating ring gear 42 thereby transfers power to the transmission output shaft 39. The sun gear 41 may also rotate, but power may not be transferred to the second energy conversion machine 28. This may, for example, be due to the disengagement of a second machine coupling in the second machine shaft 46.

ALTERNATE POWER MODE

As shown in Figure 9, in an alternate power mode 101 an alternate route is utilised for transferring power from the power unit 26 to the transmission output shaft 39. The

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transmission coupling 36 remains disengaged such that the transmission 29 receives no power mechanically from the power unit 26. The power unit 26 may supply power to the first energy conversion machine 27, which operates as a power generator (i.e. a hydraulic pump or electric generator). The power transfer arrangement 37 may transfer the power to the second energy conversion machine 28, which operates as a motor (i.e. a hydraulic or electric motor), and to the transmission 29. The transmission 29 may then transfer the power to the transmission output 38 and onto the propulsion element 40. In particular, the transmission lock 45 may be engaged to prevent the carrier 44 from rotating. Therefore, power may be transferred from the rotating second machine shaft 46 and sun gear 41 to the ring gear 42 by rotating the planetary gears 43. The ring gear 42 may also rotate, thereby transferring power to the transmission output shaft 39.

COMBINED POWER MODE

As shown in Figure 10, in a combined power mode 102 the power may be supplied to the transmission output shaft 39 from the power unit 26 via a combination of the mechanical route and alternate route disclosed above. The transmission coupling 36 may be engaged and the transmission lock 45 disengaged. In particular, power may be transferred sequentially via the third gear 33, the fourth gear 34, the first machine shaft 35, the first energy conversion machine 27, the power transfer arrangement 37, the second energy conversion machine 28, the second machine shaft 46, the sun gear 41 and the plurality of planetary gears 43 to the ring gear 42. Power may also be transferred sequentially via the power unit output shaft 30, the engaged transmission

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coupling 36, the first gear 31, the second gear 32, the carrier 44 and the plurality of planetary gears 43 to the ring gear 42. The ring gear 42 may transfer the combined power from both routes to the transmission output shaft 39.

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REVERSE POWER MODE

As shown in Figure 11, in a reverse power mode 103 power may be transferred to the transmission output shaft 39 via the mechanical route previously disclosed herein. As the plurality of planetary gears 43 rotate they may also rotate the sun gear 41 and second machine shaft 46. The second energy conversion machine 28 may operate as a power generator, thereby providing power to the power transfer arrangement 37. The power transfer arrangement 37 may provide power to the first energy conversion machine 27, thereby rotating the first machine shaft 35. The first energy conversion machine 27 may therefore provide supplementary power to the power unit output shaft 30. The power output of the power unit 26 may be reduced by the same value as the supplementary power provided by the first energy conversion machine 27. Thereby the power unit output shaft 30 may maintain the same rotational power with reduced power unit 26 output. Alternatively, the power transfer arrangement 37 may direct power to components of the power transfer arrangement 37. For example, where the power transfer arrangement 37 is an electrical system, electrical power may be provided to a battery and the like.

IMPLEMENTATION OF DIFFERENT MODES

Figures 12 to 16 are nomographs illustrating the operation of the propulsion system 25 as a system output speed 104 is increased. The system output speed axis 105 may

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represent the rotational speed of the transmission output shaft 39 and is shown as a percentage of rotational output speed of the power unit output shaft 30. A second energy conversion machine speed axis 106 may represent the rotational speed of input/output of the second energy conversion machine 28, wherein 100% is full speed in one rotational direction and -100% is full speed in the opposite rotational direction.

A second energy conversion machine speed 107 may represent the actual rotational speed of the second energy conversion machine 28, the second machine shaft 46 and the sun gear 41 (assuming a 1:1 speed ratio between each). A power unit output speed 108 may represent the rotational speed of the carrier 44, the power unit output shaft 30 and the power unit 26 (assuming a 1:1 speed ratio between the first and second gears 19, 20). A system output speed 104 may represent the rotational speed of the ring gear 42 and the transmission output shaft 39 (assuming a 1:1 speed ratio between the two). The horizontal distance between the lines showing the second energy conversion machine speed 107, power unit output speed 108 and system output speed 104 may represent the gear ratio between the sun gear 41, the carrier 44 and the ring gear 42.

Figure 12 shows the propulsion system 25 when the second energy conversion machine speed 107, power unit output speed 108 and system output speed 104 are zero, for example when the propulsion system 25 is not operational.

The system output speed 104 may be increased from zero by the engagement of the alternate power mode 101. The

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alternate power mode 101 may be engaged by engaging the transmission lock 45 and disengaging the transmission coupling 36. In the alternate power mode 101, system output speed 104 may be increased by increasing power unit output speed 108 (i.e. by increasing the power output of the power unit 26) until a maximum power unit output speed 109 is reached. The first energy conversion machine 27 may transfer the power to the second energy conversion machine 28 via the power transfer arrangement 37. The second energy conversion machine 28 may drive the transmission 29, which drives the transmission output shaft 39 and thereby provides a system output speed 104.

Figure 13 illustrates the propulsion system 25 operating at maximum power unit output speed 109, which may be when the power output of the power unit 26 is at a maximum. The second machine speed 107 may also be at a maximum at this point.

Figure 14 illustrates a further increase in system output speed 104, which may be implemented by engaging the reverse power mode 103 whilst maintaining the maximum power unit output speed 109. The reverse power mode 103 may be engaged by unlocking the transmission lock 45 and engaging the transmission coupling 36. Power may be transferred from the second energy conversion machine 28 to the first energy conversion machine 27. Maximum power unit output speed 109 may be maintained by providing power from the first energy conversion machine 27 to the power unit output shaft 30 whilst reducing the power output of the power unit 26.

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To further increase system output speed 104, the second machine speed 107 may be reduced. Increased power may therefore be transferred to the ring gear 42 and thus the system output speed 104 increases.

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Figure 15 illustrates the point at which second machine speed 107 reaches zero. The propulsion system 25 may be maintained in the mechanical mode 100 only. The power unit 26 may be designed to operate at peak efficiency at this point and the system output speed 104 at this point may be a cruising speed 110.

To further increase system output speed 104 above cruising speed 110 the combined power mode 102 may be engaged. As shown in Figure 16, the system output speed 104 may be increased by increasing second machine speed 107 in the reverse direction.

Whilst the hereinbefore described method of operation for increasing system output speed 104 may be preferable, any other suitable combination of the hereinbefore described modes may be engaged. To reduce system output speed 104 the opposite of the method of operation disclosed above may be followed. Alternatively, any other suitable combination of the hereinbefore described modes may be engaged to reduce system output speed 104.

With reference to the propulsion systems comprising multiple power units 26, 65, 66, each power unit 26, 65, 66 may be sequentially engaged to increase the system output speed 104.

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With reference to the propulsion system 64 shown in Figure 6, power can be transmitted from the first and second power units 65, 66 in different ways in each of the different modes 100, 101, 102, 103 described previously
5 herein. The first torque coupling 79 may be disengaged and the second torque coupling 80 engaged such that power is transmitted from the second power unit 66 only to the first reversible hydraulic machine 67 and the transmission 29. The first and second torque couplings 79, 80 may be engaged such
10 that power is transmitted from the first and second power units 65, 66 to the first reversible hydraulic machine 67 and the transmission 29. Power may be continuously provided from the first and/or second power units 65, 66 to the electrical generator 69 to supply power to the electrical
15 system 70.

The use of multiple power units 65, 66 enables lower rated power units 65, 66 to be used. Furthermore, the use of multiple power units 65, 66 provides the possibility for at
20 least two levels of efficiency for different cruising speeds 110 in the mechanical mode 100. For example, a first cruising speed may be set at the optimum efficiency of output of the second power unit 66 and a second cruising speed at the optimum efficiency of the combined outputs of
25 the first and second power units 65, 66.

With reference to the propulsion system 86 shown in Figure 7, improved flexibility in terms of the power supply to/from the first and second energy conversion machines 27,
30 28 may be achieved.

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The propulsion systems 25, 64, 86 enable the power units 26, 65, 66 to be selected such that their optimum engine output is at a cruising speed. Alternatively, the optimum engine output may be set to maintain a load factor
5 above 80%, which may still be relatively efficient. The use of multiple power units 26, 65, 66 may improve flexibility as they provide multiple cruising speeds 110 at which efficient operation occurs. Furthermore, power unit size may be reduced via the used of multiple power units 26, 65, 66,
10 thereby potentially improving weight distribution and reducing costs.

Multiple propulsion systems 25, 64, 86 may also be provided such that multiple propulsion elements 40 provide
15 thrust. Each of the propulsion systems 25, 64, 86 may be connected to one another via the power transfer arrangement 37. Therefore, power may be generated in one propulsion system 25, 64, 86 and transferred to another propulsion system 25, 64, 86.

20

Redundancy may be improved as the power transfer arrangement 37 may comprise batteries for running the second energy conversion machine 28 alone. Safety and electrical losses may be reduced in comparison to a purely electrical
25 drive system, since power can be transferred via a more efficient mechanical route.

Furthermore, the combined improvements in the efficiency and flexibility of the propulsion system 25, 64,
30 86 may enable fixed pitch propellers to be used whilst maintaining the same flexibility and efficiency obtained

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from variable pitch propellers. Therefore, shrouds may also be used to improve efficiency further.

5 The propulsion system 25, 64, 86 may also be easily scaled to large and smaller work machines by simply adapting the size and/or number of the power units 26, 65, 66. For example, such propulsion systems 25, 64, 86 may be implemented in tugboats or large tankers.

10 In addition, the use of one or more planetary gearboxes for the transmission 29 enables a ship incorporating such a propulsion system 25, 64, 86 to have a smaller keel width than is possible in previously known transmission arrangements for ships. As illustrated in Figure 4, the
15 transmission 29 may have the gearbox width 47. Where the transmission 29 is a planetary gearbox, the gearbox width 47 may be relatively smaller than the output gear diameter 23 disclosed previously herein when achieving the same gear
20 gearboxes even when a large gear ratio is implemented. Therefore, by utilising a planetary gearbox in a ship the keel width may be reduced.

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CLAIMS:

1. A propulsion system for providing a power output; said propulsion system comprising;

a transmission configured to provide the power output;

5 at least one first energy conversion machine;

at least one power unit operable to selectively drive the transmission and/or the at least one first energy conversion machine;

10 at least one second energy conversion machine operable to selectively drive or be driven by the transmission; and

a power transfer arrangement for transferring power between the first and second energy conversion machines.

2. A propulsion system as claimed in claim 1 wherein the at least one first and second energy conversion machines are reversible hydraulic or electrical machines.

3. A propulsion system as claimed in claim 2 wherein the power transfer arrangement is hydraulic or electrical.

20

4. A propulsion system as claimed in any one of the preceding claims wherein the at least one power unit is operable to selectively drive the transmission via at least one drive shaft, at least one transmission coupling and at least one kinematic connection element.

25

5. A propulsion system as claimed in any one of the preceding claims wherein the at least one power unit is operable to selectively drive the at least one first energy conversion machine via at least one drive shaft and at least one kinematic connection element.

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6. A propulsion system as claimed in claim 4 and claim 5 wherein the kinematic connection elements are gears, and the propulsion system comprises;

5 first and third gears mounted on a power unit output shaft;

a second gear interconnected with the first gear and providing a rotatable input to the transmission;

10 a fourth gear mounted on a first machine shaft and interconnected with the third gear, said first machine shaft providing an input or output to/from the at least one first energy conversion machine.

7. A propulsion system as claimed in any one of the preceding claims wherein the transmission comprises at least
15 one planetary gearbox.

8. A propulsion system as claimed in claim 7 wherein the at least one planetary gearbox comprises a sun gear, a plurality of planetary gears attached to a carrier and a
20 rotatable ring gear.

9. A propulsion system as claimed in claim 8 wherein the sun gear is rotatably connected to the at least one second energy conversion machine, the ring gear is rotatably
25 connected to provide the power output and the carrier is operably connected to the at least one power unit.

10. A propulsion system as claimed in claim 6 and claim 9 wherein the carrier is rotatably connected to the second
30 gear.

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11. A propulsion system as claimed in claim 9 or claim 10 wherein the power output is provided by a rotatable transmission output shaft and the ring gear is rotatably connected to the transmission output shaft.

5

12. A work machine comprising at least one propulsion system of any one of claims 1 to 11.

13. A marine vessel comprising at least one propulsion
10 system of any one of claims 1 to 11.

14. A method of operating a propulsion system, said propulsion system comprising;

15 a transmission configured to provide the power output;
 at least one first energy conversion machine;
 at least one power unit operable to selectively drive the transmission and/or the at least one first energy conversion machine;

20 at least one second energy conversion machine operable to selectively drive or be driven by the transmission; and
 a power transfer arrangement for transferring power between the first and second energy conversion machines;
said method comprising;

25 connecting the power unit to drive the transmission; or
 connecting the power unit to drive the at least one first energy conversion machine; or

 connecting the power unit to drive the transmission and the at least one first energy conversion machine.

30 15. A method as claimed in claim 14 comprising a first mode wherein power is transferred to the transmission via at

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least one shaft, at least one kinematic connection element and at least one transmission coupling.

16. A method as claimed in claim 14 or claim 15 comprising a
5 second mode wherein power is transferred via at least one shaft and at least one kinematic connection element to the at least one first energy conversion machine, said power being transferred from the at least one first energy conversion machine to the transmission via the power
10 transfer arrangement and the second energy conversion machine.

17. A method as claimed in claim 15 and claim 16 comprising a third mode wherein power is transferred simultaneously in
15 the first mode and the second mode.

18. A method as claimed in claim 15 to claim 17 comprising a fourth mode wherein power is transferred to the transmission in the first mode whilst power is transferred from the
20 transmission to the second energy conversion machine.

19. A marine vessel comprising a propulsion system for providing propulsion to the ship, said propulsion system comprising;
25 a power unit providing a rotational output to a power unit output shaft;
a first kinematic connection element attached to the power unit output shaft; and
at least one planetary gearbox providing a rotational
30 output to a transmission output shaft, said transmission output shaft being connected to a propulsion element;

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wherein the first kinematic connection element is operably connected to the at least one planetary gearbox.

20. A marine vessel as claimed in claim 19 wherein the ship
5 comprises a keel and the at least one planetary gearbox is located substantially within the keel.

21. A marine vessel as claimed in claim 19 or claim 20
further comprising a second kinematic connection element
10 interlocked with the first kinematic connection element, the first kinematic connection element being operably connected to the at least one planetary gearbox via the second kinematic connection element.

15 22. A marine vessel as claimed in any one of claims 19 to 21 comprising multiple planetary gearboxes arranged in series.

23. A marine vessel as claimed in any one of claims 19 to 22
wherein the propulsion system comprises at least one first
20 energy conversion machine operably connected to at least one second energy conversion machine, the power unit providing power to the at least one first energy conversion machine and the at least one second energy conversion machine being operably connected to the at least one planetary gearbox.

25

24. A propulsion system comprising;

first and second power units;

a transmission configured to transmit power to a transmission shaft;

30 at least one first energy conversion machine; and

a power unit transmission;

wherein said power unit transmission comprises;

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a plurality of transmission shafts operably connecting the power unit transmission to the first and second power units, the transmission and the at least one first energy conversion machine;

5 a first torque coupling for selectively operably connecting the second power unit to the power unit transmission; and

a second torque coupling for selectively operably connecting the transmission to the power unit transmission.

10

25. A propulsion system as claimed in claim 24 wherein one of the plurality of transmission shafts is configured to connect the power unit transmission to at least one electrical generator.

15

26. A propulsion system as claimed in claim 24 or claim 25 further comprising at least one second energy conversion machine operable to drive the transmission; and

a power transfer arrangement for transferring power
20 between the first and second energy conversion machines.

27. A propulsion system as claimed in any one of claims 24 to 26 wherein the at least one first energy conversion machine is a reversible hydraulic or electrical machine.

25

28. A propulsion system as claimed in claim 26 or claim 27 wherein the at least one second energy conversion machine is a reversible hydraulic or electrical machine.

30 29. A propulsion system as claimed in any one of claims 26 to 28 wherein the power transfer arrangement is hydraulic or electrical.

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30. A propulsion system as claimed in any one of claims 24 to 29 wherein the first and second power units are operable to selectively drive the transmission and/or the at least one first energy conversion machine via the power unit transmission.

31. A propulsion system as claimed in any one of claims 24 to 30 comprising;

10 a first kinematic connection element mounted on one of the plurality of transmission shafts;

a second kinematic connection element interconnected with the first kinematic connection element and providing a rotatable input to the transmission.

15 32. A propulsion system as claimed in any one claims 24 to 31 wherein the transmission comprises at least one planetary gearbox.

20 33. A propulsion system as claimed in claim 32 wherein the at least one planetary gearbox comprises a sun gear, a plurality of planetary gears attached to a carrier and a rotatable ring gear.

25 34. A propulsion system as claimed in claim 33 wherein the sun gear is rotatably connected to the at least one second energy conversion machine, the ring gear is rotatably connected to provide the power output and the carrier is operably connected to the power unit transmission.

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35. A propulsion system as claimed in claim 31 and claim 34 wherein the carrier is rotatably connected to the second kinematic connection element.

5 36. A propulsion system as claimed in claim 34 or claim 35 wherein the power output is provided by a rotatable transmission output shaft and the ring gear is rotatably connected to the transmission output shaft.

10 37. A work machine comprising the propulsion system of any one of claims 24 to 36.

38. A marine vessel comprising at least one propulsion system of any one of claims 24 to 36.

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