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Control method for a fast reversal of a reciprocating piston internal combustion engine.

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The invention relates to a control method for a fast reversal or braking of a rotation in a first direction of rotation of a crankshaft of a reciprocating piston internal combustion engine, in particular a slow-running, uniflow-scavenged large two-stroke diesel engine in accordance with the preamble of independent claim 1.

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Large diesel engines are frequently used as drive units for ships or also in stationary operation, e.g. for the driving of large generators for the generation of electrical energy. In this respect, the engines as a rule run in permanent operation over considerable time periods, which makes high demands on the operating security and on the availability. In particular long servicing intervals, low wear and an economic handling of fuels and operating materials are therefore central criteria for the operation of the machine for the operator. The piston running behavior of such large-bore slow running diesel engines is, among others, a determining factor for the length of the servicing intervals, the availability and, over the lubricant consumption, also directly for the operating costs and thus for the operating efficiency. An example for a propulsion engine of this kind is provided by State of the Art GB 722 568.

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In deep-sea shipping there has always been a desire and a need to brake ships from full speed in as short a time as possible and thus over as short a distance as

possible in an emergency situation or to reverse the engine as fast as possible so that the propeller rotates in the opposite direction as soon as possible so that the ship can continue to sail in the opposite direction as immediately as possible.

Whereas various tried and tested processes have been available for a long time

5 for this purpose for relatively small motorships or motorboats and the reversal can frequently be effected simply via transmissions, the "emergency braking", i.e. the fast braking from full speed with large ships which are equipped with large reciprocating piston internal combustion engines, such as with slow-running, uniflow-scavenged large two-stroke diesel engines, is a previously largely
10 unsolved problem. This relates, in addition to the braking of the ships, to the problem closely related therewith of a fast reversal of the engine from one direction of rotation to the opposite direction of rotation.

This is in particular a problem which is not to be underestimated with the slow-

15 running, uniflow-scavenged large two-stroke diesel engines since with these engines, due to their huge size and power, the sensible use of a transmission and/or of a clutch between the engine and the propeller is practically precluded so that the propeller is rotationally fixedly connected via a shaft to the crankshaft of the large diesel engine in ships with such engines.

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The construction of the drive is thus admittedly substantially simpler in comparison with a drive in which a transmission is provided between the propeller and the engine. The disadvantage of such a construction without a transmission and without a clutch is, however, that the propeller is always, that is in every operating
25 state, rotationally fixedly connected to the engine and cannot be disconnected from it, at least in the operating state of the engine, that is as long as it has not come to a state of complete standstill. That is, in an operating state in which the engine is stopped to brake the ship, which essentially means in practice that the fuel supply to the engine is interrupted, the ship does not immediately stop on the

spot, but will initially continue to sail on due to its huge mass of inertia and will only gradually lose speed bit by bit.

The propeller is in this respect now admittedly no longer driven by the engine;
5 however, it is driven by the progress through the water by the continuing relative speed between the propeller and the water. Since the propeller is, however, rotationally fixedly connected to the engine and can also not be disconnected from the engine, the engine is now also driven by the propeller in such an operating state. This means that the motor will nevertheless continue to rotate in the original
10 direction for a considerable period of time after the stopping of the fuel supply because it is now driven by the propeller.

An acceleration of the braking of the ship or a reversal of the direction of travel of the ship can only be achieved in that the engine is restarted in the reverse
15 direction of rotation. With most known ship's engines and in particular with the huge uniflow-scavenged large two-stroke diesel engines, this can only be achieved in that at a suitable point in time, i.e. with a suitable crank angle, compressed air, also called starting air in technical language, is pressed into the cylinder liner at a sufficiently high pressure so that the engine is restarted in the
20 desired reverse direction of rotation by the starting air acting on the pistons.

Due to the enormous forces which, as explained above, the propeller exerts via the crank shaft on the pistons in the cylinder liners of the engine such that the engine continues to rotate in the original direction despite the stopped fuel supply,
25 the engine can then be restarted in the opposite direction at the earliest when the maximum available pressure of the starting air is sufficient to compensate the forces from the propeller acting on the pistons so much that the engine can be set into a sufficiently fast rotation in the opposite direction by the starting air so that the engine can ultimately restart independently in the opposite direction on a
30 reactivation of the fuel supply. When the engine is restarted in the opposite

direction of rotation, the propeller rotationally fixedly connected to the engine is naturally likewise driven in the opposite direction by the engine, whereby the braking of the ship can then be increasingly accelerated until the travel of the ship finally comes to a standstill or, if desired, the ship can start to travel in the opposite
5 direction.

The disadvantages of the above-described and previously customary process for braking and reversing of a ship are obvious. On the one hand, the braking of a ship, in particular of a ship having a slow-running uniflow-scavenged large two-
10 stroke diesel engine, requires a great deal of time because, before the engine can be restarted in the opposition direction, it is first necessary to wait for so long until the ship has lost sufficient speed and has become sufficiently slow so that the drive of the engine via the propeller can be compensated by the starting air. This still takes up a considerable length of time, which is in particular a big
15 disadvantage when the ship has to be braked very fast, e.g. to prevent a collision with another ship, with an iceberg or with another obstacle reliably and in good time in an emergency situation. The catastrophe with the famous Titanic, where it was inter alia no longer possible to brake the ship in good time, has remained in the public mind up to the present day. Even though the Titanic was not driven by a
20 slow-running uniflow-scavenged large two-stroke diesel engine, the problem is the same in principle.

So that the distance covered by the ship when braking or when reversing into the opposite direction of travel is minimized, an attempt is frequently made to reverse
25 the engine at the earliest possible time by supplying the starting air into the cylinder liner. The faster the engine runs in the old direction, driven by the propeller, however, the more starting air or starting air energy is required to be able to initiate the reversal in the opposite direction. This is not only expensive and energy-intensive, because the starting air first has to be generated using
30 corresponding compressors and has to be stored in pressure stores. But the

method also produces the risk that more or less the total store of starting air is consumed and it is nevertheless not possible that the engine starts in the opposite direction. This not only further delays the braking, but can even become a safety risk because, in such a situation, new starting air has to be provided again and the engine can no longer be started again in the meantime, which may have fatal consequences under certain circumstances since the ship is without drive in such a situation.

It is therefore the object of the invention to provide a method with which an engine, in particular a slow-running uniflow-scavenged large two-stroke diesel engine, can be reversed in an opposition direction more efficiently and faster, wherein the problems described from the prior art are very largely avoided; in particular the fatal safety problems known from the prior art can be bypassed and the reversal of the engine can additionally be carried out more economically and with greater energy saving.

The subjects of the invention satisfying these objects are characterized by the features of independent claim 1.

The dependent claims relate to particularly advantageous embodiments of the invention.

The invention thus relates to a control method for a fast reversal or braking of a rotation in a first direction of rotation of a crankshaft of a reciprocating piston internal combustion engine, in particular a slow-running uniflow-scavenged large two-stroke diesel engine, comprising a cylinder in which a piston is arranged movable to and fro between a top dead center corresponding to a crank angle of 180° and a bottom dead center corresponding to a crank angle of 0° or 360° respectively, and having an outlet valve which can be hydraulically actuated by means of a hydraulic medium, preferably hydraulic oil, at a predefined opening

pressure via valve hydraulics. In accordance with the invention, a fuel supply to the reciprocating piston internal combustion engine is interrupted in a braking phase and the hydraulic medium is provided at a predefined maximum opening pressure to valve hydraulics of a first outlet valve of a first cylinder at a first crank angle in the region of the top dead center position of the first piston associated with the first cylinder so that the first outlet valve is automatically opened by the valve hydraulics at a second crank angle, at the earliest on the passing of the first piston through its top dead center position.

- 10 A method is provided for the first time by the present invention with which an engine, in particular a slow-running uniflow-scavenged large two-stroke diesel engine, can be reversed into an opposition direction of rotation more efficiently and faster, with simultaneously valuable starting air additionally being able to be saved. In a particularly preferred embodiment of a method in accordance with the invention, a restart in the opposition direction of rotation can even be initiated completely without any starting air in a ship, for example, while utilizing the braking energy provided to the engine by the propeller, which naturally not only represents an improvement which cannot be underestimated under economic aspects, but in particular also represents huge progress under safety-technical aspects when the method in accordance with the invention is used for reversing or braking an engine of a ship.

In an embodiment particularly preferred for practice, the reciprocating piston internal combustion engine is a slow-running uniflow-scavenged large two-stroke diesel engine of a ship, for example of a container ship having an enormously large engine which has, for example, up to twelve or more cylinders and which can have a power of up to 10,000 kW per cylinder or even greater powers.

As the skilled person is aware per se, a piston moves to and fro between a top dead center and a bottom dead center in a cylinder liner in a normal operating

state of the reciprocating piston internal combustion engine and drives the propeller via a crankshaft which is operationally fixedly connected to the piston and to a propeller. An outlet valve at a cylinder cover of the cylinder liner is hydraulically actuated via valve hydraulics by means of a programmable control
5 device which can in practice comprise a hydraulic device and an electronic device. In this respect, a crank angle at which the outlet valve is actuated can in principle be predefined as desired by the programmable control device. The engine can either started from a standstill by actuating a starting air valve or, at a sufficiently smaller rotational speed, the direction of rotation of the engine can be changed.

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For the better understanding of the invention, the general operating mode in the normal operating state of a reciprocating piston internal combustion engine, which is known per se, will again be briefly schematically recalled in the following. Within the framework of this application, a crank angle of 0° or 360° respectively is
15 identified with the bottom dead center UT and a crank angle of 180° is identified with the top dead center OT.

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Starting from the bottom dead center, corresponding to a crank angle of 0° , the piston first moves in the operating state in the direction OT, corresponding to a crank angle of 180° . When the piston is located in a position close to the bottom dead center, the scavenging slits are released in the lower region of the cylinder liner and the outlet valve 5 is opened in the normal operating state. As long as the scavenging slits are released by the piston, fresh air is supplied to the combustion space of the cylinder liner through the scavenging slits and combustion residues
25 are simultaneously flushed out of the combustion space through the outlet valve by the movement of the piston in the direction toward the top dead center. When the piston has completely passed the scavenging slits so that there can no longer be any communication between the combustion space and the scavenging slits, the outlet valve will also be closed by means of the control device at a predefined
30 crank angle as the cranking angle increases. In the further process, fuel is

supplied by an injection valve to the combustion space of the engine which is formed from the upper cylinder region, the cylinder cover located above it and the piston base, said fuel igniting in the air heated by the compression in the region of the top dead center, subsequently combusting and producing by this energy
5 release a pressure increase in the combustion space.

After passing through the top dead center, the piston again moves in the direction toward the bottom dead center corresponding to a crank angle of 360° . In the normal operating and travel state of the ship, the outlet valve is then opened again
10 and a new work cycle of the cylinder is initiated at a crank angle which is considerably larger than 180° .

In the event that the ship is to be braked, in particular when it should be braked within a distance which is as short as possible in an emergency, the reciprocating
15 piston internal combustion engine would also be set into a different operating state for braking or reversing with the already known methods. In a first step, it is known to interrupt the fuel supply into the cylinders liners of the reciprocating piston internal combustion engine. It is achieved by the interruption of the fuel supply that the rotational speed of the engine first drops, which produces a first moderate
20 slowing of the ship. If no further measures are taken, the speed of the ship is substantially reduced due to the friction of the ship in the water. This friction is generally comparatively small so that the speed of the ship only reduces very slowly. The propeller, which is no longer driven by the reciprocating piston internal combustion engine after the fuel supply has been interrupted now operates, driven
25 by the still present kinetic energy of the ship, as a turbine and now drives the engine to which it is rotationally fixedly connected via the crankshaft.

If the control of the outlet valve is now maintained without change as in normal operation and as previously practiced in the prior art, a portion of the kinetic
30 energy of the ship is admittedly converted into compression energy in the cylinder

in the crank angle range between 0° and 180° ; however, this compression energy is almost completely returned to the ship again via the propeller in the form of kinetic energy on the subsequent expansion of the scavenging air enclosed in the cylinder liner during the movement of the piston from the top dead center to the
5 bottom dead center.

The invention now starts from this point and is based on the recognition that a fast reversal or braking of the engine is substantially possible solely by a suitable control of the outlet valve, and can indeed be restarted in the opposite direction
10 specifically even without starting air and at least with less starting air than previously required in the prior art, provided that the braking energy transferred to the engine via the propeller is used skillfully in accordance with the invention.

In a preferred embodiment of a control process in accordance with the invention,
15 the second crank angle is selected in a range between the top dead center and the bottom dead center of the first piston at a value between 180° and 360° , preferably at a value between 180° and 225° , or between 180° and 200° , particularly preferably at a second crank angle which lies between 180° and 190° after the top dead center of the first piston.

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To obtain a further improvement of the braking effect on the reversal, the first outlet valve is closed again at a third crank angle in the region between the second crank angle and the bottom dead center of the first piston to generate a predefined vacuum in the first cylinder.

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Depending on the phase of the reversal of the engine in which this measure is taken, two positive effects can substantially be brought about.

If the generation of the vacuum in the first cylinder is carried out in the braking
30 phase of the rotation of the reciprocating piston internal combustion engine in the

first direction of rotation and if the third crank angle is selected accordingly, a vacuum can be built up in the first cylinder by the closing of the outlet valve with a suitable selection of the third crank angle such that the braking of the rotation of the reciprocating piston internal combustion engine in the first direction of rotation is assisted by the build-up of the vacuum. An at least slight suction effect on the piston thereby therefore arises such that a corresponding braking of the piston movement is effected which additionally removes kinetic energy from the engine and thus accelerates the braking.

- 10 On the other hand, it is also possible that the third crank angle is selected in a reversal phase of the reciprocating piston internal combustion engine following the braking phase such that a vacuum is built up in the first cylinder by the closing of the first outlet valve at the third crank angle such that a restart of the reciprocating piston internal combustion engine in a second direction of rotation opposite to the first direction of rotation initiated in a second cylinder by a fuel supply is assisted by the build-up of the vacuum in the first cylinder. This means that since a braking suction effect is generated in the first cylinder with respect to the first direction of rotation of the engine, a restart of the engine, that is a reversal of the engine in the new second direction of rotation of the engine opposite to the first direction of rotation is facilitated or assisted such that an earlier reversal become possible or possibly still required starting air can be minimized or even completely saved.

- 25 A further additional or alternative measure of a method in accordance with the invention comprises the first outlet valve being closed at a fourth crank angle between the bottom dead center and the top dead center, preferably at a fourth crank angle which is reached after a termination of the supply of scavenging air into the cylinder.

- 30 Even with the last-named measure, the situation is that, depending on the phase of the reversal of the engine in which the closing of the outlet valve is carried out at

the fourth crank angle, substantially two additional positive effects can be brought about.

On the one hand, when the fourth crank angle is selected in the braking phase of the rotation of the reciprocating piston internal combustion engine such that an excess pressure is built up in the first cylinder by the closing of the first outlet valve at the fourth crank angle, and the braking of the rotation of the reciprocating piston internal combustion engine in the first direction of rotation is assisted by the build-up of the excess pressure. And indeed because kinetic energy is removed from the engine due to the pressure building up in the cylinder in that the kinetic energy is converted into pressure energy, whereby the braking of the engine in the first direction of rotation is very effectively assisted.

On the other hand, when the fourth crank angle in the reversal phase of the reciprocating piston internal combustion engine following the braking phase is selected such that an excess pressure is built up in the first cylinder by the closing of the first outlet valve at the fourth crank angle such that the excess pressure building up in the first cylinder is suitably coordinated with a restart of the reciprocating piston internal combustion engine in a second direction of rotation opposite to the first direction of rotation initiated by a fuel supply, the restart in the opposite direction of rotation can be effectively assisted by the build-up of the excess pressure in the first cylinder.

This means that since a braking pressure effect is generated in the first cylinder with respect to the first direction of rotation of the engine, a restart of the engine, that is a reversal of the engine in the new second direction of rotation of the engine opposite to the first direction of rotation is facilitated or assisted such that an earlier reversal become possible or possibly still required starting air can be minimized or even completely saved.

In particular when the reversal should take place particularly fast or when e.g. there is a need for an emergency braking of the ship or if another necessity is present for the very fast carrying out of the method in accordance with the invention, the restart of the reciprocating piston internal combustion engine in the second direction of rotation opposite to the first direction of rotation initiated during the reversal phase can naturally additionally be assisted by introducing a predefined minimal amount of starting air into at least one cylinder of the reciprocating piston internal combustion engine, whereby the reversal into the second direction of rotation or the braking from the first direction of rotation can additionally be accelerated.

In particular, but not only, when there is no need for a very fast procedure as in an emergency, the starting air can also be introduced sequentially only into some of the cylinders of the reciprocating piston internal combustion engine, preferably even only into one single selected cylinder and not into any other cylinder, to assist the restart in the second direction of rotation during the reversal phase.

The method in accordance with the invention even allows, as already mentioned above, that the restart of the reciprocating piston internal combustion engine in the second direction of rotation opposite to the first direction of rotation initiated during the reversal phase can take place completely without the use of starting air in that the outlet valve is controlled so skillfully that the kinetic energy is ideally used which is fed back into the engine by the propeller.

In practice, the reciprocating piston internal combustion engine has a plurality of cylinders which are located in a manner known per se at least partly in each case at different crank angles at the same time so that the measures named here for accelerating the braking or reversal of the engine can be taken simultaneously so that a cumulative effect of the different measures is produced.

It is understood that the embodiments of the invention described in this application can also be combined in any suitable manner in dependence on the application and that the described special embodiments are only to be understood by way of example. The skilled person immediately recognizes simple advantageous further
5 developments of the described embodiments of the invention and understands that such simple further developments are naturally also covered by the invention.

P A T E N T K R A V

1. Styrefremgangsmåde til hurtig omstyring eller bremsning af en rotation i en første rotationsretning for en krumtapaksel i en stempelforbrændingsmotor, især en stor langsomt løbende længdeskyllet totaktsdieselmotor, omfattende en cylinder, hvori et stempel er anbragt bevægeligt frem og tilbage mellem et øvre død-
punkt svarende til en krumtapvinkel på 180° og et nedre dødpoint svarende til en krumtapvinkel på hhv. 0° og 360° , samt med en udstødningsventil, som kan aktiveres hydraulisk via en ventilhydraulik ved hjælp af et under et forudbestemt
åbningstryk stående hydraulikmedium, fortrinsvis hydraulikolie, hvor en brænd-
stofftilførsel til stempelforbrændingsmotoren afbrydes i en bremsefase, og hydraulikmediet stilles til rådighed under et forudbestemt maksimalt åbningstryk i en ventilhydraulik i en første cylinders første udstødningsventil ved en første krumtap-
vinkel i området af den øvre dødpunktssposition af det første til den første cylinder
knyttede stempel, således at den første udstødningsventil tidligst ved det første
stempels gennemløb gennem dets øvre dødpunktssposition åbnes automatisk af
ventilhydraulikken ved en anden krumtapvinkel, **kendetegnet ved, at** den første
udstødningsventil til frembringelse af et forudbestemt undertryk i den første
cylinder lukkes igen ved en tredje krumtapvinkel i området mellem den anden
krumtapvinkel og det første stempels nedre dødpoint, hvor den tredje krumtap-
vinkel i bremsefasen for stempelforbrændingsmotorens rotation i den første
rotationsretning vælges således, at der med lukningen af den første udstødnings-
ventil ved den tredje krumtapvinkel opbygges et undertryk i den første cylinder
således, at bremsningen af stempelforbrændingsmotorens rotation i den første
rotationsretning understøttes af opbygningen af undertrykket.

2. Styrefremgangsmåde ifølge krav 1, hvor den anden krumtapvinkel i et område mellem det første stempels øvre dødpoint og nedre dødpoint ved en værdi mellem 180° og 360° , fortrinsvis ved en værdi mellem 180° og 225° eller mellem 180° og 200° , særligt foretrukket ved en anden krumtapvinkel mellem 180° og 190° , ligger efter det første stempels øvre dødpoint.

3. Styrefremgangsmåde ifølge krav 1 eller 2, hvor den tredje krumtapvinkel i en efter bremsefasen følgende omstyrefase for stempelforbrændingsmotoren vælges således, at der med lukningen af den første udstødningsventil ved den tredje krumtapvinkel opbygges et undertryk i den første cylinder således, at en i en anden cylinder ved hjælp af en brændstoftilførsel initieret nystart af stempelforbrændingsmotoren i en i forhold til den første rotationsretning modsat anden rotationsretning understøttes af opbygningen af undertrykket i den første cylinder.

4. Styrefremgangsmåde ifølge et af de foregående krav, hvor den første udstødningsventil ved en fjerde krumtapvinkel lukkes mellem det nedre dødpunkt og det øvre dødpunkt, fortrinsvis ved en fjerde krumtapvinkel, som opnås ved afslutningen af tilførslen af skylleluft til cylinderen.

5. Styrefremgangsmåde ifølge krav 4, hvor den fjerde krumtapvinkel i bremsefasen for stempelforbrændingsmotorens rotation vælges således, at der med lukningen af den første udstødningsventil ved den fjerde krumtapvinkel opbygges et overtryk i den første cylinder således, at bremsningen af stempelforbrændingsmotorens rotation i den første rotationsretning understøttes af opbygningen af overtrykket.

6. Styrefremgangsmåde ifølge krav 4, hvor den fjerde krumtapvinkel i den efter bremsefasen følgende omstyrefase for stempelforbrændingsmotoren vælges således, at der med lukningen af den første udstødningsventil ved den fjerde krumtapvinkel opbygges et overtryk i den første cylinder således, at en i en anden cylinder ved hjælp af en brændstoftilførsel initieret nystart af stempelforbrændingsmotoren i en i forhold til den første rotationsretning modsat anden rotationsretning understøttes af opbygningen af overtrykket i den første cylinder.

7. Styrefremgangsmåde ifølge et af de foregående krav, hvor den under omstyrefasen initierede nystart af stempelforbrændingsmotoren i den i forhold til den første rotationsretning modsatte anden rotationsretning understøttes af ind-

førsel af en forudbestemt minimal mængde startluft i mindst en cylinder i stempelforbrændingsmotoren.

- 5 8. Styrefremgangsmåde ifølge krav 7, hvor startluften til understøtning af nystarten i den anden rotationsretning under omstyrefasen sekventielt kun indføres i en del af stempelforbrændingsmotorens cylindre, fortrinsvis kun indføres i en enkelt udvalgt cylinder og i ingen anden cylinder.
- 10 9. Styrefremgangsmåde ifølge et af kravene 1 til 6, hvor den under omstyrefasen initierede nystart af stempelforbrændingsmotoren i den i forhold til den første rotationsretning modsatte anden rotationsretning sker under anvendelse af startluft.
- 15 10. Styrefremgangsmåde ifølge et af de foregående krav, hvor stempelforbrændingsmotoren er drivaggregatet i et skib.