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(73) Patenthaver: **WinGD AG, Schützenstrasse 3, 8400 Winterthur, Schweiz**

(72) Opfinder: **Ott, Marcel, Emil-Klöti-Strasse 41, 8406 Winterthur, Schweiz**

(74) Fuldmægtig i Danmark: **Larsen & Birkeholm A/S Skandinavisk Patentbureau, Banegårdspladsen 1, 1570 København V, Danmark**

(54) Benævnelse: **Fremgangsmåde til drift af en stor dieselmotor, anvendelse af denne fremgangsmåde samt stor dieselmotor**

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Method of operating a large diesel engine, use of this method, as well as large diesel engine

Description

The invention relates to a method of operating a large diesel engine, to a large diesel engine, and to the use of the method in accordance with preamble of the independent patent claim of the respective category.

Large diesel engines that can be configured as two stroke or as four stroke machines, for example as longitudinally scavenged two-stroke large diesel engine, are frequently used as drive aggregates for ships or also in a stationary mode of operation, e.g. for the drive of large generators for the generation of electrical energy. In this connection the engines generally run for considerable periods of time in a continuous mode of operation which represents high requirements with respect to the operational safety and the availability. For this reasons in particular long intervals between maintenance, low wear and an economic handling of the operating fuels are central criteria for the operator.

For a few years a further essential point and an essential point having increasing importance, is the quality of the exhaust gas, in particular the nitrogen oxide concentration in the exhaust gases. Here the legal provisions and threshold values for the corresponding exhaust gas values are becoming more and more stringent. In particular having regard to two-stroke large diesel engines this has the consequence that the combustion of the classical heavy fuel oil highly loaded with contaminants, and also the combustion of diesel oil or any other fuel becomes more problematic, as the maintenance of the exhaust gas threshold values becomes more and more difficult, technically more demanding and in this way more expensive or in the end, their maintenance is no longer even possible in a sensible manner.

For this reason, the requirement for so-called "dual fuel engines" has existed for a long period of time in practice, this means engines that can be operated with two different kinds of fuel. In a gas mode a gas, e.g. a natural gas, such as LNG (liquefied natural gas) or a gas in the form of a liquefied petroleum gas or of a different gas suitable for the drive of a combustion engine is combusted, whereas in a liquid mode a suitable liquid fuel, such as petrol, diesel, heavy fuel oil or a different suitable liquid fuel is combusted in the same engine. The engines can in this connection be both two-stroke engines as well as four-stroke engines and in this connection these engines can be small sized engines, medium sized engines and also large sized engines, in particular also longitudinally scavenged two-stroke large diesel engines.

Using the term "large diesel engine" also such large engines are meant that can be operated in a form that is different from the diesel mode of operation, that is characterized by the self-ignition of the fuel, also in a petrol engine mode of operation that is characterized by an external ignition of the fuel, or in a mixed form of operation of these two modes of operation. The term large diesel engine further comprises, in particular also the so-called dual fuel engines and such large engines in which the self-ignition of the fuel is used for the external ignition of a different fuel.

In the liquid mode, the fuel is typically introduced directly into the combustion space of the cylinder and is combusted there in accordance with the principle of self-ignition. In the gas mode it is known to mix the gas in the gaseous state with the scavenging air in accordance with the Otto principle mode of operation in order to thus generate an ignitable mixture in the combustion space of the cylinder. Having regard to this low pressure method, the ignition of the mixture typically takes place in the cylinder in that at the right moment in time a small amount of liquid fuel is injected into the combustion space of the cylinder or into a pre-chamber that then leads to an ignition of the air gas mixture. A dual fuel engine can be switched during the operation of the gas mode into the liquid mode and vice versa.

However, also pure gas engines, this means engines that are only operable with gas and not alternatively with diesel, heavy fuel oil or a different fuel are in demand, in particular then, when high requirements with regard to the exhaust gas are required that can only be maintained through the combustion of gas, with an acceptable technical demand and in an economically viable manner. Such a pure gas engine is, for example, provided in the WO 2010 147071 A1. Further state of the art is present in e.g. the DE 10 2010 005814 A1, DE 198 09 618 A1, WO 94/29585 A1, EP 2 860 376 A1 and DE 10 2004 001825 A1.

Regardless of whether it is a dual fuel engine or a pure gas engine the process of the introduction of the fuel gas into the combustion space of the cylinder of a corresponding reciprocating piston combustion engine is of large importance for the reliable, contaminant low and safe operation of such an engine.

In the gas mode in particular the setting of the correct ratio of scavenging air to gas, the so-called air to fuel ratio is of decisive importance. The scavenging air or charging air is typically made available by a turbocharger in a large diesel engine, the turbocharger generating a scavenging air pressure or loading air pressure which depends on the load of the engine and in this way on the power and/or the torque and/or the speed of rotation of the engine. For a given scavenging air pressure, the amount of air in the cylinder can be calculated and then the respectively required drive torque which is generated by the engine can be determined and/or a suitable amount of the gaseous fuel can be determined for the desired speed of rotation, the amount of torque and/or of the speed of rotation leading to an ideal combustion process for this operating state.

In particular when the gas mode is operated in accordance with the Otto principle, the correct setting of the air gas ratio is of decisive importance for an operation of the engine that is as low as possible from the contamination point of view, efficient and economically viable. If the gas portion is too large then the air gas mixture becomes too rich. The combustion of the mixture takes place too fast or too early which leads to a knocking of the engine. As the combustion process is no longer correctly tuned to the piston movement in the cylinder, this amongst other things, also leads thereto that the combustion partly works against the movement of the piston.

Also when the correct setting of the air to gas ratio no longer represents any large problems in modern large diesel engines under normal operating conditions, disadvantages frequently result under operating conditions having very sudden, frequent and strong changes in load of the engine.

An example that should be mentioned in this connection is a ship driven by a large diesel engine that arrives in heavy sea. This can have the consequence that the ships propeller driven directly by the engine more or less periodically partially or even completely leaves the water due to the high waves in order to subsequently be completely immersed again. This naturally has very large and sudden changes of load of the engine and/or of the drive torque transmitted by the engine to the water as a consequence. As the turbocharger system for making available the scavenging air reacts in a phase-shifted manner with regard to the change of load of the engine it can possibly happen in such modes of operation that the air gas mixture in the cylinder becomes too rich due to a too low scavenging air pressure which then leads to a fast or knocking combustion that is naturally disadvantageous. Such fast and sudden changes of load in the gas mode can only be regulated very difficultly or even not at all in practice, such that, for example, a down regulation of the engine performance or a continuous change and/or adaptation of the engine speed is required or, however, a change from the gas mode into the liquid mode is required. Having regard to a large diesel engine that is operated in the liquid mode, for example with heavy fuel oil, in the future it may no longer be allowed to operate it in the liquid mode in the vicinity of the coast, due to the existing exhaust gas requirements, as in the liquid mode the exhaust gas values may possibly no longer be maintainable.

A different example in which very sudden, frequent or strong changes of load of the engine can arise is the carrying out of manoeuvers of a ship.

For this reason it is an object of the invention starting from the state of the art to suggest a method of operating a large diesel engine in which the large diesel engine can still be operated reliably, efficiently and in an environmentally friendly manner also for sudden, frequent or strong changes in load such as they, for example, arise for a ship in heavy swell or a ship that is carrying out maneuvers. Furthermore, it is an object of the invention to suggest a corresponding large diesel engine.

The subject matter of the invention satisfying this object is characterized by the features of the independent patent claim of the respective category.

In accordance with the invention a method is thus suggested of operating a large diesel engine which has the features of claim 1.

Due to the fact that a transient dwell angle for the outlet valve is determined by means of a correction of the dwell angle, the amount of air that is compressed during a work cycle in the cylinder and is made available for the combustion can be set in a targeted and controlled manner. It can hereby be ensured that the combustion of the air gas mixture in the cylinder does not arrive in the range of a too fast combustion or a knocking combustion and such that the combustion of the air gas mixture in the cylinder does not arrive in the range in which the mixture is too lean, this means that the amount of air present in the cylinder is too large and that spark failures are brought about. If the currently present charging pressure of the scavenging air is too low for an ideal composition of the air to gas mixture, then the correction value is determined in such a way that the transient dwell angle for the outlet valve is smaller than in the normal gas mode of operation, this means that the outlet valve now closes earlier with regard to the work cycle such that a larger amount of air is made available in the cylinder for the compression. Thereby the too low a charging pressure of the scavenging air can be compensated. If the currently present charging pressure of the scavenging air is too large for an ideal composition of the air to gas mixture, then the correction value is determined in such a way that the transient dwell angle for the outlet valve is larger than in the normal gas mode of operation, this means that with respect to the work cycle the outlet valve now closes later such that a smaller amount of air is made available in the cylinder for the compression. Thereby the too high a charging pressure of the charging air can be compensated.

In this way it is made possible to use the gas mode also with regard to sudden, frequent or periodic changes of load or shifts in load, without the danger resulting of an inefficient, pollutant rich and non-economic operation resulting.

In accordance with the invention the large diesel engine is configured as a dual fuel engine for the combustion of a gas and for the combustion of a liquid fuel, in particular diesel or heavy fuel oil. By means of the method in accordance with the invention it is thus made possible that a dual fuel engine itself can be operated even for sudden and frequent changes of load efficiently in the gas mode. In the case of the important case of application of a large diesel engine as a drive aggregate of a ship this means that, also for heavy swell or on carrying out maneuvers, the gas mode can still be efficiently used.

In accordance with the invention the correction value is added to the dwell angle in order to determine the transient dwell angle, as this represents a particularly simple kind of the correction of the dwell angle.

If the outlet valve should be closed earlier, then the correction value is negative. In practice it has been found advantageous when the magnitude amounts to at most 60 degrees in this connection.

If the outlet valve should be closed at a later point in time, then the correction value is positive. In practice it has been found advantageous when the correction value in this connection amounts to at most 60 degrees.

In the method in accordance with the invention also the amount of gas is limited in the transient mode that is introduced per work cycle in the cylinder. In addition to the gas then a predetermined amount of liquid fuel is introduced into the cylinder in order to compensate the power that is lacking due to the limited or reduced supply of gas. Having regard to this preferred embodiment the transient mode comprises the following steps:
- specifying a desired value for the speed of rotation or the torque of the engine,
- determining an upper threshold for the amount of gas that is made available as fuel per work cycle of the large diesel engine,
- determining an additional amount of a liquid fuel that is introduced in the combustion space in addition to the gas, wherein the additional amount is dimensioned in such a way that the desired value for the speed of rotation is realized. The limitation of the amount of gas in the transient mode represents a further preferred measure that, in particular in combination with the change of the dwell angle for

the outlet valve enables the maintenance of the composition of the air to gas mixture in the cylinder within its boundaries in which an ideal combustion process is ensured in an efficient way.

The limitation of the supplied gas to an upper threshold in particular contributes thereto that the combustion of the air gas mixture in the cylinder does not arrive in the range of a too fast a combustion or that of a knocking combustion. The power lacking for achieving the wanted desired speed of rotation, due to the limited or reduced gas supply, is then generated thereby that, in the transient mode, the predetermined amount of liquid fuel is introduced into the cylinder in addition to the gas, the combustion of which provides the lacking energy, respectively the lacking power.

It is in this way possible in particular by means of this preferred embodiment to realize a similar response to the load in a large diesel engine that can be operated in at least one gas mode as is possible in a large diesel engine that is only operated in a liquid mode. This is made possible thereby that the air gas mixture cannot become too rich and also not too lean in the cylinder and the additional combustion of the liquid fuel, that generally takes place in accordance with the diesel principle, reacts significantly less sensitive to changes in the scavenging air. Also the running smoothness of the engine is increased and the fluctuations in speed are significantly reduced.

It is advantageous when the respective actual pressure of the scavenging air made available is drawn on for the determination of the upper threshold for the amount of gas. In this way the portion that is based on the combustion of the gas can be optimized.

In accordance with an embodiment the transient mode is manually initiated. Thus, for example, the operating personnel on a ship can activate the transient mode of the engine on the emergence of heavy swell or on carrying out maneouvers.

It is preferred when alternatively or additionally the transient mode can be initiated in dependence on at least one of the following parameters: actual pressure of the scavenging air, cylinder pressure, calculated air to gas ratio, signal of a knocking detector, ratio of the speed of rotation to load of the engine, changes to the ratio of speed of rotation to load of the engine, torque of the engine, changes of the torque, amount of the fuel required for the injection, changes in the amount of the fuel required for the injection. The continuous or regular determination of at least one of these parameters also enables an automatic activation of the transient mode.

Having regard to this embodiment having the additional combustion of the liquid fuel, a plurality of preferred variants exists in order to introduce the additional amount of liquid fuel into the combustion space in the transient mode:

The additional amount of the liquid fuel can be introduced into the combustion space by means of an injection apparatus which is used in a liquid mode of the large diesel engine.

The additional amount of the liquid fuel can be introduced into the combustion space by means of a pilot injection apparatus which is used in the gas mode for the ignition of the gas.

The additional amount of the liquid fuel can be introduced into the combustion space by means of a separate injection apparatus which is provided for the transient mode of operation.

Also having regard to the supply of the gas into the combustion space a plurality of preferred variants exists:

The supply of the gas into the cylinder can take place through a cylinder liner. For this purpose, generally known gas supply systems are known that are provided at the wall of the cylinder and that introduce the gas through the cylinder liner into the internal space of the cylinder. Such gas supply systems are preferably arranged in such a way that they introduce the gas at a location into the cylinder that has a spacing from the upper or lower dead center position of the piston in the cylinder, in particular such a spacing that amounts to 40%-60%, preferably to 50% of the spacing between the upper dead center position and the lower dead center position.

The supply of the gas into the cylinder can also take place at a cylinder head. Gas supply systems are also known for this purpose.

It is also possible that the gas is supplied to the scavenging air before the scavenging air is introduced into the cylinder or when the scavenging air is introduced into the cylinder. The last mentioned variant can in particular also be realized in such a way that one or more gas inlet nozzles are provided at one or at a plurality of webs that separate adjacent scavenging air openings or scavenging air slits from one another.

In accordance with the invention a large diesel engine is further suggested which can be operated in at least one gas mode and which is operated in accordance with the method in accordance with the invention. The resulting advantages correspond to the above explanations of the method in accordance with the invention.

In accordance with the invention, the large diesel engine is configured as a dual fuel engine for the combustion of a gas and for the combustion of a liquid fuel, in particular diesel or heavy fuel oil.

In a preferred embodiment an engine control is provided that comprises a control apparatus for initiating and carrying out the transient mode of operation.

Furthermore, the use of a method in accordance with the invention for retrofitting a large diesel engine, in particular a dual fuel engine is suggested in accordance with the invention. As the method in accordance with the invention can be realized in many cases of application without larger additional demand from an apparatus point of view, it is in particular also suitable for modifying and/or retrofitting already existing large diesel engines, in this way, in particular having regard to frequent and suddenly occurring changes of load, for example having regard to heavy swell, these can be operated more efficiently, safely and in an economically viable manner.

Further advantageous measures and designs of the invention result from the dependent claims.

In the following the invention will be described in detail both from an apparatus point of view as well as from a process engineering point of view by means of embodiments and with reference to the drawing. In the drawing there is shown:

Fig. 1	a schematic illustration of an embodiment of a large diesel engine in accordance with the invention,
Fig. 2	a schematic illustration for the emphasis of the dependence of the torque on the air to gas ratio in the embodiment of the large diesel engine,

Fig. 3 a schematic illustration of a first embodiment of a method in accordance with the invention,

Fig. 4 a schematic illustration of a second embodiment of a method in accordance with the invention, and

Fig. 5 a schematic exemplary illustration of the progression in time of the torque.

Having regard to the following description of the invention with reference to embodiments, reference is made with exemplary character to the particularly important case of application in practice of a large diesel engine that is configured as a dual fuel engine, this means an engine that can be operated with two different types of fuel. In particular this embodiment of the large diesel engine can be operated in a liquid mode in which only a liquid fuel is injected into a combustion space of a cylinder. Typically, the liquid fuel, for example heavy fuel oil or a diesel oil is directly injected into the combustion space at a suitable point in time and ignites there in accordance with the diesel principle of self-ignition. The large diesel engine can, however, also be operated in a gas mode of operation in which a gas serving as a fuel, for example natural gas is introduced into the combustion space in the form of an air gas mixture and is ignited there. In particular the large diesel engine works in a gas mode of operation in accordance with a low pressure method, this means that the gas is introduced into the cylinder in a gaseous state. The mixing with the air can in this connection take place in the cylinder itself or also before the cylinder. The air gas mixture is ignited externally in the combustion space in accordance with the Otto principle. This external ignition is typically brought about thereby that a small amount of liquid fuel is introduced into the combustion space at a suitable point in time and that then ignites itself and thereby causes an external ignition of the air gas mixture.

The large diesel engine can be configured both as a four-stroke engine, as well as a two-stroke engine. Having regard to the embodiments described in this way the large diesel engine is configured as a longitudinally scavenged two-stroke large diesel engine that works in the liquid mode with a common-rail system.

Fig. 1 in a very starkly schematically emphasized illustration shows a cylinder 21 of this embodiment of a large diesel engine that is referred to in totality using the reference numeral 20. In the interior of the cylinder 21 a piston 23 moves in a manner known per se.

The assembly and the individual components of the large diesel engine 20, such as, for example, the injection system for the liquid mode, the gas supply system for the gas mode, the gas exchange system, the exhaust gas system or the turbocharger system for the provision of the scavenging air and/or the charging air, as well as the control and regulating system for a large diesel engine are well known to the person of ordinary skill in the art, both having regard to the design as a two-stroke engine and also with regard to the design as a four-stroke engine and for this reason do not require a further explanation here. Of these components, only an outlet valve 24 is illustrated in Fig. 1 which is sufficient for the understanding of the invention.

Having regard to the embodiment described here of a longitudinally scavenged two-stroke large diesel engine 20, scavenging air slits 22 are typically provided in the lower region of each cylinder 21 and/or cylinder liner that are periodically closed and opened by means of the movement of the piston 23 in the cylinder 21, such that the scavenging air, provided by the turbocharger, can flow into the cylinder through the scavenging air slits at a charging pressure, as long as these are open. This is indicated in Fig. 1 by the two arrows provided with the reference numeral L. The typically centrally arranged outlet valve 24 is provided in the cylinder head and/or in the cylinder cover through which the combustion gases can be dispensed again after the combustion process out of the cylinder and into an exhaust gas system 25. For the introduction of the liquid fuel, one or more fuel injection nozzles are provided (not shown) that are, for example, arranged in the cylinder head in the vicinity of the outlet valve 24. A gas supply system is provided (not shown) for the gas supply in the gas mode that comprises at least one gas inlet valve having a gas inlet nozzle. The gas inlet nozzle is typically provided in the wall of the cylinder, for example, at a height that lies approximately in the middle between the upper dead center position and the lower dead center position of the piston.

Different crank angles are additionally stated at the left hand side in Fig. 1 which characterize the work cycle of the large diesel engine 20 in a manner known per se. The stated crank angles in this connection relate to the compression stroke of the piston 23. Having regard to the crank angle of 180° the piston 23 is present at the lower dead center position or point of reversal, at the crank angle of 360° the piston 23 is present at the upper dead center position or point of reversal. Having regard to the design as a two-stroke engine a complete work cycle comprises 360°. Starting at 0° - at which the piston 23 is in the same position as at 360°, namely in the upper dead center position - the piston 23 moves downwardly up until it has arrived at the lower dead center position at 180° and is then moved again upwardly on the compression stroke up until it arrives at the upper dead center position at 360°. In the illustration of Fig. 1 the piston 23 is precisely in a position that corresponds to the crank angle of 270°.

Having regard to the design as a four-stroke engine a complete work cycle comprises 720°, as this is well known.

Furthermore, reference will be made in the following by way of example to the case of application in which the large diesel engine is the drive aggregate of a ship.

Due to the legal provisions having regard to the exhaust gas values, large diesel engines today are frequently operated in the gas mode of operation in the vicinity of the coast, as otherwise the prescribed threshold values for the exhaust gas emission, in particular this is nitrogen oxide, NO_x and sulfur dioxide, can no longer be maintained.

In the gas mode of operation, the efficiency and the combustion of the air gas mixture that is as low in contaminants as possible, is very sensitive to the ratio of the amount of air and the amount of gas. This ratio is typically stated by the λ value which is used for the ratio of the mass of the air made available for the combustion and the mass of the gas which is used as a fuel.

The ideal air to gas ratio depends, amongst other things, on the drive torque to be generated by the engine and in this way on the desired speed of the ship. As large diesel engines are typically directly connected to the propeller of the ship, the speed in each case corresponds to a speed of rotation of the engine having regard to e.g. a fixed pitch propeller.

In a very schematic illustration Fig. 2 shows an exemplary connection between the air to gas ratio 1 and the torque 2 generated by the engine which drives the ship. This illustration is true for a particular torque which corresponds to a specific speed of the ship - or to a certain speed of rotation of the engine - when the ship moves in essentially calm waters. In particular the torque 2 illustrated in Fig. 2 is the BMEP torque (Brake Mean Effective Pressure) that is essentially a torqued average out over one work cycle (a period of the piston movement for two-stroke machines and two periods of the piston movement for four-stroke machines).

In the illustration in Fig. 2 two limit curves can be seen, namely a knocking limit (knocking curve) 3 and a misfiring limit (misfiring curve) 4. Having regard to operating states that are present in accordance with the illustration above the knocking limit 3 the air to gas ratio is too rich, this means that too little air is present in the mixture. A too rich a mixture can lead to different problems, namely that the combustion takes place too fast (fast combustion) or that the engine starts to knock or that the mixture in the cylinder then usually starts to combust too early (pre-ignition) by means of self-ignition due to the high content of gas (with respect to the work cycle). Having regard to operating states that lie above the misfiring limit 4 in accordance with the illustration, the air to gas ratio is too lean, this means that there is not sufficient gas - or too much air - present for an ideal combustion in the combustion space.

For this reason, one strives to always operate the large diesel engine at an ideal point 5 for the air to gas ratio. In practice natural deviations of the torque and/or of the air to gas ratio 1 cannot be avoided or regulated also for a constant speed of rotation and/or a constant speed of the ship, for this reason a tolerance range 6 exists that is limited in the Fig. 2 by the two straight lines 7 and 8, within which deviations of the air to gas ratio 1 from the ideal point 5 are tolerated. An ideal operation in the gas mode is given in the Fig. 2 by the operating point referred to with A.

When the ship now leaves calm waters (to which Fig. 2 refers) and arrives in heavy swell then very sudden and strong changes of load can result for the engine, this means that the torque exerted by the engine via the ships propeller onto the water can change very fast and by a large amount (shift in load). Thus, for example, for a heavy sea it can occur that the ships propeller partly or completely leaves the water for a short period of time which reduces the actual load of the engine considerably. If the ships propeller is subsequently immersed again completely into the water then this leads to a significant increase in load and in this way to an increase of the torque. In Fig. 2 this in practice means that one moves, for example, from the point A to the point referred to with B, that lies above the knocking curve 3 and in this way in the range of fast combustion and/or in the range of knocking.

On the other hand, the engine can arrive in an operating state having a significantly reduced load that lies above the misfiring limit 4, where, with regard to the amount of gas, too much air is present in the cylinder 21, the air of the air to gas mixture is thus too lean. Such an operating state is, for example, achieved in Fig. 2 at the point C. Due to the phase shifted response of the turbocharger system, the scavenging air is made available at too high a charging pressure such that the air to gas mixture becomes too lean.

As in heavy sea these strong fluctuations of the engine load arise frequently one after the other, and approximately periodically, an efficient, economic and low emission mode of operation of the large diesel engine 20 in the gas mode is no longer possible.

Remedial action is provided by the method in accordance with the invention. Fig. 3 in a schematic illustration shows a first embodiment of the method in accordance with the invention. Starting point is, in a step 10, that the large diesel engine is operated in the gas mode. If the ship now arrives in heavy sea, then this state can be detected by observations of the operating personal 11 and/or by means of the evaluation of operating parameters that are detected by the engine control or by different control apparatuses in the step 12. If the thereby caused strong changes of load are determined to be too large, then a decision is made in step 13 to switch the large diesel engine into a transient mode.

In this transient mode the dwell angle for the closure of the outlet valve 24 is initially determined in the gas mode. In this connection the crank angle is understood by the dwell angle at which the outlet valve 24 is closed for the upward movement of the piston 23. For the gas mode typically the dwell angle of the outlet valve is stored in a matrix - like the values for other operating parameters also - whose one dimension is the load of the engine (determined by the generated torque) and whose other dimension is the speed of rotation of the engine. In this way the correct dwell angle for the gas mode can be read out of this matrix for each value pair composed of load and speed of rotation. This amounts, for example, to 270° which in Fig. 1 corresponds to the position of the piston 23. In a step 14 the control apparatus then determines a correction value for the dwell angle. This correction value can be determined in a variety of ways. In particular empirical values can also flow into the control value that is stored in the control apparatus.

A particularly preferred method of determining the correction value consists therein to draw on the currently available charging pressure of the scavenging air for the determination of the correction value. This charging pressure is typically detected by way of measurement in a large diesel engine and in this way is made available in the control apparatus or can be transmitted to this. In this connection the determination of the correction value can in particular be determined with the aid of the difference between the current value of the charging pressure of the scavenging air currently made available and the required charging pressure of the scavenging air. The required charging pressure for the actual operating parameters is, for example, stored in lookup tables or lookup matrices. From the differences between the currently made available charging pressure and the required charging pressure, a determination can be made by how much earlier or later the outlet valve 24 has to be closed for a known volume of the cylinder and/or the space between the cylinder head and the upper side of the piston, in such a way that the same amount of air is present in the cylinder for the currently made available charging pressure directly after the closing of the outlet valve 24, as would be required at the dwell angle for the gas mode and the required charging pressure.

The control apparatus then determines a transient dwell angle for the outlet valve by linking the dwell angle to the correction value. Preferably the correction value is added to the dwell angle in order to determine the transient dwell angle. In step 15 the control apparatus then initiates the closure of the outlet valve 24 at the transient dwell angle.

Thus, if due to the phase-shifted response of the turbocharger system the current charging pressure is too small with respect to a change of load, then the correction value is negative, this means that the outlet valve 24 is already closed at a transient dwell angle that is smaller than the dwell angle for the gas mode.

If in contrast to this, due to the phase-shifted response of the turbocharger system with respect to a change of load, the current charging pressure is too large, then the correction value is positive, this means that the outlet valve 24 is closed only at a transient dwell angle that is larger than the dwell angle for the gas mode.

In step 17 a check is continuously made or is made at regular intervals by observations of the operating personnel and/or by means of the determination of operating parameters whether the conditions for the activation of the transient mode are still satisfied. If yes then the transient mode is maintained, as is indicated by the arrow 18 in Fig. 3, wherein preferably the value for the correction value and/or of the transient dwell angles is/are checked and/or updated.

If the conditions for the transient mode are no longer satisfied in the step 17, then a change back into the normal gas mode can be made in step 19.

The control apparatus for introducing and carrying out the transient mode is preferably integrated into the engine control.

By means of these changes with respect to the closure of the outlet valve 24 it can also be ensured in the transient mode that the large diesel engine works in an operating state that lies within the tolerance range 6 that is limited in the Fig. 2 by the two straight lines 7 and 8.

In practice it has been tried and tested when in the case of a negative correction value, its size amounts to at most 60° and in the case of a positive correction value this amount amounts to at most 60°. This means that, in accordance with the illustration in Fig. 1, the minimum transient dwell angle is at 210° and the maximum transient dwell angle is at 330° for a dwell angle of the outlet valve 24 of 270° in the gas mode.

Through the change of the dwell angle to the transient dwell angle in the transient mode of operation the compression end temperature of the air to gas mixture in the cylinder can be increased or can be reduced. This is generally, however, not very critical but it should be avoided that the compression end temperature takes on such a large value that a self-ignition of the air to gas mixture takes place in a cylinder. This can, for example, be ensured in specific applications by the provision of maximum values for the correction value and/or its amount.

In the following a second preferred embodiment will be described which represents an extension of the first embodiment. The explanations made so far, in particular the explanations of the first embodiment are for this reason true in a like analog manner also with regard to the second embodiment. In the second embodiment, in addition to the correction of the dwell angle for the outlet valve with respect to the transient dwell angle the amount of gas that is made available per work cycle of the large diesel engine as fuel is limited by an upper threshold and an additional amount of a liquid fuel is determined that is introduced into the combustion space in addition to the gas in the transient mode, wherein the additional amount is dimensioned in such a way that a desired value for the speed of rotation is realized.

In a schematic illustration analog to that of Fig. 3, Fig. 4 shows the second embodiment of the method in accordance with the invention. Starting point is in step 10 that the large diesel engine is operated in the gas mode. As was already the case having regard to the first embodiment, the state of strong or sudden changes of load can also be detected in this example such as they can occur for heavy sea or also in the maneuvering mode of operation, by means of observations of the operating personal 11 and/or with reference to the evaluation of operating parameters by means of the engine control or different control apparatuses in step 12. If the strong changes of load are determined to be too large, then a decision is made in step 13 to change the large diesel engine into the transient mode.

In this transient mode a desired value for the speed of rotation of the engine or of the torque to be generated by the engine is initially determined. This can, for example, be the value which corresponds to the movement of the ship in calm waters. In a step 14' the control apparatus then determines an upper threshold for the amount of gas that is made available per work cycle of the large diesel engine as fuel. This upper threshold is in this connection determined in such a way that the scavenging air made available in the cylinder 21 is sufficient in order to combust the maximum amount of gas determined by the upper threshold in such a way that the range of fast combustion and/or the range of knocking combustion and/or the range of pre-ignition is avoided, this means that the air to gas ratio is thus not too rich. The upper threshold for the maximum allowable amount of gas for the avoidance of exceeding the knocking limit 3 (Fig. 1) depends on the amount of air present in the cylinder. Having regard to known cylinder volumes this amount of air can be determined with the aid of the charging pressure of the scavenging air made available. In this connection naturally the deviations of the charging pressure are considered, this means one advantageously assumes a minimum charging pressure that is made available in any case. Naturally also empirical values or different known operating parameters of the large diesel engine can be drawn on, during the determination of a suitable upper threshold for the amount of gas. Moreover, in step 14' - as was described in connection with the first embodiment - a correction value for the dwell angle is determined and this correction value is linked to the dwell angle, preferably by way of addition in order to determine the transient dwell angle for the outlet valve 24.

Particularly preferably the currently made available charging pressure of the scavenging air is drawn on for the determination of the upper threshold of the amount of gas. In particular in this connection the determination of the upper threshold for the amount of gas can be determined with the aid of the difference between the current value of the changing pressure of the scavenging air currently available and the required charging pressure of the scavenging air. The required charging pressure for the actual operating parameters is, for example, stored in lookup tables or lookup matrices.

The control apparatus then comprises an upper threshold dependent on the charging pressure and possible also on the transient dwell angle for the amount of gas that can be supplied as fuel gas to the cylinder and limits the amount of gas to this upper threshold. So that now the speed of rotation or the torque generated by the engine can be maintained at the desired value, an additional amount of liquid fuel is further specified by means of the control apparatus in step 14' that is dimensioned in such a way that it compensates the difference between the desired value for the speed of rotation or the torque and the value to be achieved with the maximum amount of gas.

This means that the control apparatus determines that value for the torque or the speed of rotation that can be achieved with the maximum amount of gas determined by the upper threshold. Then the difference between the desired value and this value is determined. Subsequently the amount of liquid fuel is determined that is required in order to compensate this difference.

The measures of the determination of the upper threshold for the amount of gas, of the additional amount of the liquid fuel and of the transient dwell angle are naturally not independent of one another, but it does not represent a larger problem to tune these measures with respect to one another in such a way that an as ideal as possible operation of the large diesel engine is ensured in the transient mode.

It is naturally also possible to fix the additional amount of the liquid fuel to a fixed rated value.

Now the outlet valve 24 is closed at the transient dwell angle in the step 15 and the determined amount of gas is introduced into the cylinder in the step 15a and is caused to combust there like in the gas mode. At the same time, this means in the same work cycle, the previously determined amount of the liquid fuel is introduced into the cylinder in step 15b and ignites there on its own. By means of the common combustion of the gas and of the additionally introduced liquid fuel, the desired value for the speed of rotation or for the torque can in this way be generated. The self-ignition of the liquid fuel can in this connection be used for the external ignition of the air to gas mixture.

In the step 17 a continuous check is made or a check is made at regular intervals by means of observations of the operating personnel and/or by means of the determination of the operating parameters, whether the conditions for the activation of the transient mode are still satisfied. If yes, then the transient mode is maintained, as this is indicated by the arrow 18 in Fig. 4, wherein preferably the values for the upper threshold of the amount of gas, for the transient dwell angle and for the additional amount of liquid fuel is checked and/or updated.

If the conditions for the transient mode are no longer satisfied on the check in step 17 then a change can be made again in step 19 back into the normal gas mode.

The control apparatus for initiating and carrying out the transient mode is preferably integrated into the engine control.

In this way it is ensured that the desired value for the engine speed, this means the speed of rotation, or the desired value for the torque can be maintained in the transient mode by means of a combination of the combustion of gas with a combustion of liquid fuel and an adaptation of the dwell angle of the outlet valve 24 without the combustion of the gas taking place in the range of fast combustion and/or in the range of knocking. It is ensured by the upper threshold for the amount of gas that the air to gas mixture does not become too rich in the combustion space. Furthermore, it is avoided, in particular by the change of the dwell angle to the transient dwell angle that the misfiring limit 4 (Fig. 2) is exceeded. In this way the large diesel engine 20 is also operated in the transient mode within the tolerance range 6 (Fig. 2).

Thus, by means of this method for example, a dual fuel large diesel engine, that works according to the Otto principle in the gas mode of operation, can achieve a response to the change of load that is at least approximately like that of a large diesel engine only working in accordance with the diesel principle that is exclusively operated with liquid fuel. As, on the one hand, it is ensured that, with regard to the method in accordance with the invention and/or with regard to the large diesel engine in accordance with the invention, the air to gas mixture does not become too rich as well as not too lean and, on the other hand, the combustion part associated with the liquid fuel reacts significantly less sensitive to a too low a charging pressure of the scavenging air. In this way, in particular in heavy sea also during the gas mode of operation the running stability of the large diesel engine can be improved and the fluctuations in speed can be reduced.

The schematic illustration in Fig. 5 emphasizes the cooperation of the gas combustion and the combustion of the liquid fuel in the transient mode again by means of an example. The torque T of the large diesel engine is applied in dependence on the time t, as it can occur having regard to heavy sea. The high wave movements to which the ship is then subjected, cause an – approximately - periodic change in time of the torque T. The curve G shows the portion of the torque that is caused by the combustion of the gas, wherein the maximum amount of gas is limited in such a way that the scavenging air made available is sufficient on consideration of the transient dwell angle in such a way that the air to gas mixture does not become too rich. The two curves having the reference numeral F, which limit the region illustrated by means of hatching show the additional amount with respect to the torque T that is generated by the addition of combustion of the liquid fuel.

For the avoidance of too lean a mixture in the cylinder the determination of the transient dwell angle is in particular suitable. As a late closure of the outlet valve 24 in comparison to that in the gas mode, which in this example corresponds to a positive correction value and in this way to a transient dwell angle that is larger than the dwell angle in the gas mode of operation, too much of the air present in the cylinder 21 can be pushed out via the outlet valve 24 before this is closed.

For the introduction of the additional amount of liquid fuel into the combustion space of the cylinders during the transient mode, different possibilities exist. In the event that the large diesel engine is configured as a dual fuel engine, the same injection apparatus can be used for the injection of the liquid fuel that is also used for the injection of the fuel in the liquid mode.

A further possibility for the introduction of the liquid fuel in the transient mode consists therein that the liquid fuel can be introduced into the combustion space by means of a pilot injection apparatus which is used in the gas mode for the ignition of the air to gas mixture.

Naturally it is also possible that a separate injection apparatus is provided for the introduction of the liquid fuel during the transient mode. This is in particular preferred when the large diesel engine is not configured for the liquid mode and has no corresponding injection apparatus.

Having regard to the introduction of the gas into the combustion space of the cylinder, both during the transient mode and also during the gas mode, several preferred variants exist. As was already mentioned in the foregoing, a gas supply system can be provided having at least one gas inlet nozzle which is arranged in the cylinder liner in such a way that the gas can be introduced into the cylinder and can mix there with the scavenging air to an ignitable air to gas mixture.

However, it is also possible to provide one or more gas inlet nozzles at the cylinder head and/or at the cylinder cover in such a way that the supply of the gas into the cylinder takes place from the cylinder head and the gas then mixes with the scavenging air.

A further possibility exists therein to supply the gas to the scavenging air before the scavenging air is introduced into the cylinder. The gas then already mixes with the scavenging air outside of the cylinder inner space to an air to gas mixture that is then introduced into the cylinder, for example, through the scavenging air slits or scavenging air openings. Hereby the gas supply to the scavenging air can take place at a point between the outlet of the turbocharger system and the inlet openings into the inner space of the cylinder, for example, the scavenging air slits.

In particular, it is also possible to supply the gas to the scavenging air then when the scavenging air is introduced into the cylinder. For this purpose, it is then, for example, possible to respectively provide one or more gas inlet nozzles at one or more webs that separate the adjacent scavenging air slits in such a way that the scavenging air mixes with the gas on its passage through the scavenging air slits.

The operating parameters which are determined in the step 12 (Fig. 3 and Fig. 4) or are analyzed in order to judge in step 13, whether a change should be made into the transient mode, are preferably such parameters that are already present in an engine control, this means are in any way detected for the operation, or during the operation, of the large diesel engine or values that can be derived from such parameters. However, it is also possible that only one operating parameter is drawn on for the decision to change into the transient mode alternatively the decision to change into the transient mode takes place purely due to the observations by the operating personal which then can also manually initiate the transient mode.

For example, one or more of the following parameters are suitable as operating parameters for the step 12 and/or the decision in the step 13: The actual pressure of the scavenging air that is made available by the turbocharger system and/or the change of this pressure, the cylinder pressure, the calculated air to gas ratio, signals of a knocking detector by means of which it can be recognized when the combustion in the cylinder takes place in a knocking manner, this means that the air to gas mixture is too rich, the ratio of torque to load of the engine or changes in this ratio or the measured torque or its changes in time, or the amount of the fuel for the injection that is required in order to maintain the speed of rotation of the engine (injected amount) or changes of this injected amount.

The method in accordance with the invention can in particular also be used for the purpose of retrofitting already existing large diesel engines, in particular dual fuel engines. As in such large diesel engines the prerequisites from an apparatus point of view for carrying out a method in accordance with the invention are frequently already satisfied or can be realized with a low demand in effort and cost and/or by means of conversion, it is frequently possible to make the large diesel engine ready for the transient mode by a corresponding adaptation or supplementation in the engine control. This possibility of the retrofitting is of large advantage in particular also having regard to the maintenance of the emission values.

Also when in this connection the measures of the determination of an upper threshold for the amount of gas that is made available per work cycle as fuel and the determination of an additional amount of the liquid fuel that is introduced in addition to the gas into the combustion space is only described in combination with the determination of the transient dwell angle for the transient mode these measures can also be carried out on their own, this means without changes of the dwell angle for the outlet valve. This means that the second embodiment can also be modified in such a way that the dwell angle is not changed in comparison to the gas mode of operation.

PATENTKRAV

1. Fremgangsmåde til drift af en stor dieselmotor, der er udformet som dual-fuel-motor til forbrænding af en gas og til forbrænding af et flydende brændstof, især diesel eller tungolie, og som kan drives i det mindste i en gasmodus, hvori gassen ledes ind i en cylinder (21) som brændstof og udledes gennem en udstødningsventil (24) efter forbrændingen, hvor den store motor under driften i gasmodussen (10) drives afhængigt af detekterede lastvekslinger i en transient modus, som omfatter de følgende trin:

- fastsættelse af en lukkevinkel for lukningen af udstødningsventilen i gasmodussen,

- bestemmelse af en korrekturværdi for lukkevinklen (14),

- bestemmelse af en transient lukkevinkel (14) ved at lægge korrekturværdien til lukkevinklen,

- lukning af udstødningsventilen ved den transiente lukkevinkel (15),

kendetegnet ved, at den transiente modus omfatter de følgende trin:

- fastlæggelse af en ønsket værdi for motorens omdrejningstal eller drejningsmoment

- bestemmelse af en øvre grænse for mængden af gas (14), der stilles til rådighed som brændstof pr. arbejdscyklus for den store dieselmotor,

- bestemmelse af en yderligere mængde af det flydende brændstof (14), der foruden gassen ledes ind i forbrændingskammeret, hvor den yderligere mængde er dimensioneret således, at den ønskede værdi for omdrejningstallet eller drejningsmomentet realiseres.

2. Fremgangsmåde ifølge krav 1, hvor korrekturværdien er negativ, og dens mængde udgør højst 60 grader.

3. Fremgangsmåde ifølge krav 1, hvor korrekturværdien er positiv og udgør højst 60 grader.

4. Fremgangsmåde ifølge et af de foregående krav, hvor det til enhver tid aktuelle til rådighed stående tryk i skylleluften anvendes til bestemmelse af den øvre grænse for mængden af gas (14) eller korrekturværdien (14).

5. Fremgangsmåde ifølge et af de foregående krav, hvor den transiente modus initieres manuelt.

6. Fremgangsmåde ifølge et af de foregående krav, hvor den transiente modus initieres afhængigt af mindst et af de følgende parametre: aktuelt tryk i skylleluften, cylindertryk, beregnet forhold mellem luft og gas, signal fra en bankedetektor, forholdet mellem omdrejningstal og belastning af motoren, ændring i forholdet mellem omdrejningstal og belastning af motoren, motorens drejningsmoment, ændring af drejningsmomentet, mængden af det brændstof, der kræves til indsprøjtning, ændring af mængden af det brændstof, der kræves til indsprøjtning.

7. Fremgangsmåde ifølge et af de foregående krav, hvor tilførslen af gassen til cylinderen (21) foregår gennem en cylinderliner.

8. Fremgangsmåde ifølge et af de foregående krav, hvor gassen tilføres skylleluften, inden skylleluften ledes ind i cylinderen (21), eller når skylleluften ledes ind i cylinderen (21).

9. Stor dieselmotor, der er udformet som dual-fuel-motor til forbrænding af en gas og til forbrænding af et flydende brændstof, især diesel eller tungolie, som kan drives i det mindste i en gasmodus (10), og som drives i overensstemmelse med en fremgangsmåde ifølge et af de foregående krav.

10. Stor dieselmotor ifølge krav 9, hvor der er tilvejebragt en motorstyring, som omfatter en kontrolindretning (14) til at initiere og gennemføre den transiente modus.

11. Anvendelse af en fremgangsmåde ifølge et af kravene 1-8 til efterfølgende tilpasning af en stor dieselmotor, især en dual-fuel-motor.

Fig.1

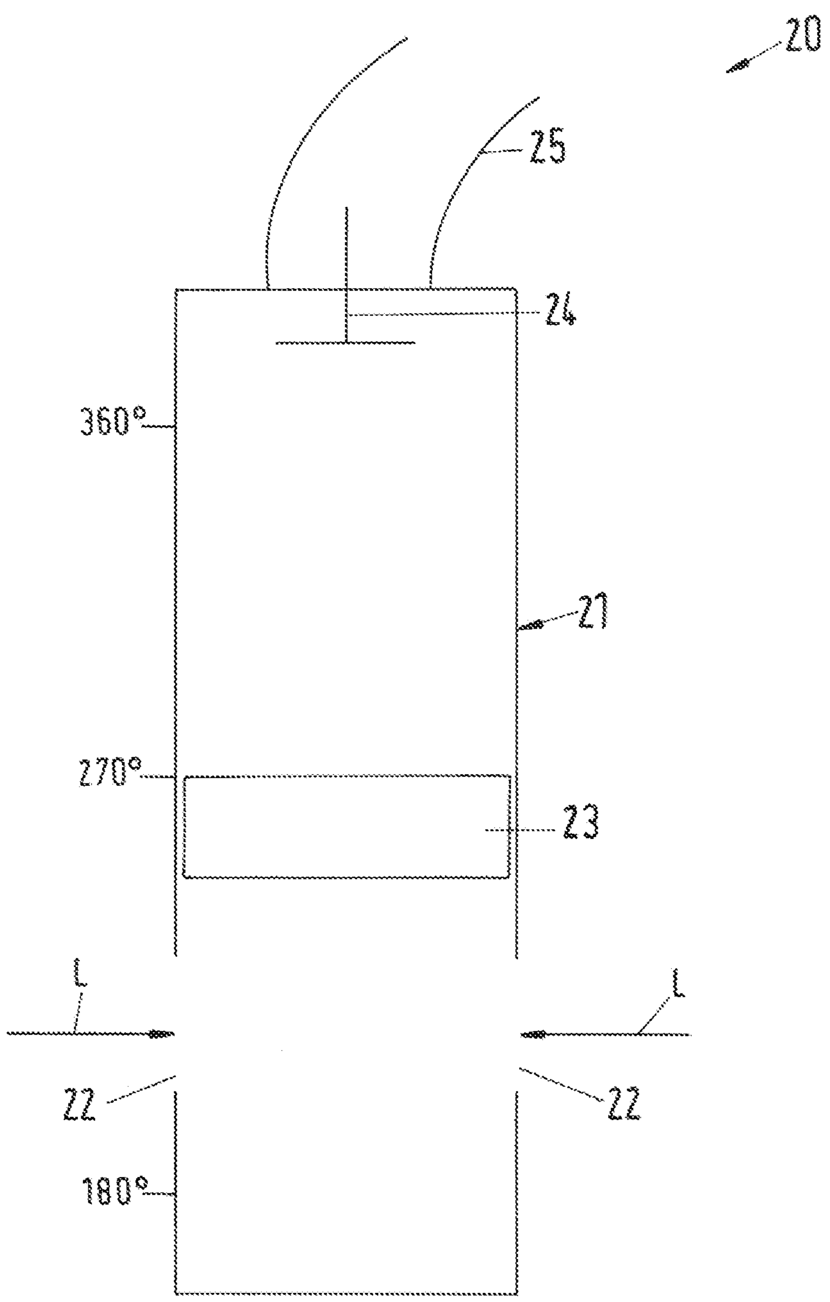


Fig.2

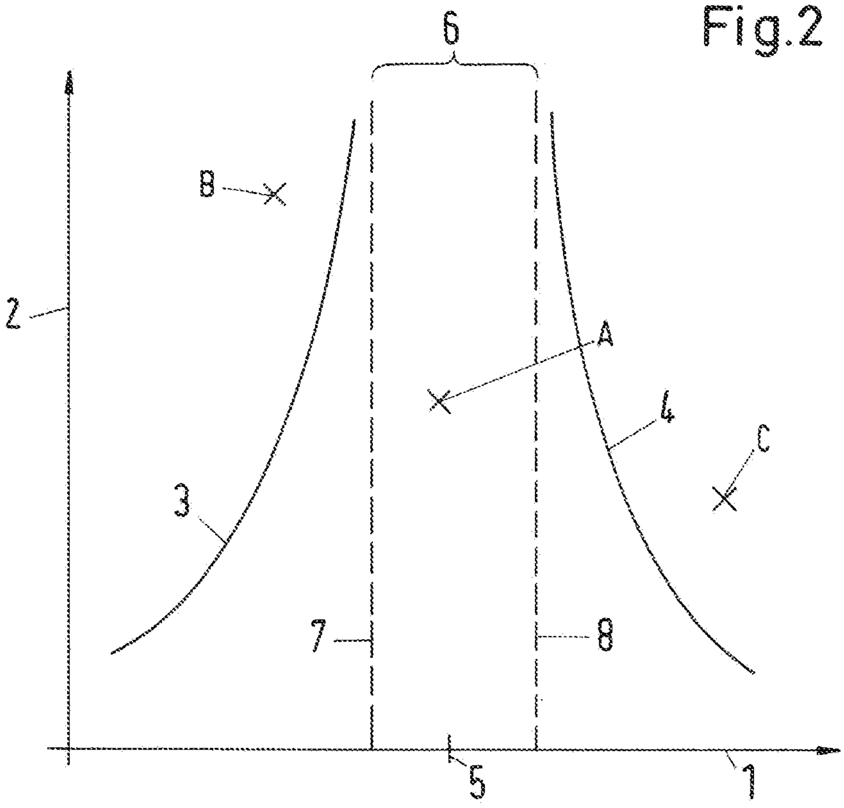


Fig.5

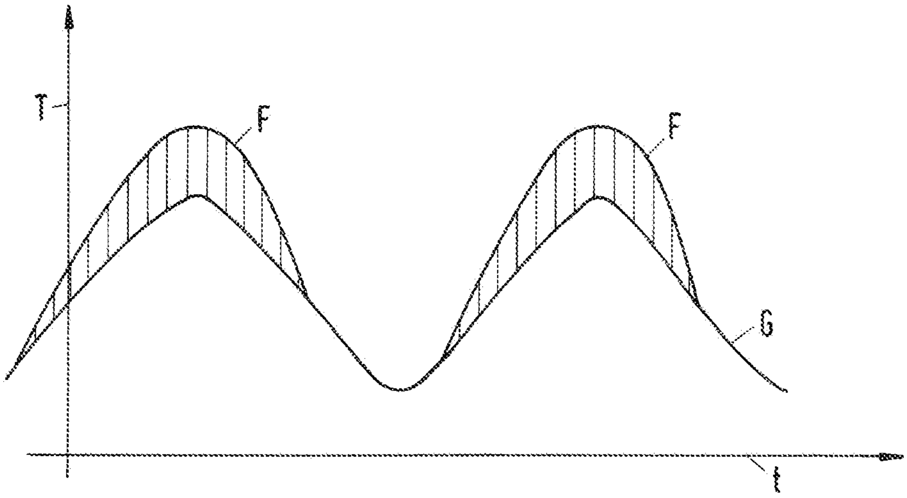


Fig.3

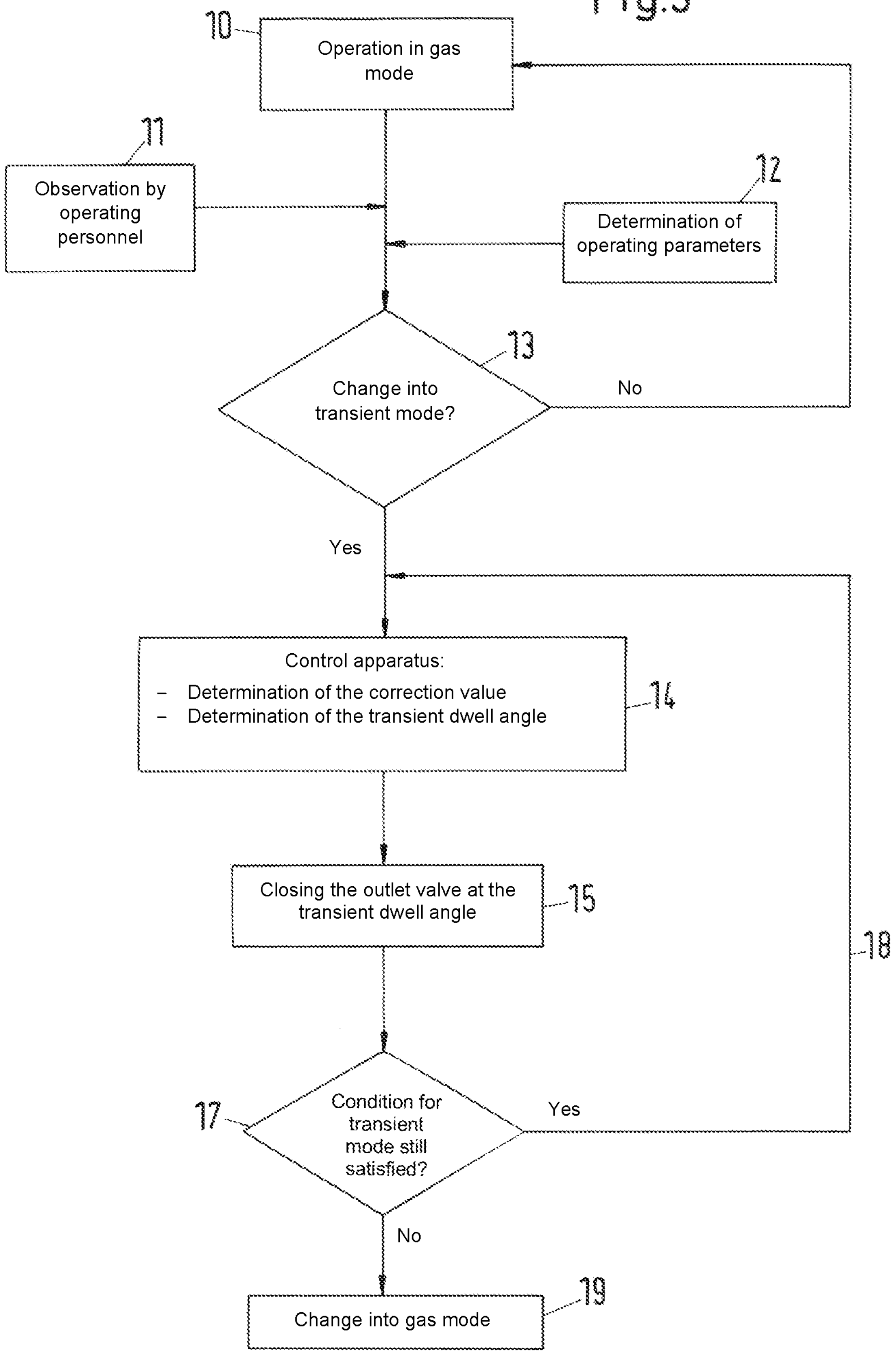
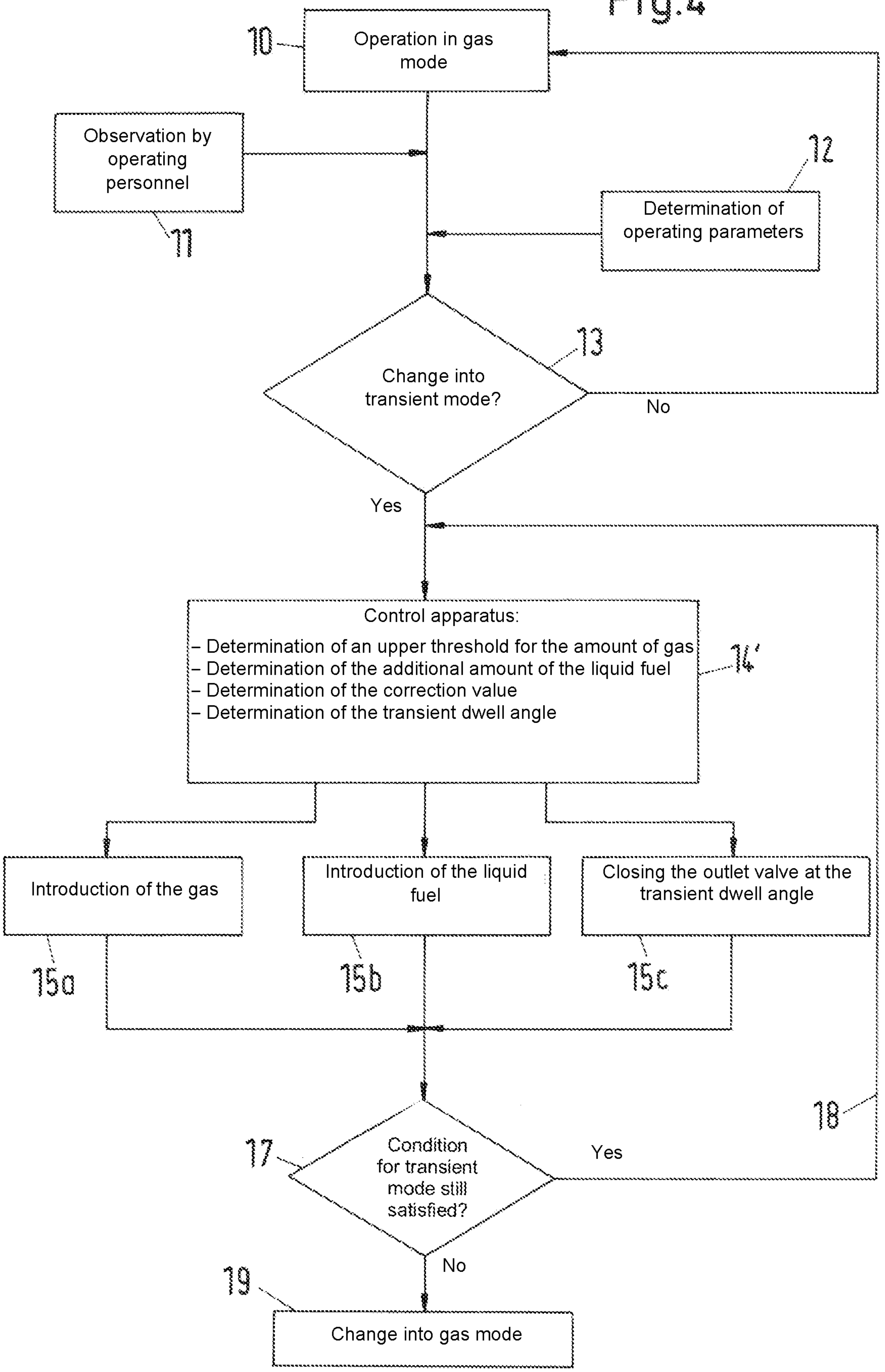

10
Operation in gas mode
11
Observation by operating personnel
12
Determination of operating parameters
13
Change into transient mode?
No
Yes
Control apparatus:
– Determination of the correction value
– Determination of the transient dwell angle
14
Closing the outlet valve at the transient dwell angle
15
18
17
Condition for transient mode still satisfied?
Yes
No
Change into gas mode
19

Fig.4


Operation in gas mode
10
Observation by operating personnel
11
Determination of operating parameters
12
Change into transient mode?
13
No
Yes
Control apparatus:
– Determination of an upper threshold for the amount of gas
– Determination of the additional amount of the liquid fuel
– Determination of the correction value
– Determination of the transient dwell angle
14'
Introduction of the gas
15a
Introduction of the liquid fuel
15b
Closing the outlet valve at the transient dwell angle
15c
18
Condition for transient mode still satisfied?
17
Yes
No
19
Change into gas mode