

Lubricant injector for large slow-running two-stroke engine and production method

FIELD OF THE INVENTION

5 The present invention relates to an injector for injection of lubrication oil into the cylinder of a large slow-running two-stroke engine, for example marine diesel engine or gas or diesel engine in a power plant. It also relates to a method of production and to such an engine.

BACKGROUND OF THE INVENTION

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For lubricating of large slow-running two-stroke marine diesel engines, several different systems exist, including injection of lubrication oil directly onto the cylinder liner and/or the piston surface. An alternative method, commercially called Swirl Injection Principle (SIP), is based on injection of an atomized spray of lubricant into the scavenging air swirl inside the cylinder. The swirl results in the lubricant being pressed outwards against the cylinder wall as a thin and even layer. In all cases, the timing of the lubricant injection is crucial. The lubrication oil injection valves, also called lubrication oil injectors, are non-return valves that comprise an injector housing inside which a reciprocating valve member is provided, typically a valve needle. The valve member, for example with a needle tip, closes and opens access to a nozzle aperture according to a precise timing. In such large marine engines, a number of injectors are arranged in a circle around the cylinder in a plane perpendicular to a cylinder axis and each injector comprises one or more nozzle apertures at the tip for delivering lubricant jets or sprays into the cylinder from each injector. Examples of lubricant injectors in marine engines are disclosed in international patent applications WO02/35068, WO2004/038189, WO2005/124112, WO2012/126480, WO2012/126473, and WO2014/048438.

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A general principle for fuel injectors having a valve body inside which a needle is reciprocating for ejection of fuel is known from car engines. For longevity, it is known to apply hardened surface to various parts of such fuel valves, for example as

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disclosed in the patent documents DE10013198, DE102005020143, EP1940577, EP2138705, US2011/133002, US2014/203109, US2015/083829. Although hardened surfaces are known for such injectors in general, no distinct rule for which component to harden appears as dominant.

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However, as compared to fuel injectors, the conditions and, thus, requirements and operational parameters are different for lubrication oil injectors. Especially, the lubrication oil viscosity is higher than the viscosity of diesel or gasoline fuel. Injecting viscous lubrication oil at pressure in the range of 25-100 bars with high precision in timing sets some crucial demands on the performance of the injectors and involves problems different from fuel injectors. Due to these different conditions and requirements, the developments of lubrication oil injectors for large slow-running two-stroke marine diesel engines have followed separate routes than fuel injectors for car and motorcycle engines, such that the two technical fields are regarded as separate by experts in the respective fields.

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One of the specific challenges that providers of lubrication oil injectors face, in contrast to providers of fuel injectors, is increased wear due to particles in the oil. This is a well-known problem, and efforts are made by oil cleaning, for example by centrifugal oil cleaners. However, efforts are also made with respect to improving the injectors themselves. In this regard, it is known to apply hardened surfaces to the needles in lubrication oil injectors. The needle is reciprocating in a liner of the valve body, and whereas the needle is hardened, the valve body is not. The theory behind the advantage of using dissimilar material hardness between needle and liner for lubrication oil injectors, especially SIP injectors, is described in the Handbook by Nam P. Suh "Complexity: Theory and Applications, Oxford University Press 2005. In the chapter "7.2 Review of Friction and Wear Mechanism", the so called "plowing mechanism" by particles entrapped in the sliding contact region is studied, and the case where particles are pressed into the softer material between two surfaces of different hardness is compared to the case where both surfaces have equal hardness. The conclusion is that

"Therefore, when two identical materials are sliding against each other, the coefficient of friction is higher than when dissimilar materials slide against each other,

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because while the particles penetrate both surfaces, the depth of penetration is the greatest when the hardness is the same.”

Due to the focus on environmental protection, efforts are ongoing with respect reduction of emissions from marine engines. This also involves the steady optimization of lubrication systems for such engines. Thereto adds increased competition and the economic aspects of reducing oil consumption, as this is a significant part of the operational costs of ships. Thus, there is a need for steady improvements with respect to precision and lifetime of lubrication oil injectors, including SIP injectors.

Hardened surfaces are in general disclosed for lubrication oil injection valves that are used for piston cooling, for example as disclosed in US2005/252997 and US2015/068471. In these cases, the valves are connected to the nozzle aperture via a tube, and the oil is ejected from the nozzle aperture as a jet against the piston surface on the crankshaft-side of the piston, which opposite to the fuel burning side of the piston. This is a very different principle than the use of the above-mentioned SIP valves, and the general mentioning of hardened valves does not point towards any specific considerations for how to improve SIP injectors where a needle slides in a valve liner and closes the nozzle aperture.

DESCRIPTION / SUMMARY OF THE INVENTION

It is therefore the objective of the invention to provide an improvement in the art. In particular, it is an objective to provide improved lubrication oil injectors for large slow-running two-stroke engines. It is a further objective to improve SIP injectors. The improvement is particularly directed towards precision for injection and uniformity in performance for a plurality of injectors. Furthermore, an objective is improved longevity. Such objectives are achieved with lubrication oil injectors as described in the following.

Especially, as will be explained in greater detail in the following, it was found that injectors proved better uniform performance when using hardened surfaces for the plain bearing in which a valve member slides. Also, hardened surfaces for valve seats at the nozzle were an improvement.

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Although, with the currently existing injectors, sufficient and apparently proper lubrication was provided inside the cylinder liner, a more extended investigation showed some variation in performance among otherwise identical lubrication oil injectors that have been running for a while as a group in a single cylinder. Some of the group of injectors changed performance after a relatively short period of operation, whereas others had a longer life span. Some injectors got stuck, whereas others seem to work properly for long periods. Whereas, ordinary wear due to particles in the oil is expected and very well known, the discovered variations in performance could not solely be attributed to ordinary wear.

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For this reason, various tests were conducted and the experiments performed in relation to changed production techniques in order to solve this problem. It turned out that the problems could be overcome by changing the production such that the surfaces of valve member and plain bearing, which are slidably abutting each other, both were hardened to yield the same surface hardness or only differed by a minor degree in hardness. This is against the belief in the field that it should be best if valve needle stem and plain bearings have substantially different hardness along their contact region. Although, it has not been proven that the hitherto used tribological theory is incorrect, it turned nevertheless out that the use of two abutting hardened surfaces that slide against each other did lead to a remarkable improvement. Whereas the generally increased lifetime can be attributed to reduced wear, the elimination of the large performance variations of identically produced injectors cannot. The precise reason for the improvement in the performance is not known, but it is believed that the hardening of both surfaces, instead of only one surface, leads to improved parametric uniformity among the products with improved dimensional tolerances or leads to improved maintenance of the dimensional tolerances. The belief stems from the fact that a very uniform performance was observed and proper functioning over an increased lifetime.

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The injectors for injection of lubrication oil into the cylinder of a large slow-running two-stroke engine, with improved properties are explained in the following. Typically, such engine comprises a controller functionally connected to a lubrication oil pump which is fluid-flow connected to the injectors by lubrication supply lines for providing
5 lubrication oil at a predetermined oil pressure level, which is at a level within the interval of 25-100 bars.

Typical uses of the injectors are for marine engines. However, the injectors are also useful for large engines used in power plants. For example, these engines are burning
10 diesel or gas fuel.

The injector comprises an injector housing configured for being mounted in a cylinder wall of the engine cylinder. The injector housing comprises a nozzle tip at one end of the injector housing that reaches into the cylinder when the injector housing is mounted in the cylinder wall. For example, the nozzle tip is an integral part of the injector
15 housing, but this is not always the case. A nozzle is provided in the nozzle tip. The nozzle extends from an inner cavity inside the injector housing and through a wall of the nozzle tip, such that lubrication oil in the inner cavity is pressed under high pressure, typically between 25 and 100 bars, out of the injector housing through the nozzle
20 for providing a spray. A valve member is mounted inside the injector housing for reciprocal sliding along its longitudinal axis between an open and closed state of the injector. The valve member is sealingly covering the nozzle when in the closed state for preventing access of lubrication oil to the nozzle, and the valve member is movable away from the nozzle during an open state for giving access of the lubrication oil
25 from the inner cavity to the nozzle during an oil ejection phase.

In one embodiment, the injector housing comprises a plain bearing with a first surface, and the valve member comprises a stem with a second surface, the second surface being provided slidably abutting the first surface in order for the stem being reciprocally guided by the plain bearing along a contact region between the stem and the
30 plain bearing. The valve member comprises a valve needle in coaxial longitudinal extension of the stem. The valve needle comprises a needle tip that is closing the nozzle when abutting a cooperating valve seat in the nozzle tip. For example, the princi-

ple of the injector is as disclosed in WO02/35068, WO2004/038189 or WO2005/124212 for a single nozzle aperture or as disclosed in WO2012/126480 for multiple nozzle apertures. Alternatively, the injector is similar to the one disclosed in WO2012/126473. Other examples are disclosed in the prior art.

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A general improvement has been achieved by a high hardness of not only the surface of the stem but also by providing the plain bearing with a high hardness. For this reason, it is advantageous to surface-harden both the first and the second surface. Alternatively, the stem is provided in a very hard material from the onset, for example ce-
10 ramics, and the surface of the bearing, which is the first surface, is surface-hardened in order to provide hard surfaces that are abutting each other along a contact region, where the stem is sliding in the plain bearing.

Optionally, or alternatively, the valve seat comprises a hardened surface. In this case,
15 the needle tip is has a hard surface, either due to surface-hardening or by the valve needle being provided as a hard material, for example ceramics. Correspondingly, also the valve seat is surface-hardened, especially if it is part of the injector housing. Both the needle tip and the valve seat are correspondingly hard. For example, the valve needle comprises a conical part at the end of an otherwise cylindrical valve needle,
20 although the end part may be tapering differently than conical as an alternative. As a further alternative, the needle tip comprises a ball that forms the front most part and which cooperates sealingly with the valve seat. A useful hardness for the valve seat in terms of Rockwell Hardness C (HRC) is at least of 50, for example at least 55 or at least 60.

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In another embodiment, the injector housing comprises a cylindrical cavity part with a cylindrical first surface inside the nozzle tip. The cylindrical cavity extends parallel with the reciprocal movement of the valve member. The nozzle extends from the first surface through the wall of the nozzle tip. The valve member comprises a cylindrical
30 sealing head with a cylindrical second surface which is arranged slidably abutting the first surface in order for the sealing head to sealingly cover the nozzle when the injector is in a closed state. For example, the principle of the injector is as disclosed in WO2014/048438.

A general improvement has been achieved by a high hardness of the cylindrical sealing head as well as a high hardness of the cavity wall along the contact region between the surface of the cavity wall, which is the first surface, and the surface of the cylindrical sealing head, which is the second surface. For this reason, it is advantageous to surface-harden both the first and the second surface. Alternatively, the cylindrical sealing head of the valve member is provided in a very hard material from the onset, for example ceramics, and the surface of the cavity wall is surface-hardened in order to provide hard surfaces that are abutting each other along the contact region, where the cylindrical sealing head is sliding in the cylindrical cavity.

Use of surface-hardening of such surfaces improves uniform long term performance among a plurality of identical lubrication oil injectors for a large slow-running two-stroke engine, especially marine engines or engines in power plants, for example burning diesel or gas. Hardening is performed during production of the injectors for the first surface and the second surface or for the valve seat or for the first and second surface as well as the valve seat. Optionally, also the needle tip is hardened or provided in a hard material that corresponds to the hardness of hardened material.

A useful material that is surface-hardened for the purpose herein is carbon steel or low alloy steel. A useful is steel of the type ETG® 88. Such steel comprises 0.42-0.48% carbon, 0.10-0.30% silicon, 1.35-1.65% Manganese, less than 0.04% phosphorous and 0.24-0.33% sulphur. Although the steel name is a trademark, the steel has a content of chemical elements and has physical properties that remain unchanged according to readily available data sheets.

For example, the hardening method comprises hardening the steel surfaces by carbonitriding, optionally, austenitic carbonitriding, which is generally known in the art as a steel hardening method. An example of a suitable temperature is around 850 °C. It is performed in a gas atmosphere containing carbon and nitrogen and minor amounts of oxygen. An example is an atmosphere to which were added between 0.5 and 0.8 % carbon and between 0.2 and 0.4 % nitrogen. Optionally, after the diffusion, the components are immediately submerged into oil. A further option is subsequent tempering at a temperature of 150-200 °C.

An alternative surface hardening process is gas nitriding, which is generally known in the art as a steel hardening method. It is typically performed around 520°C. A further alternative is nitrocarburizing, which is similar to gas nitriding but where carbon gas is added. The layer thickness of the hardened surface is influenced by the gas composition during the process. A further process in the prior art is gaseous ferritic nitrocarburizing, which is also known under the trade name Corr-I-Dur® and various other trade names.

The hardness of the ETG 88 steel expressed in terms of Rockwell Hardness C (HRC) is 28. This is typical for materials used for the housing of such type of injectors. In prior art injectors of the general type as described herein, needle valves were used that were hardened to HRC of 62. This is a substantial hardness difference of more than a factor of 2 between the values. After hardening of the housing to a value of HRC 58, the difference in hardness of the housing as compared to the needle valve is $(62-58)/62=6\%$. This yielded good experimental results. It is believed, however, that the experimental results are equally valid if the surface hardness of the component with the lowest hardness is less than 40% smaller, for example less than 30% or 20% smaller or, even better, less than 10% smaller. A useful hardness for the hardest of the first or the second surface is at least HRC of 50, for example at least 55 or at least 60.

The term hardened surface means that the surface has a higher hardness than the underlying bulk material. Such hardened surfaces are provided for higher degree of product uniformity and better dimensional tolerances. In addition, the tolerances have a better longevity until dimensional changes occur to a substantial degree. A further advantage is reduced wear, possibly due to the better dimensional tolerance. It also influences the longevity.

SHORT DESCRIPTION OF THE DRAWINGS

The invention will be explained in more detail with reference to the drawing, where FIG. 1 illustrates a cylinder lubrication system in a large slow-running two-stroke engine, for example marine diesel engine; FIG. 2 a), b), and c) illustrate three types of lubrication oil injectors;

FIG. 3 shows pressure measurements for injectors with a) a hardened stem and b) a hardened stem and hardened plain bearing;

FIG. 4 a and b show tables from pressure measurements of injectors in a marine diesel engine from a) a first and b) a second cylinder of the engine.

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DETAILED DESCRIPTION / PREFERRED EMBODIMENT

FIG. 1 illustrates one half of a cylinder of a large slow-running two-stroke engine, for example marine diesel engine. The cylinder comprises a cylinder liner 2 on the inner side of the cylinder wall 3. Inside the cylinder wall 3, there are provided a plurality of lubrication oil injectors 4 distributed along a circle with the same angular distance between adjacent injectors. The injectors 4 receive lubrication oil from a lubricator pump and controller system 11 through lubrication supply lines 9. Some of the lubrication is returned to the pump by lubrication return lines 10. The lubricator pump and controller system 11 supplies pressurised lubrication oil to the injectors 4 in precisely timed pulses, synchronised with the piston motion in the cylinder 1 of the engine. For the synchronisation, the lubricator pump and controller system 11 comprises a computer that monitors parameters for the actual state and motion of the engine, including speed, load, and position of the crankshaft, as the latter reveals the position of the pistons in the cylinders.

Each of the injectors 4 has a nozzle 5 from which a spray of small droplets 7 is ejected under high pressure into the cylinder. The swirl 9 of the scavenging air in the cylinder 1 presses the spray 8 against the cylinder liner 2 such that an even distribution of lubrication oil on the cylinder liner 2 is achieved. This lubrication system is known in the field as Swirl Injection Principle, SIP, although also other principles are envisaged in connection with the improved injectors, for example injectors that have jets directed towards the cylinder liner. Optionally, the cylinder liner is provided with free cuts 6 for providing adequate space for the spray or jet from the injector.

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FIG. 2a illustrates a first type 4a of lubrication oil injector. The generalised principle of the injector is similar to the ones disclosed in WO02/35068, WO2004/038189 or WO2005/124212 for a single nozzle aperture or as disclosed in WO2012/126480 for

multiple nozzle apertures. These references also provide additional technical details as well as explanations to the functioning of the injectors presented here, which are not repeated here, for convenience.

5 The injector 4a comprises an injector housing 12 having a nozzle tip 13 which is integral with the injector housing 12 at one end. A nozzle 14 with a nozzle aperture 14' is provided in the nozzle tip 13 for ejection of lubrication oil. The nozzle 14 also comprises a duct 20 that extends from the nozzle aperture 14' through the wall 21 of the nozzle tip 13 into a cylindrical inner cavity 15 of the injector housing 12. A valve member 16 is provided inside the injector housing 12. The valve member 16 comprises a stem 17 that is slidingly guided for reciprocation inside a plain bearing 23, which in the shown embodiment is as a separate stationary part inside the injector housing, although it could also be part of the injector housing 12, itself. As a coaxial longitudinal extension of the stem 17, a valve needle 18 is provided in the inner cavity 15 of the injector housing 12. The valve needle 18 has a diameter that is smaller than the diameter of the inner cavity 15 such that lubrication can flow along the valve needle 18 and to the duct 20 and out of the nozzle aperture 14' when a needle tip 22, for example a conical end part, at the end of the valve needle 18 is retracted from a valve seat 19 at a second end of the duct 14 such that the duct 20 is open for flow of lubricant to the nozzle aperture 14' from where it is ejected. The position of the valve member 16 and the valve needle 18 is pre-stressed forwards towards the nozzle tip 13 by moderate spring pressure acting on the opposite end of the valve member; and the valve member 16 with the valve needle 18 is offset backwards away from the seat 19 by increase of oil pressure in the cavity 15. This is explained in greater detail in the prior art references cited herein.

Along the contact region 24 between the plain bearing 23 and the stem 17 of the valve member 16, hardened surfaces are provided on the stem 17 and on the plain bearing 23 such that two hardened surfaces are sliding along each other at the contact region 24. Alternatively, or optionally in addition, the valve seat 19 comprises a hardened surface at the contact region between the valve seat 19 and the needle tip 22 of the valve needle 18. As a further option, also the needle tip 22 comprises a hardened surface.

FIG. 2b illustrates a second type 4b of lubrication oil injector. The generalised principle of the injector is similar to the one disclosed in WO2014/048438. This reference also provides additional technical details as well as explanations to the functioning of the injector presented here, which are not repeated here, for convenience.

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The injector 4b comprises an injector housing 12 having a nozzle tip 13 which is integral with the injector housing 12 at one end thereof. A nozzle aperture 14' is provided in the nozzle tip 13 for ejection of lubrication oil. Inside a cavity 15 of the injector housing 12, a valve member 16 is provided, the valve member 16 comprising a stem 10 17 and a cylindrical sealing head 25 which is arranged slidingly in a cylindrical cavity part 15' at the nozzle tip 13 of the injector housing 12. The position of the valve member 16 is pre-stressed backwards away from the nozzle tip 13 by a spring 26 and is offset forwards by oil pressure acting through a channel 28 upon the back part 27 of the stem, the oil pressure acting against the spring 26 force. The nozzle aperture 14' is 15 sealingly covered by the sealing head 25 which abuts the cylindrical cavity part 15' at the nozzle tip 13, unless the valve member 16 is pushed forward such that the sealing head 25 slides pass and away from the nozzle aperture 14' to allow lubricant oil to flow from the inner cavity 15 through the nozzle aperture 14' for ejection.

20 At the contact region 29 between the cylindrical sealing head 25 which is abutting the cylindrical part 15' of the inner cavity 15, both the cylindrical part 15' of the inner cavity 15 and the sealing head 25 have a hardened surface.

FIG. 2c illustrates a third type 4c of lubrication oil injector. The generalised principle 25 of the injector is similar to the one disclosed in WO2012/126473. This reference also provides additional technical details as well as explanations to the functioning of the injectors presented here, which are not repeated here, for convenience.

The injector 4c comprises an injector housing 12 having a nozzle tip 13, at which a 30 nozzle 14 is provided with a duct 20 and a nozzle aperture 14' at a first end of the duct 20. The duct 20 extends from the nozzle aperture 14' through the wall 21 of the nozzle tip 13 into the inner cavity 15 of the injector housing 12. Inside the cavity 15 of the injector housing 12, a valve member 16 is provided, the valve member 16 comprising

a stem 17 that is slidingly guided for reciprocation inside a plain bearing 23, which in the embodiment is shown as a separate stationary part inside the injector housing, although it could also be part of the injector housing 12 itself. The position of the valve member 16 is pre-stressed forward towards the nozzle tip 13 by a spring 26. One possible retraction mechanism is disclosed in WO2012/126473 in which an electrical coil exerts an electromagnetic force on the valve member, which is equipped with a correspondingly electromagnetic responsive part. However, in principle, it is also possible by suitable construction that the valve member 16 is offset backwards by increased oil pressure in the cavity 15 acting on the valve member 16 against the spring 26 force.

As a coaxial longitudinal extension of the stem 17, the valve member 16 comprises a valve needle 18 to which there is fastened a sealing ball member 28 as part of a needle tip 22, which in closed valve conditions is pressed against the seat valve 19 for closure of the duct 20 and which in open valve conditions is offset from the seat 19 a distance to allow lubrication oil to pass from the inner cavity 15 pass the needle tip 22 with the ball 28 and into the duct 20 and out of the nozzle aperture 14'. By an O-ring 31, the inner cavity 15 is sealed backwards towards the remaining parts inside the injector housing 12.

The valve seat 19 comprises a hardened surface at the sealing contact region 30 between the valve seat 19 and the ball member 28 in order to prolong lifetime against wear from the repeated hits of the ball member 28. Alternatively, or in optionally in addition, a hardened surface is provided on the surface of the stem 17 and on the surface of the plain bearing 23 such that two hardened surfaces are sliding along each other at the contact region 24.

The term hardened surface means that the surface has a higher hardness than the underlying bulk material. Such hardened surfaces on both surfaces are provided for higher degree of product uniformity and better dimensional tolerances with good longevity. A further advantage is reduced wear, possibly due to the better dimensional tolerance. The abutting surfaces should have identical hardness, or at least a hardness that is the same within 40%, for example with a difference in hardness of less than 30% or 20%, or even as little as less than 10%.

Typical dimensions for the injector housings are 10-30 mm in diameter and 50-130 mm in length, although, the injector including the back end where the supply lines are connected can be somewhat longer. The valve member 16 has a typical length of 40-80 mm and a diameter of 5-7 mm at the stem and a smaller diameter for the valve
5 needle 18. The housing tip 13 has a typical diameter of 6-10 mm, depending on the overall size of the injector housing 12.

FIG. 3a and FIG. 3b illustrate measurements from pressure tests for lubrication oil injectors of the type 4a with a stem diameter of 6 mm and a displacement of 2 mm.
10 FIG. 3a is a graph for measurements taken from a lubrication oil injector of the type 4a, where only the surface of the stem 17 of the valve member 16 was hardened but not the surface of the plain bearing 23. FIG. 3b is a graph for measurements taken from an otherwise identical lubrication oil injector 4a which, however, has been provided with with a contact region 24 where both the surface of the stem 17 and the
15 surface of the plain bearing 23 were hardened. The experiments were conducted after operation of the injectors in a nine cylinder two-stroke marine diesel engine, where each cylinder has ten SIP spray injectors distributed along the circumference of the cylinder liner.

20 The abscissa shows the time with about 2 seconds between repeated measurements in FIG. 3a and about 2.7 seconds in FIG. 3b, the onset of a measurements indicated by a spike. The ordinate is the pressure in bars. In FIG. 3a, the pressure decreases about 10 bars from 63.5 bars onset of a measurement till 53.5 bars prior to the next measurement, and in FIG. 3b, the pressure varies less than 0.7 bar between 63 and 64 bars. It
25 is clearly apparent that a better performance of the injector was achieved if the stem as well as the plain bearing were hardened.

The surfaces were hardened by austenitic carbonitriding, which involves carbon and nitrogen in the surface of the hardened component. The carbonitriding was performed
30 at a temperature of about 850 °C in a gas atmosphere to which were added between 0.5 and 0.8 % carbon and 0.2-0.4 % (<5 %) nitrogen to the surface of carbon steel or low alloy steel. After the diffusion, the components were immediately submerged into oil. The typical hardening depth was not above 0.7 mm and did not solely depend on

the carbonitriding depth but also on the hardening temperature and the time until cooling. Subsequent tempering at a temperature of 150-200 °C can be used for larger hardening depth and reduced brittleness.

5 FIG. 4a shows a table with indications for injector performance. The left column shows dates for measurements and the heading above the columns shows the number of the ten injectors of a cylinder. The number in each entry of the table shows the number of hours of operation of the injector. A light grey indication corresponds to a minor pressure loss of 0-1 bars, for example as in FIG. 3b. The slightly darker grey
10 shade corresponds to a pressure loss of 1-5 bars which is acceptable. The dark grey indication shows a pressure loss of more than 5 bars, which affects the spray characteristics substantially. In FIG. 4a, it is observed that the performances for the injectors are very different even after identical hours of operation. The first injector (col. 1) changes performance after only 200 hours of operation, whereas others operated stable
15 up to 640 hours of operation.

In the lower part of the table, measurements are shown for injectors in which the housing was hardened. Thus, the contact region between the stem and the plain bearing had both surfaces hardened. Such injectors were inserted into cylinder No. 1 on
20 05.07.2014, and all ten injectors performed well up to 4280 hours. A slight leak was observed for injector No. 8, which was not critical, however.

Due to the hardening of the entire housing, also the seat for the valve needle was hardened and may potentially have influence on the overall result, which, however, is
25 believed to have less influence than the double-surface hardening of the contact region.

In FIG. 4b, measurements were performed in cylinder No. 2 of the same engine with injectors having only the stem hardened but not the plain bearing surface. For FIG. 4b,
30 there is also a black indication for stopped operation. It is seen that the substantial variations of performance among the injectors are similar to the patterns in FIG. 4a prior to exchange of the injectors to the improved ones.

As a conclusion, the performance was remarkably improved not only with respect to longevity but also particularly with respect to uniform performance for those injectors where both the surface of the steel stem as well as the surface of the steel plain bearing were hardened.

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The prior art citations mentioned above are incorporated herein by reference. The examples in the detailed description are provided for illustration and do not delimit the principles of the invention.

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Numbering

1 cylinder

2 cylinder liner

3 cylinder wall

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4 oil injector

4a first type of oil injector

4b second type of oil injector

4c third type of oil injector

5 nozzle

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6 free cut in liner

7 spray droplets

8 spray from a single injector

9 lubrication supply lines

10 lubrication return lines

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11 lubricator pump and controller system

12 injector housing

13 nozzle tip of injector housing 12

14 nozzle aperture

15 inner cavity of injector housing 12

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15' cylindrical part of the inner cavity 15

16 valve member with stem 17

16' sealing front part with integrated ball

17 stem of valve member 16

- 18 valve needle of valve member 16
 - 19 valve seat 19
 - 20 duct through nozzle tip 13 from inner cavity 15 to nozzle aperture 14'
 - 21 wall of nozzle tip 13
 - 5 22 needle tip of valve needle 18, for example conical part
 - 23 plain bearing
 - 24 contact region between stem 17 and plain bearing 23
 - 25 cylindrical sealing head
 - 26 spring
 - 10 27 back part of valve member 26
 - 28 ball member forming needle tip 22
 - 30 sealing contact region at valve seat 19
 - 31 O-ring
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CLAIMS

1. A lubricant injector (4) for injection of lubrication oil into the cylinder (1) of a large slow-running two-stroke engine; wherein the injector (4) comprises an injector housing (12) configured for being mounted in a cylinder wall (3) of the cylinder (1);
 5 the injector housing (12) comprising a nozzle tip (13) at one end of the injector housing (12) for reaching into the cylinder (1) when the injector housing (12) is mounted in the cylinder wall (3); wherein a nozzle (14) is provided in the nozzle tip (13), the nozzle (14) extending from an inner cavity (15) inside the injector housing (12) and
 10 through a wall (21) of the nozzle tip (13) for ejection of lubrication oil from the inner cavity (15) out of the injector housing (12) through the nozzle (14); wherein a valve member (16) is provided inside the injector housing (12), the valve member (16) being mounted reciprocal between an open and closed state of the injector (4); the valve member (16) sealingly covering the nozzle (14) when in the closed state for preventing
 15 access of lubrication oil to the nozzle (14), and the valve member (16) being movable away from the nozzle (14) during an open state for giving access of the lubrication oil from the inner cavity (15) to the nozzle (14) during an oil ejection phase; wherein
 either,
 20 A) the injector housing (12) comprises a plain bearing (23) with a first surface, and the valve member (16) comprises a stem (17) with a second surface, the second surface being provided slidably abutting the first surface in order for the stem (17) being reciprocally guided by the plain bearing (23) along a contact region (24) between the (17) stem and the plain bearing (23); wherein the valve member (16) comprises a valve needle (18) in coaxial longitudinal extension of the stem (17), the valve
 25 needle (18) comprising a needle tip (22) which is closing the nozzle (14) when abutting a cooperating valve seat (19) in the nozzle tip (13); wherein the first surface and the second surface are hardened surfaces;
 or
 30 B) the injector housing (12) comprises a cylindrical cavity part (15') with a first surface inside the nozzle tip (13), the nozzle (14) extending from the first surface through the wall (21) of the nozzle tip (13); wherein the valve member (16) comprises a cylindrical sealing head (25) with a second surface that is arranged slidably abutting

the first surface in order for the sealing head (25) to sealingly cover the nozzle (14) when in closed state; wherein for the first surface and the second surface are hardened surfaces.

- 5 2. An injector according to claim 1, wherein the hardness of the softest of the two surfaces deviates less than 10% from the hardness of the other surface.
3. An injector according to any preceding claim, wherein the hardest of the first and the second surface has a surface hardness according to Rockwell Hardness C of least
10 50.
4. An injector according to any preceding claim, wherein the first and the second surface are hardened steel surfaces.
- 15 5. An injector according to any one of the preceding claims, wherein the injector is a spray injector configured to eject lubrication oil as a spray when operated at a predetermined oil pressure level, which is a level within the interval of 25-100 bars.
6. An injector according to any one of the preceding claims, wherein the valve seat
20 (19) comprises a hardened surface.
7. An injector according to claim 6, wherein the valve seat (19) has a surface hardness according to Rockwell Hardness C of least 50.
- 25 8. A lubricant injector (4) for injection of lubrication oil into the cylinder (1) of a large slow-running two-stroke engine; wherein the injector (4) comprises an injector housing (12) configured for being mounted in a cylinder wall (3) of the cylinder (1); the injector housing (12) comprising a nozzle tip (13) at one end of the injector housing (12) for reaching into the cylinder (1) when the injector housing (12) is mounted
30 in the cylinder wall (3); wherein a nozzle (14) is provided in the nozzle tip (13), the nozzle (14) extending from an inner cavity (15) inside the injector housing (12) and through a wall (21) of the nozzle tip (13) for ejection of lubrication oil from the inner cavity (15) out of the injector housing (12) through the nozzle (14); wherein a valve

member (16) is provided inside the injector housing (12), the valve member (16) being mounted reciprocal between an open and closed state of the injector (4); the valve member (16) sealingly covering the nozzle (14) when in the closed state for preventing access of lubrication oil to the nozzle (14), and the valve member (16) being movable away from the nozzle (14) during an open state for giving access of the lubrication oil from the inner cavity (15) to the nozzle (14) during an oil ejection phase;

wherein the injector housing (12) comprises a plain bearing (23) with a first surface, and the valve member (16) comprises a stem (17) with a second surface, the second surface being provided slidably abutting the first surface in order for the stem (17) being reciprocally guided by the plain bearing (23) along a contact region (24) between the (17) stem and the plain bearing (23); wherein the valve member (16) comprises a valve needle (18) in coaxial longitudinal extension of the stem (17), the valve needle (18) comprising a needle tip (22) which is closing the nozzle (14) when abutting a cooperating valve seat (19) in the nozzle tip (13);

wherein the valve seat (19) comprises a hardened surface.

9. An injector according to claim 8, wherein the injector (4) is a spray injector configured to eject lubrication oil as a spray when operated at a predetermined oil pressure level, which is a level within the interval of 25-100 bars.

10. An injector according to claim 8 or 9, wherein the needle tip (22) is hardened or provided in a hard material that corresponds to the hardness of the hardened surface of the valve seat (19).

11. An injector according to anyone of the claims 8-10, wherein the valve seat (19) has a surface hardness according to Rockwell Hardness C of least 50.

12. An injector according to claim anyone of the claims 8-11, wherein the needle tip (22) for sealing cooperation with the valve seat comprises a conical end part of a cylindrical valve needle (18) or an end part that is tapering differently from a cone, or wherein the needle tip (22) comprises a ball (28).

13. A large slow-running two-stroke engine with a plurality of cylinders and a piston within each cylinder, the piston being reciprocal between two dead points; each cylinder having an ignition chamber for ignition of fuel; wherein at least three lubricant injectors (4) according to any one of the preceding claims are mounted along an inner circumference of each cylinder between the two dead points for lubrication of the cylinder wall in the ignition chamber.
14. An engine according to claim 13, wherein the engine is a marine engine.
15. An engine according to claim 13 or 14, wherein a lubrication oil pump and controller is provided which is connected to the injectors by lubrication supply lines, the lubrication oil pump configured for providing lubrication oil to the injectors at a predetermined oil pressure level, which is a level within the interval of 25-100 bars.
16. A method of achieving uniform long term performance among a plurality of identically produced lubricant injectors for a large slow-running two-stroke engine; wherein the injector (4) comprises an injector housing (12) mounted in a cylinder wall (3) of the cylinder (1); the injector housing (12) comprising a nozzle tip (13) at one end of the injector housing (12) reaching into the cylinder (1) when the injector housing (12) is mounted in the cylinder wall (3); wherein a nozzle (14) is provided in the nozzle tip (13), the nozzle (14) extending from an inner cavity (15) inside the injector housing (12) and through a wall (21) of the nozzle tip (13), the method comprising ejection of lubrication oil from the inner cavity (15) out of the injector housing (12) through the nozzle (14) during operation of the engine; wherein a valve member (16) is provided inside the injector housing (12), the valve member (16) being mounted reciprocal between an open and closed state of the injector (4); the valve member (16) sealingly covering the nozzle (14) when in the closed state for preventing access of lubrication oil to the nozzle (14), and the valve member (16) being movable away from the nozzle (14) during an open state for giving access of the lubrication oil from the inner cavity (15) to the nozzle (14) during an oil ejection phase; wherein either
- A) the injector housing (12) comprises a plain bearing (23) with a first surface, and the valve member (16) comprises a stem (17) with a second surface, the second surface being provided slidably abutting the first surface in order for the stem (17)

being reciprocally guided by the plain bearing (23) along a contact region (24) between the (17) stem and the plain bearing (23); wherein the valve member (16) comprises a valve needle (18) in coaxial longitudinal extension of the stem (17), the valve needle (18) comprising a needle tip (22) which is closing the nozzle (14) when abutting a cooperating valve seat (19) in the nozzle tip (13);

or

B) the injector housing (12) comprises a cylindrical cavity part (15') with a first surface inside the nozzle tip (13), the nozzle (14) extending from the first surface through the wall (21) of the nozzle tip (13); wherein the valve member (16) comprises a cylindrical sealing head (25) with a second surface that is arranged slidably abutting the first surface in order for the sealing head (25) to sealingly cover the nozzle (14) when in closed state;

wherein the method comprises, during production of the injectors, hardening for the first surface and the second surface.

17. A method according to claim 16, wherein the hardest of the first and the second surface has a surface hardness according to Rockwell Hardness C of least 50.

18. A method according to claim 16 or claim 17, wherein the method comprises providing the surfaces as steel surfaces and hardening the steel surfaces.

19. A method according to claim 18, wherein the method comprises hardening the steel surfaces by carbonitriding.

20. A method according to claim 19, wherein the method comprises hardening the steel surfaces by austenitic carbonitriding at a temperature of 850 °C in a gas atmosphere to which were added between 0.5 and 0.8 % carbon and between 0.2 and 0.4% nitrogen.

21. A method according any one of the claims 16-20, wherein the method comprises hardening the valve seat.

22. A method of achieving uniform long term performance among a plurality of identically produced lubricant injectors for a large slow-running two-stroke engine; wherein the lubricant injector (4) comprises an injector housing (12) configured for being mounted in a cylinder wall (3) of the cylinder (1); the injector housing (12) comprising a nozzle tip (13) at one end of the injector housing (12) for reaching into the cylinder (1) when the injector housing (12) is mounted in the cylinder wall (3); wherein a nozzle (14) is provided in the nozzle tip (13), the nozzle (14) extending from an inner cavity (15) inside the injector housing (12) and through a wall (21) of the nozzle tip (13), and wherein the method comprises ejection of lubrication oil from the inner cavity (15) out of the injector housing (12) through the nozzle (14) during operation of the engine; wherein a valve member (16) is provided inside the injector housing (12), the valve member (16) being mounted reciprocal between an open and closed state of the injector (4); the valve member (16) sealingly covering the nozzle (14) when in the closed state for preventing access of lubrication oil to the nozzle (14), and the valve member (16) being movable away from the nozzle (14) during an open state for giving access of the lubrication oil from the inner cavity (15) to the nozzle (14) during an oil ejection phase; wherein the injector housing (12) comprises a plain bearing (23) with a first surface, and the valve member (16) comprises a stem (17) with a second surface, the second surface being provided slidably abutting the first surface in order for the stem (17) being reciprocally guided by the plain bearing (23) along a contact region (24) between the (17) stem and the plain bearing (23); wherein the valve member (16) comprises a valve needle (18) in coaxial longitudinal extension of the stem (17), the valve needle (18) comprising a needle tip (22) which is closing the nozzle (14) when abutting a cooperating valve seat (19) in the nozzle tip (13); wherein the method comprises hardening the valve seat (19).

23. A method according to claim 22, wherein the method comprises providing the valve seat as a steel surface and hardening the steel surface by carbonitriding.

24. A method according to claim 23, wherein the method comprises hardening the steel surfaces by austenitic carbonitriding at a temperature of 850 °C in a gas at-

mosphere to which were added between 0.5 and 0.8 % carbon and between 0.2 and 0.4 % nitrogen.

25. Use of surface-hardening for achieving uniform long term performance among a plurality of identical lubricant injectors for a large slow-running two-stroke engine; wherein for each injector, the injector (4) comprises an injector housing (12) configured for being mounted in a cylinder wall (3) of the cylinder (1); the injector housing (12) comprising a nozzle tip (13) at one end of the injector housing (12) for reaching into the cylinder (1) when the injector housing (12) is mounted in the cylinder wall (3); wherein a nozzle (14) is provided in the nozzle tip (13), the nozzle (14) extending from an inner cavity (15) inside the injector housing (12) and through a wall (21) of the nozzle tip (13) for ejection of lubrication oil from the inner cavity (15) out of the injector housing (12) through the nozzle (14); wherein a valve member (16) is provided inside the injector housing (12), the valve member (16) being mounted reciprocal between an open and closed state of the injector (4); the valve member (16) sealingly covering the nozzle (14) when in the closed state for preventing access of lubrication oil to the nozzle (14), and the valve member (16) being movable away from the nozzle (14) during an open state for giving access of the lubrication oil from the inner cavity (15) to the nozzle (14) during an oil ejection phase; wherein either

20 A) the injector housing (12) comprises a plain bearing (23) with a first surface, and the valve member (16) comprises a stem (17) with a second surface, the second surface being provided slidably abutting the first surface in order for the stem (17) being reciprocally guided by the plain bearing (23) along a contact region (24) between the (17) stem and the plain bearing (23); wherein the valve member (16) comprises a valve needle (18) in coaxial longitudinal extension of the stem (17), the valve needle (18) comprising a needle tip (22) which is closing the nozzle (14) when abutting a cooperating valve seat (19) in the nozzle tip (13);

or

30 B) the injector housing (12) comprises a cylindrical cavity part (15') with a first surface inside the nozzle tip (13), the nozzle (14) extending from the first surface through the wall (21) of the nozzle tip (13); wherein the valve member (16) comprises a cylindrical sealing head (25) with a second surface that is arranged slidably abutting

the first surface in order for the sealing head (25) to sealingly cover the nozzle (14) when in closed state;

wherein the surface-hardening comprises, during production of the injectors, hardening of the first surface and the second.

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26. Use according to claim 25, wherein the hardest of the first and the second surface has a surface hardness according to Rockwell Hardness C of least 50.

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27. Use according to claim 25 or 26, wherein the method comprises hardening the valve seat.

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28. Use of surface-hardening for achieving uniform long term performance among a plurality of identical lubricant injectors for a large slow-running two-stroke engine; wherein for each injector, the injector (4) comprises an injector housing (12) configured for being mounted in a cylinder wall (3) of the cylinder (1); the injector housing (12) comprising a nozzle tip (13) at one end of the injector housing (12) for reaching into the cylinder (1) when the injector housing (12) is mounted in the cylinder wall (3); wherein a nozzle (14) is provided in the nozzle tip (13), the nozzle (14) extending from an inner cavity (15) inside the injector housing (12) and through a wall (21) of the nozzle tip (13) for ejection of lubrication oil from the inner cavity (15) out of the injector housing (12) through the nozzle (14); wherein a valve member (16) is provided inside the injector housing (12), the valve member (16) being mounted reciprocal between an open and closed state of the injector (4); the valve member (16) sealingly covering the nozzle (14) when in the closed state for preventing access of lubrication oil to the nozzle (14), and the valve member (16) being movable away from the nozzle (14) during an open state for giving access of the lubrication oil from the inner cavity (15) to the nozzle (14) during an oil ejection phase; wherein

the injector housing (12) comprises a plain bearing (23) with a first surface, and the valve member (16) comprises a stem (17) with a second surface, the second surface being provided slidably abutting the first surface in order for the stem (17) being reciprocally guided by the plain bearing (23) along a contact region (24) between the (17) stem and the plain bearing (23); wherein the valve member (16) comprises a valve needle (18) in coaxial longitudinal extension of the stem (17), the valve

needle (18) comprising a needle tip (22) which is closing the nozzle (14) when abutting a cooperating valve seat (19) in the nozzle tip (13);

wherein the surface-hardening comprises, during production of the injectors, hardening of the valve seat (19).

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29. Use of a plurality of injectors according to anyone of the claims 1-12 for lubrication of a large slow-running two-stroke engine with a plurality of cylinders (2) and a piston within each cylinder (2), the piston being reciprocal between two dead points; each cylinder (2) having an ignition chamber for ignition of fuel; wherein at least three of the plurality of injectors (4) are mounted along an inner circumference of each cylinder between the two dead points for lubrication of the cylinder wall (3) in the ignition chamber.

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30. Use according to claim 29, wherein the engine is a marine engine.

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31. Use according to claim 29 or 30, wherein the engine comprises a lubrication oil pump and controller (11) which is connected to the injectors (4) by lubrication supply lines (9), wherein the injectors (4) are provided with lubrication oil at a predetermined oil pressure level, which is a level within the interval of 25-100 bars and used for providing a spray of lubrication oil.

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