

METHOD FOR TREATING CYLINDRICAL TRACKS OF CYLINDERS OR CYLINDRICAL SLEEVES BY LASER APPLICATION

Technical field

[0001] The present invention relates to a process for treating cylinder running surfaces of cylinders or cylinder liners for reciprocating piston engines.

Technical background

[0002] Cylinder running surfaces or cylinder liners are critical components in reciprocating piston engines, providing a durable surface for piston movement and combustion processes. These liners may consist of lamella graphite cast iron with a pearlitic microstructure containing cementite portions, ferrite portions and graphite lamella portions. The surface properties of cylinder liners have a significant influence on engine performance, efficiency and service life.

[0003] Over time, cylinder liners are exposed to extreme conditions, including high temperatures, pressures and mechanical loads. This can lead to wear, deterioration of the surface properties and accumulation of combustion residues in the honing grooves and secondary grooves of the liner surface. These factors can adversely affect engine performance, increase oil consumption and potentially shorten the engine's service life.

[0004] Various methods have been used to improve the surface properties of cylinder liners, including honing processes to produce a cross-hatch pattern that supports oil retention and distribution. However, conventional honing processes do not always provide optimal surface properties for modern high-performance engines.

[0005] There is an ongoing need for improved processes and technologies for treating cylinder running surfaces and liners, both in the manufacture of new engines and in the reconditioning of used engines. Advances

in this field could lead to engines with better performance, increased efficiency, reduced emissions and extended operating life.

Description

[0006] Based on the known prior art, the object of the present invention is to provide an improved process for treating cylinder running surfaces of cylinders or cylinder liners of reciprocating piston engines, in particular to improve the surface properties of the cylinder running surfaces of the cylinders or the cylinder liners.

[0007] This object is achieved by a process having the features of claim 1. Advantageous further developments arise from the dependent claims, the description and the figures.

[0008] According to one aspect of the present disclosure, a process for treating cylinder running surfaces of cylinders or cylinder liners is proposed, the process comprising the steps of non-contact exposure of a honed surface of the cylinder running surface or the cylinder liner to a pulsed laser beam, the honed surface having honing grooves and/or secondary grooves, and the exposure to the pulsed laser beam being configured such that cementite portions on the honed surface are remelted into a cementite layer.

[0009] Cementite, also known as iron carbide, has, among other things, a very high hardness, so that the cementite layer on the honed surface leads to increased stability and wear resistance of the cylinder bore or the cylinder liner. In this way, the endurance strength of the cylinder running surfaces of the cylinders or the cylinder liners can be improved by means of the process.

[0010] The cylinder running surface of the cylinder or the cylinder liner may comprise or consist of lamella graphite cast iron with a pearlitic microstructure and comprise cementite portions, ferrite portions and graphite lamella portions, wherein the exposure to the pulsed laser beam may further be

configured such that graphite lamella portions on the honed surface are exposed and ferrite portions are evaporated.

[0011] In this way, the tribological properties of the honed surface can be improved, because exposing the graphite lamella portions improves oil retention and lubrication. This leads to improved wear resistance, improved oil retention and an extended engine life, thereby improving the properties of the engine treated accordingly.

[0012] For reconditioning honing grooves and/or secondary grooves clogged by combustion residues, in particular by combustion residues in the form of oil coal in a liquid-fuel engine or coating in a gas engine, the pulsed laser beam can be configured to remove the combustion residues in the honing grooves and/or the secondary grooves of the honed surface by evaporation.

[0013] This means that the process can be used not only for machining new cylinder running surfaces of the cylinder or cylinder liners, but also for reconditioning cylinder running surfaces or cylinder liners that have already been used. The process can therefore be used with particular flexibility.

[0014] In particular, the above-mentioned advantages can be achieved with a single treatment with the pulsed laser beam. Thus, by means of the treatment, remelting of the cementite portions into the cementite layer, exposure of the graphite lamella portions, evaporation of the ferrite portions and cleaning by evaporation of the combustion residues can be achieved in a single process step of exposing the honed surface to the pulsed laser beam.

[0015] The application with the pulsed laser beam can be repeated until the cementite layer on the honed surface is formed as a largely closed surface or a completely closed surface, preferably with a homogeneous surface structure.

[0016] A largely closed surface of the cementite layer is understood, for example, to be one in which the cementite layer extends over all areas of the honed surface, but excludes the honing grooves and/or secondary

grooves. In other words, no cementite layer is formed in the honing grooves or the secondary grooves.

[0017] A completely closed surface of the cementite layer is understood, for example, to be one in which the cementite layer is present on the entire honed surface and is also present in the honing grooves and/or secondary grooves. The cementite layer follows the surface contour, so that the honing grooves and secondary grooves are still present, but are coated with a cementite layer.

[0018] The cementite layer can be formed with a thickness of 2 nm up to 1 μm , preferably 3–10 nm.

[0019] The pulsed laser beam can be configured to round sharp-edged structures and/or edges of honing grooves and/or protruding material tongues and/or edges of secondary grooves by melting during exposure of the honed surface to the pulsed laser beam, in particular in order to improve the tribological properties of the honed surface.

[0020] By rounding the structures mentioned, wear on the honed surface can be reduced and the tribological properties are improved by homogenizing the surface.

[0021] The pulsed laser beam can be configured to melt and/or redistribute material on the honed surface in order to achieve a more uniform surface structure with reduced sharp edges and projections compared with the surface structure before application the pulsed laser beam.

[0022] In this way, wear resistance of the treated surface can also be improved.

[0023] The pulsed laser beam can have an average laser power of 90–300 W, a wavelength of 1060–1070 nm, a pulse frequency of 135–165 kHz and a pulse width of 18–22 ns.

[0024] In this way, the above-mentioned advantages can be achieved.

[0025] The object described above is further achieved by a process for treating cylinder running surfaces of cylinders or cylinder liners which have a honed surface with honing grooves and/or secondary grooves, wherein the honed surface is subjected to a pulsed laser beam, wherein the pulsed laser beam has an average laser power of 90–300 W, a wavelength of 1060–1070 nm, a pulse frequency of 135–165 kHz and a pulse width of 18–22 ns.

[0026] With a correspondingly configured pulsed laser beam for exposing the honed surface, the treatment steps and advantages described above can be achieved.

[0027] The average laser power can be adjusted for all the above processes and process variants depending on the loading of the honed surface with combustion residues. Preferably, for a new honed surface not loaded with combustion residues, the average laser power is adjusted to 90–110 W, for a honed surface lightly loaded with combustion residues the average laser power is adjusted to 125–155 W, and for a honed surface heavily loaded with combustion residues the average laser power is adjusted to 180–220 W.

[0028] As already described, this allows the process to be used very flexibly and independently of the respective condition of the honed surfaces. Accordingly, new and used cylinder running surfaces or cylinder liners can be treated.

[0029] The application with the pulsed laser beam can be configured such that graphite lamella portions on the honed surface are exposed, ferrite portions are evaporated and remaining cementite portions are remelted into a cementite layer, wherein the cylinder running surface of the cylinder or the cylinder liner comprises or consists of lamella graphite cast iron with a pearlitic microstructure and comprises cementite portions, ferrite portions and graphite lamella portions.

[0030] By means of an optical arrangement, the pulsed laser beam can be applied to the honed surface in such a way that the honed surface is

subjected to a processing spot having a length of 28–32 nm and a width of 1.9–2.1 nm.

[0031] The pulsed laser beam can be guided over the honed surface at a scanning speed of 7200–8800 mm/s in order to subject it to the laser beam.

[0032] By means of this scanning of the surface, it can be achieved that the entire honed surface is exposed to the pulsed laser beam and accordingly all areas of the honed surface are processed. By means of the scanning described, it is possible to adapt the treatment simply to the respective geometry and dimensions of the honed surface.

[0033] The individual pulses of the pulsed laser beam can have a single-pulse energy of up to 1.8 mJ, preferably 0.2–2.5 μ J.

[0034] This enables reliable and rapid processing.

[0035] The process can be carried out with an engine in the installed state.

[0036] This allows a particularly simple and efficient treatment to be carried out, especially when reconditioning cylinder running surfaces or cylinder liners that have already been used, without the engine having to be largely dismantled.

[0037] The object mentioned above is also achieved by a cylinder or a cylinder liner of a reciprocating piston engine which has a honed surface with honing grooves and/or secondary grooves, wherein the honed surface has a cementite layer with a thickness of 2 nm up to 1 μ m, preferably 3–10 nm.

[0038] Such a cylinder or such a cylinder liner offers the advantage of improved wear resistance, improved oil retention and extended service life due to the unique surface structure produced by the laser treatment process.

[0039] The cementite layer can be largely closed or closed and preferably form a homogeneous surface structure, wherein the cementite layer particularly preferably extends over the entire honed surface.

[0040] A largely closed surface of the cementite layer is understood, for example, to be one in which the cementite layer extends over all areas of the honed surface, but excludes the honing grooves and/or secondary grooves. In other words, no cementite layer is formed in the honing grooves or the secondary grooves.

[0041] A completely closed surface of the cementite layer is understood, for example, to be one in which the cementite layer is present on the entire honed surface and is also present in the honing grooves and/or secondary grooves. The cementite layer follows the surface contour, so that the honing grooves and secondary grooves are still present, but are coated with a cementite layer.

[0042] The cylinder or the cylinder liner may comprise a pearlitic microstructure with cementite portions, ferrite portions and graphite lamella portions, and graphite lamella portions may be exposed on the honed surface and ferrite portions removed, preferably evaporated.

[0043] Sharp-edged structures and/or edges of honing grooves and/or protruding material tongues and/or edges of secondary grooves can be rounded by melting.

[0044] The cementite layer on the honed surface can be formed as a largely closed surface or as a closed surface, preferably with a homogeneous surface structure, particularly preferably over the entire honed surface.

[0045] Graphite lamella portions on the honed surface can be exposed and create a network of exposed graphite lamellae, thereby improving the tribological properties of the surface.

[0046] The process and the apparatus for laser treatment of cylinder running surfaces of cylinders or cylinder liners offer several technical advantages. First, the laser treatment process simultaneously achieves several beneficial effects in a single operation. It effectively removes combustion residues and contaminants from the honed surface, including clogged honing grooves and secondary grooves, by evaporation. This cleaning effect restores the

original tribological properties of the surface texture, which is crucial for proper lubrication and reduced friction during engine operation.

[0047] At the same time, the laser treatment exposes graphite lamella portions on the honed surface. This exposure of graphite lamellae improves the self-lubricating properties of the cylinder liner material, which further contributes to reducing friction and wear during engine operation.

[0048] The laser-induced thermal effects also lead to rounding of sharp-edged structures, honing-groove edges and protruding material tongues. This rounding effect produces a more uniform surface topography that is less prone to the accumulation of combustion residues and has improved tribological properties.

[0049] The laser treatment can bring about a transformation of the surface microstructure by evaporating ferrite portions and remelting remaining cementite portions into a cementite layer. This cementite layer with a thickness from a few nanometers up to 1 μm forms a ceramic-like structure on the honed surface. The presence of this cementite layer significantly improves the wear resistance of the cylinder liner and extends its operating life. In addition, the cementite layer has a reduced material affinity to friction partners such as piston rings and piston skirts, which reduces the tendency to adhesive wear.

[0050] The versatility of the process is another important advantage. It can be applied both to new cylinder liners and to honed surfaces that are lightly or heavily loaded with combustion residues, with the laser parameters being adjustable to different surface conditions. This flexibility enables treatment of engines at different stages of their life cycle, from manufacture to maintenance and reconditioning.

[0051] In addition, the process can be carried out with the cylinder liners installed in the engine, with only the cylinder head needing to be removed. This in-situ capability significantly reduces maintenance time and costs compared with conventional reconditioning methods that may require complete engine disassembly or replacement of cylinder liners.

[0052] Finally, the process offers excellent process control and repeatability. The ability to visually inspect the treated surface or to use automated magnet-wave-induced surface inspection techniques ensures consistent quality and reduces reliance on subjective human assessments. This feature is particularly valuable in industrial applications where consistency and quality control are of utmost importance.

Brief description of the drawings

[0053] Preferred further embodiments of the invention are explained in more detail on the basis of the following description of the figures. Figures:

[0054] Figure 1 shows a schematic cross-sectional view of a honed surface of a cylinder running surface of a cylinder of a reciprocating piston engine or of a cylinder liner before treatment and at approximately 800× magnification of the cross-section.

[0055] Figure 2 shows a schematic cross-sectional view of the honed surface from Figure 1 after treatment with a laser beam according to aspects of the present disclosure.

[0056] Figure 3 shows a scanning electron microscope image of an untreated honed surface.

[0057] Figure 4 shows a scanning electron microscope image of a honed surface after treatment by exposure to a laser beam according to aspects of the present disclosure.

Detailed description of the figures

[0058] Preferred embodiments are described below with reference to the figures. Identical, similar or equivalent elements in the different figures are provided with identical reference signs, and a repeated description of these elements is partly omitted in order to avoid redundancy.

[0059] The present disclosure provides a process for treating cylinder running surfaces of cylinders or cylinder liners for a reciprocating piston engine, in particular those made of lamella graphite cast iron. This process uses a pulsed laser for non-contact treatment of a honed surface of the cylinder running surface or the cylinder liner, wherein the honed surface has honing grooves and/or secondary grooves.

[0060] The application of the honed surface to the pulsed laser beam first serves to remelt cementite portions on the honed surface into a cementite layer. In this way, a hard and wear-resistant honed surface can be provided.

[0061] The exposure of the honed surface can also expose graphite lamella portions on the honed surface and evaporate ferrite portions. If combustion residues are present on the honed surface, these can also be evaporated by the application with the pulsed laser. This simultaneous cleaning, restructuring and improvement of the surface properties of the honed surface can lead to improved engine performance and longevity.

[0062] The process is versatile and can be applied to new honed surfaces, honed surfaces lightly loaded with combustion residues and honed surfaces heavily loaded with combustion residues, with the treatment parameters being adaptable to the different conditions of the honed surface before treatment. This flexibility enables treatment of engines at different stages of their life cycle, from manufacture to maintenance and reconditioning.

[0063] With reference to Figures 1 and 2, these figures show a section of a cylinder, in particular a cylinder running surface, or of a cylinder liner, which in the example shown each comprise a pearlitic microstructure 1.

[0064] In the schematic cross-sectional views, a honed surface 5 is shown, which is shown in Figure 1 before treatment by application with the pulsed laser beam, and in Figure 2 after this treatment.

[0065] The cylinder with the cylinder running surface or the cylinder liner consists of or comprises lamella graphite cast iron, which has a

pearlitic microstructure 1. This microstructure 1 comprises cementite portions 2, ferrite portions 3 and graphite lamella portions 4. The honed surface 5 comprises honing grooves 7 and/or secondary grooves.

[0066] A pulsed laser is used to treat the honed surface 5 without contact. This treatment process involves exposure to the pulsed laser beam. As already mentioned, the application the pulsed laser beam can remelt cementite portions 2 on the honed surface 5 into a cementite layer 8. This remelting process can improve the surface properties of the honed surface 5 and thereby improve the cylinder running surface or the cylinder liner and create a more durable and efficient surface for engine operation.

[0067] Furthermore, the application with the pulsed laser can expose graphite lamella portions 4 on the honed surface 5. This exposure of the graphite lamella portions 4 can improve the tribological properties of the honed surface 5 and thus increase the performance and longevity of the engine.

[0068] The exposure to the pulsed laser beam can also evaporate ferrite portions 3. This evaporation process can also clean the honed surface 5 and remove unwanted materials and contaminants.

[0069] In the case of a new cylinder running surface or cylinder liner that has not yet been in operation, a honed surface 5 can be provided in this way which is freed from all residues and additives left over from the manufacture of the honed surface 5, such as chips or honing oil. This enables gentle running-in of the engine with reduced abrasion, which contributes to improving the service life of the engine.

[0070] The laser treatment process can be applied to new honed surfaces 5 that are lightly loaded with combustion residues 6 and honed surfaces 5 heavily loaded with combustion residues 6.

[0071] In some aspects, the laser parameters can be adjusted to take different surface conditions into account. This flexibility enables treatment of engines at different stages of their life cycle, from manufacture to maintenance and reconditioning.

[0072] In other words, the treatment involves remelting a pearlitic microstructure 1 into a closed cementite layer 8. The formation of this cementite layer 8 can improve the surface properties of the cylinder liner and thus increase the performance and longevity of the engine.

[0073] The treatment by application with the laser beam can have a significant influence on the surface structure of the honed surface 5. For example, the honing grooves 7 and/or secondary grooves on the surface 5 of the cylinder running surface may be clogged by combustion residues 6 or dirt. These combustion residues may, for example, comprise oil coke in a liquid-fuel engine operated, for example, with diesel, light oil or heavy oil, or coating in a gas engine operated, for example, with natural gas. The application with the laser beam during treatment can re-expose these grooves by evaporating the combustion residues 6.

[0074] This means that this cleaning process can restore the functionality of the grooves and thereby enable them to contribute effectively again to the tribological properties of the honed surface 5.

[0075] In addition to, or as an alternative to, cleaning the honing grooves and/or secondary grooves, the treatment by exposure to the pulsed laser beam can also round sharp-edged structures on the honed surface 5 of the cylinder running surface. These structures can include edges of honing grooves 7 and/or protruding material tongues and/or edges of secondary grooves. The rounding process is achieved by melting these structures during application with the laser beam. This can lead to a smoother surface structure with reduced sharp edges and projections compared with the surface structure before treatment with the pulsed laser beam.

[0076] This rounding process can improve the tribological properties of the surface and reduce friction and wear during engine operation, so that in this way the longevity of the engine is also restored.

[0077] In the case of a new cylinder running surface or cylinder liner that has not yet been in operation, a honed surface 5 can be provided in this

way which enables gentle running-in of the engine with reduced abrasion and thereby contributes to improving the service life of the engine.

[0078] The treatment with the pulsed laser beam can also redistribute material on the honed surface 5. This is achieved by partially melting the material on the honed surface 5 during application with the laser beam. The molten material is then redistributed on the honed surface 5 to fill gaps and smooth irregularities. This can lead to a more uniform surface structure with reduced roughness compared with the surface structure before the laser treatment.

[0079] The pulsed laser beam with which the honed surface 5 is exposed can have an average laser power of 90–300 W, a wavelength of 1060–1070 nm, a pulse frequency of 135–165 kHz and a pulse width of 18–22 ns.

[0080] Depending on the loading of the honed surface 5 with combustion residues 6, the laser power can be adjusted. In the case of a new honed surface 5 not loaded with combustion residues 6, the average laser power can be adjusted to 90–110 W. In the case of a honed surface 5 lightly loaded with combustion residues 6, the average laser power can be adjusted to 125–155 W. In the case of a honed surface 5 heavily loaded with combustion residues 6, the average laser power can be adjusted to 180–220 W.

[0081] The individual pulses of the pulsed laser beam can have a single-pulse energy of up to 1.8 mJ, preferably 0.2–2.5 μ J.

[0082] These settings are designed to treat the cylinder running surfaces or cylinder liners effectively without causing unnecessary damage or wear.

[0083] In order to enable complete treatment of the honed surface 5, an optical arrangement can apply the pulsed laser beam to the honed surface 5 such that the honed surface 5 is exposed with a processing spot having a length of 28–32 nm and a width of 1.9–2.1 nm.

[0084] In this case, the pulsed laser beam can be guided over the honed surface 5 at a scanning speed of 7200–8800 mm/s in order to subject it to the pulsed laser beam.

[0085] The application of the honed surface 5 to the laser beam can be carried out or repeated until the cementite layer 8 on the honed surface 5 is formed as a largely closed surface with a homogeneous surface structure.

Preferably, this cementite layer 8 is achieved on the complete honed surface 5.

[0086] This repetition of exposure to the laser beam can ensure that the entire honed surface 5 is treated uniformly, resulting in a consistent and uniform cementite layer 8 across the entire surface.

[0087] The formation of the cementite layer achieved by subjecting the honed surface 5 to the pulsed laser beam can result in a cementite layer 8 with a thickness of 2 nm up to 1 μm , preferably 3–10 nm.

[0088] This can improve the overall performance and longevity of the engine by providing a consistent and durable surface for engine operation.

[0089] With reference to Figures 3 and 4, these schematic illustrations show scanning electron microscope images of honed surfaces at different treatment stages.

[0090] Figure 3 shows a cross-sectional view of an untreated honed surface. The pearlitic microstructure 1 is visible as the base material. A layer of combustion residues 6 is present on the honed surface and appears as a dark band at the upper edge of the image. The scale bar shows that the layer of combustion residues has a thickness of a few μm .

[0091] Figure 4, on the other hand, shows a cross-sectional view of a honed surface after the laser treatment. The pearlitic microstructure 1 remains visible as the base material.

[0092] A graphite lamella 4 can be seen extending from the base material to the surface. This exposure creates a network of exposed graphite lamellae that improves the oil-retention properties of the surface. This can improve the performance and longevity of the engine by reducing friction and wear during operation.

[0093] The laser treatment has also led to the formation of a cementite layer 8, which is visible as a bright band along the upper surface. This

cementite layer 8 appears more uniform and continuous compared with the layer of combustion residues 6 in Figure 3. The scale bar shows that the thickness of the cementite layer 8 is well below 1 μm .

[0094] The comparison between Figures 3 and 4 shows the effects of the laser treatment on the honed surface, including the removal of combustion residues and the formation of the cementite layer 8. In some aspects, the cementite layer 8 has a thickness of 2 nm up to 1 μm , preferably 3–10 nm. This layer provides a durable and efficient surface for engine operation.

[0095] In some aspects, a cylinder liner treated with the laser process is visibly different from an untreated cylinder liner. This difference can be observed under a scanning electron microscope, as shown in Figures 3 and 4. The treated cylinder liner has a more uniform and more continuous cementite layer 8, reduced combustion residues and exposed graphite lamellae. These changes in the surface structure and composition resulting from the laser treatment process can lead to improved engine performance and longevity.

[0096] In some aspects, the laser used for the treatment process to provide the laser beam is a pulsed laser. The pulsed laser can have a wavelength of 1.060 to 1.070 μm , a pulse width of 10 to 500 ns, a pulse frequency of 1 to 4,000 kHz and a maximum single-pulse energy of up to 1.8 mJ.

[0097] In some cases, this is specifically an Nd:YAG laser with a wavelength of 1064 nm. This type of laser is known for its high power and precision, making it suitable for treating cylinder liners.

[0098] In some aspects, the process for treating cylinder running surfaces of cylinders or cylinder liners is carried out with an engine in the installed state. This feature makes it possible to carry out the treatment process without extensive disassembly of the engine, thereby reducing downtime and labor costs. In some cases, the laser device used in the process or its exit optics are mounted on a linear drive. This arrangement can facilitate movement of the laser device or its exit optics along the length of the cylinder running surface and ensure uniform treatment of the entire surface.

[0099] In some embodiments, the process is carried out under a range of environmental conditions. For example, the process can be carried out at a humidity of 10 to 95% and an allowable room temperature of 0 to 40°C. This flexibility in environmental conditions allows the process to be implemented in a wide range of environments, from controlled indoor spaces to outdoor locations with varying weather conditions.

[00100] In some cases, the process results in coagulation of the internal roughness of the cylinder liner. This coagulation process involves partial melting and redistribution of material on the surface of the cylinder running surface during application of the laser beam. This can lead to a more uniform surface structure with reduced roughness compared with the surface structure before the laser treatment. This can improve the tribological properties of the surface and reduce friction and wear during engine operation.

[00101] In some aspects, the process is carried out manually. This feature makes it possible to carry out the treatment process without the need for complex machinery or automated systems. This can make the process more accessible and cost-effective, especially for smaller operations or in situations where access to advanced equipment is limited. Although it is carried out manually, the process can still achieve effective and uniform treatment of the honed surface, thanks to the precision and control provided by the laser device.

[00102] In some aspects, the results of the laser treatment process on the honed surface can be inspected and verified by various methods. One such method involves visual inspection based on clearly recognizable changes in the surface texture of the honed surface. After the laser treatment process, the surface of the cylinder running surface can have a more uniform and more continuous cementite layer 8, reduced combustion residues and exposed graphite lamellae. These changes in the surface structure and composition can be observed visually and provide a simple and accessible way of verifying the results of the laser treatment process.

[00103] In some cases, automated techniques can be used to inspect and verify the results of the laser treatment process. For example, an automated magnet-wave-induced surface inspection, also known as Tom's Check method, can be used. This method involves using magnetic waves to inspect the surface of the cylinder running surface. The magnetic waves can detect changes in the surface structure and composition and provide a detailed and accurate assessment of the results of the laser treatment process. This automated inspection method can be particularly useful in situations where a high level of precision and accuracy is required, or where human factors such as fatigue or fluctuations in daily performance could impair the reliability of visual inspection.

[00104] In some aspects, the inspection and verification methods can be combined to provide a comprehensive assessment of the results of the laser treatment process. For example, visual inspection can be used for a preliminary assessment of the surface changes, followed by an automated magnet-wave-induced surface inspection for a more detailed and more accurate evaluation. This combination of methods can ensure that the laser treatment process has effectively treated the honed surface, improved its tribological properties and increased engine performance and longevity.

[00105] In some aspects, the quality of the laser-treated honed surface can be determined by various methods. One such method can involve the use of profilometry techniques to measure surface roughness parameters. For example, a stylus instrument or an optical profilometer can be used to measure the arithmetic mean roughness (Ra), the root mean square roughness (Rq) and the maximum peak-to-valley height (Rz) of the treated surface. These measurements can provide quantitative data on the smoothness and uniformity of the surface after the laser treatment.

[00106] In some cases, the surface structure of the laser-treated cylinder running surface can be determined experimentally using advanced microscopy techniques. Scanning electron microscopy (SEM) can be used to visualize the surface topography at high magnification and show details of the

cementite layer 8, exposed graphite lamellae 4 and remaining honing grooves 7. In addition, atomic force microscopy (AFM) can be used to create three-dimensional maps of the surface and provide nanometer-scale resolution of the surface features.

[00107] In some aspects, an X-ray diffraction analysis (XRD) can be carried out to determine the crystal structure of the laser-treated surface. This technique can confirm the presence and relative frequency of cementite in the newly formed layer 8 and also detect changes in the underlying pearlitic microstructure 1.

[00108] Various measurements can be carried out on the laser-treated honed surface in order to assess its quality and properties. In some cases, the thickness of the cementite layer 8 can be measured by cross-sectional SEM or transmission electron microscopy (TEM). Depending on the specific laser treatment parameters used, the thickness of this layer can range from a few nanometers up to 1 μm .

[00109] In some aspects, the process includes adjusting the treatment parameters and laser parameters depending on the condition of the surface of the cylinder liner. For new cylinder liners, the treatment may not need to include cleaning of the surface from oil coal or gas coating, as these contaminants are typically not present on unused liners. However, the treatment can still include cleaning of honing residues such as honing oil. In this case, the laser parameters can be adjusted to focus primarily on exposing graphite lamella portions and forming the cementite layer, rather than on removing combustion residues.

[00110] For lightly used cylinder liners, the process can include a mild cleaning process to remove light deposits of oil coal or gas coating. The laser parameters can be adjusted to provide sufficient energy for cleaning, while the focus remains on the surface restructuring process. In some cases, the laser power can be increased by 5–10% compared with the parameters used for new liners, and the pulse frequency can be adjusted to optimize the cleaning effect.

[00111] For heavily used cylinder liners with significant deposits of oil coal or gas coating, the process can include a more intensive cleaning process. The laser parameters can be adjusted to provide higher energy for effective removal of these deposits. In some aspects, the laser power can be increased by 15–25% compared with the parameters used for new liners, and the pulse width can be lengthened to enable more thorough evaporation of contaminants. The scanning speed can also be reduced to ensure sufficient exposure time for cleaning and surface restructuring.

[00112] In some cases, the process can include a pre-treatment assessment of the honed surface to determine its condition and the presence of contaminants. This assessment can include visual inspection, profilometry measurements or spectroscopic analyses to characterize the surface composition. Based on this assessment, the laser parameters and the treatment process can be tailored to the specific condition of each cylinder liner to ensure optimal results regardless of its usage history.

[00113] The process described here and the apparatus for laser treatment of cylinder running surfaces and cylinder liners have far-reaching industrial application possibilities, in particular in the automotive, maritime and heavy machinery industries. This technology is suitable for industrial use in engine manufacture, maintenance and reconditioning. It can be implemented both in production lines for new engines and in repair and overhaul facilities for used engines. The versatility of the process enables its application to different types and sizes of engines, from small automotive engines to large marine diesel engines. While the examples cited focus on internal combustion engines, the principles and techniques of this invention can be adapted for use in other industries where precise surface treatment of cylindrical bores is required, such as in hydraulic systems, pneumatic cylinders or even in the aerospace industry for the treatment of engine components. The scalability and adaptability of this laser treatment process make it a valuable tool for improving the performance, efficiency and longevity of a wide range of industrial machinery and equipment.

[00114] Where applicable, all the individual features shown in the embodiments can be combined with one another and/or exchanged for one another without departing from the scope of the invention.

List of reference signs

- 1 pearlitic microstructure
- 2 cementite content
- 3 ferrite content
- 4 graphite lamella
- 5 honed surface
- 6 combustion residue
- 7 honing groove
- 8 cementite layer

Claims

1. Process for treating cylinder running surfaces of cylinders or cylinder liners, wherein the process comprises the steps of:
 - non-contact application of a honed surface (5) of the cylinder running surface or the cylinder liner to a pulsed laser beam, wherein the honed surface (5) has honing grooves (7) and/or secondary grooves, wherein
 - the application with the pulsed laser beam is configured such that cementite portions (2) on the honed surface (5) are remelted into a cementite layer (8).
2. Process according to claim 1, wherein the cylinder running surface of the cylinder or the cylinder liner comprises or consists of lamella graphite cast iron with a pearlitic microstructure (1) and comprises cementite portions (2), ferrite portions (3) and graphite lamella portions (4), wherein the application with the pulsed laser beam is further configured such that graphite lamella portions (4) are exposed on the honed surface (5) and ferrite portions (3) are evaporated.
3. Process according to claim 1 or 2, wherein for reconditioning honing grooves (7) and/or secondary grooves clogged by combustion residues (6), in particular by combustion residues (6) in the form of oil coal in a liquid-fuel engine or coating in a gas engine, the pulsed laser beam is configured to remove the combustion residues (6) in the honing grooves (7) and/or the secondary grooves of the honed surface (5) by evaporation.
4. Process according to one of the preceding claims, wherein the application with the pulsed laser beam is repeated until the cementite layer (8) on

the honed surface (5) is formed as a largely closed or completely closed surface, preferably with a homogeneous surface structure.

5. Process according to one of the preceding claims, wherein the cementite layer (8) is formed with a thickness of 2 nm up to 1 μm , preferably with a thickness of 3–10 nm.

6. Process according to one of the preceding claims, wherein the pulsed laser beam is configured to round sharp-edged structures and/or edges of honing grooves (7) and/or protruding material tongues and/or edges of secondary grooves by melting during application with the pulsed laser beam, in particular in order to improve the tribological properties of the honed surface (5).

7. Process according to one of the preceding claims, wherein the pulsed laser beam is configured to melt and/or redistribute material on the honed surface (5) in order to achieve a more uniform surface structure with reduced sharp edges and projections compared with the surface structure before application with the pulsed laser beam.

8. Process according to one of the preceding claims, wherein the pulsed laser beam has an average laser power of 90–300 W, a wavelength of 1060–1070 nm, a pulse frequency of 135–165 kHz and a pulse width of 18–22 ns.

9. Process for treating cylinder running surfaces of cylinders or cylinder liners which have a honed surface (5) with honing grooves (7) and/or secondary grooves, wherein the honed surface (5) is subjected to a pulsed laser beam, wherein the pulsed laser beam has an average laser power of 90–300 W, a wavelength of 1060–1070 nm, a pulse frequency of 135–165 kHz and a pulse width of 18–22 ns.

10. Process according to claim 8 or 9, wherein the average laser power is adjusted depending on the loading of the honed surface (5) with combustion residues (6) and is preferably adjusted to 90–110 W for a new honed surface (5) not loaded with combustion residues (6), adjusted to 125–155 W for a honed surface (5) lightly loaded with combustion residues (6), and adjusted to 180–220 W for a honed surface (5) heavily loaded with combustion residues (6).

11. Process according to claim 9 or 10, wherein the application with the pulsed laser beam is configured such that graphite lamella portions (4) are exposed on the honed surface (5), ferrite portions (3) are evaporated and remaining cementite portions (2) are remelted into a cementite layer (8), wherein the cylinder running surface of the cylinder or the cylinder liner comprises or consists of lamella graphite cast iron with a pearlitic microstructure (1) and comprises cementite portions (2), ferrite portions (3) and graphite lamella portions (4).

12. Process according to one of the preceding claims, wherein the pulsed laser beam is applied to the honed surface (5) by means of an optical arrangement such that the honed surface (5) is subjected to a processing spot having a length of 28–32 nm and a width of 1.9–2.1 nm.

13. Process according to one of the preceding claims, wherein the pulsed laser beam is guided over the honed surface (5) at a scanning speed of 7200–8800 mm/s in order to subject it to the laser beam.

14. Process according to one of the preceding claims, wherein the individual pulses of the pulsed laser beam have a single-pulse energy of up to 1.8 mJ, preferably 0.2–2.5 μ J.

15. Process according to one of the preceding claims, wherein the process is carried out with an engine in the installed state.
16. Cylinder or cylinder liner of a reciprocating piston engine which has a honed surface (5) with honing grooves (7) and/or secondary grooves, wherein the honed surface (5) has a cementite layer (8) with a thickness of 2 nm up to 1 μm , preferably with a thickness of 3–10 nm.
17. Cylinder or cylinder liner according to claim 16, wherein the cementite layer (8) is closed or largely closed and preferably forms a homogeneous surface structure, wherein the cementite layer (8) particularly preferably extends over the entire honed surface (5).
18. Cylinder or cylinder liner according to claim 16 or 17, wherein the cylinder running surface of the cylinder or the cylinder liner comprises a pearlitic microstructure (1) with cementite portions (2), ferrite portions (3) and graphite lamella portions (4), and graphite lamella portions (4) are exposed on the honed surface (5) and ferrite portions (3) are removed, preferably evaporated.
19. Cylinder or cylinder liner according to one of claims 16 to 18, wherein sharp-edged structures and/or edges of honing grooves (7) and/or protruding material tongues and/or edges of secondary grooves are rounded by melting.
20. Cylinder or cylinder liner according to one of claims 16 to 19, wherein graphite lamella portions (4) are exposed on the honed surface (5) and a network of exposed graphite lamellae is created, which improves the tribological properties of the honed surface (5).

21. Cylinder or cylinder liner of a reciprocating piston engine which has a honed surface (5) with honing grooves (7) and/or secondary grooves, wherein the honed surface (5) is treated by a process according to one of claims 1 to 15.