(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 June 2015 (11.06.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/082235 A1

(51) International Patent Classification:
F16J 9/26 (2006.01)

(21) International Application Number:
PCT/EP2014/075290

(22) International Filing Date:
21 November 2014 (21.11.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10 2013 031072 7
3 December 2013 (03.12.2013) BR

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,

[Continued on next page]

(54) Title: SLIDING COMBINATION FOR USE IN AN INTERNAL COMBUSTION ENGINE

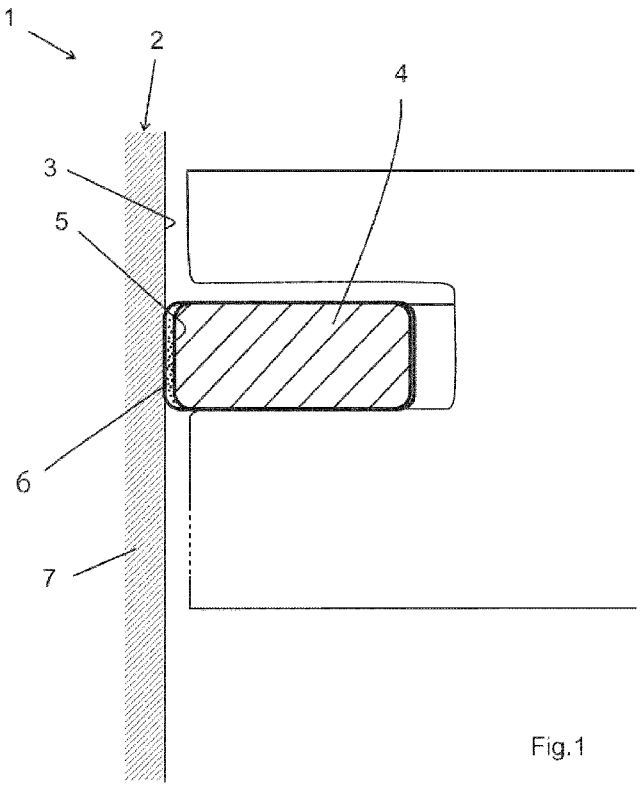

Fig.1

(57) Abstract: The present invention relates to a sliding combination for use in an internal combustion engine, comprising at least one cylinder liner (2) of cylindrical shape defining an internal sliding surface (3) and a ring (4) defined by at least one external lateral sliding surface (5), the external sliding surface (5) of the ring (4) sliding in relation to the internal surface (3) of the liner (2), the surface (5) of the ring having a first coating (6) of metal nitride applied by the physical vapour deposition (PVD) process which slides over a second coating (7) of DLC (diamond-like carbon) applied over the internal surface (3) of the liner (2).

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PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

SLIDING COMBINATION FOR USE IN AN INTERNAL COMBUSTION ENGINE

The present invention relates to a sliding combination formed by at least one piston ring and one cylinder liner, the at least one ring having a coating of metal nitride applied by the physical vapour deposition (PVD) process and the cylinder liner has a diamond-like carbon (DLC) coating. The resultant sliding combination provides greater resistance to wear in comparison with the current solutions, which are very often focused on the improvement of solely one of the elements of the combination.

Description of the state of the art

In an internal combustion engine, the friction existing between the cylinder liner and the piston rings is widely studied because the reduction thereof is crucial to optimise the functioning of engines, improving performance, reducing the consumption of fuel and decreasing the burning of lubricating oil present on the cylinder wall.

A paradigm current until very recently was that wherein the improvement was sought of each component individually. Consequently, research workers developed new improvements (such as, for example, base materials and coatings) for rings and cylinder liners, in terms of the properties of each one thereof. A systematic study having the objective of optimising the performance of more than one component of the combustion cell was uncommon.

Consequently, in many situations the development of a piston ring having a certain coating being very efficient in terms of wear did not provide economic benefits by virtue of the fact that the said new

coating did not perform satisfactorily in the cylinder liners in use.

The great majority of cylinder liners currently in existence are produced in cast iron, a material with excellent properties in terms of tribological compatibility with the rings and the skirts of the piston. This compatibility arises from the fact that cast iron has, naturally, particles of free carbon (graphite) which, by virtue of being a solid lubricant, contributes to the reduction of dynamic friction and, by inference, to the greater durability of the said components.

Recently, with the increase in pressure for a reduction in consumption and pollution by engines brought about by increasingly restrictive pollutant control legislation, engine designers have made use of solutions such as supercharging at increasingly high pressures and new strategies for pollution reduction, such as the utilisation of exhaust gas recirculation (EGR) systems.

These solutions have taken the liners of cast iron to what appears to be the limit of tribological application by virtue of the fact that the said components have demonstrated accelerated wear in these new engines, in particular in the region of the top dead centre (TDC).

As a consequence, the aforementioned increase in pressures to reduce consumption and pollution by engines, as a result of increasingly restrictive pollutant control legislation, has brought about the need for a paradigm change and manufacturers have started thinking about the joint development of rings and liners in a systematic manner, going on to develop new sliding pairs.

A first fruit of this joint approach may be found in international patent application WO2009/069703 which refers to the combined structure of a piston ring and a cylinder liner of an internal combustion engine. The combined structure comprises: (i) a cylinder liner, the sliding surface whereof has an average roughness, taken at 10 different points, of 0.5 µm to 1.0 µm, an effective load roughness (Rk) of 0.2 µm to 0.4 µm, an initial wear height (Rpk) of between 0.05 µm and 0.1 µm, and an oil sump depth (Rvk) of between 0.08 µm and 0.2 µm; and (ii) a piston ring, the external lateral face whereof has an average roughness, taken at 10 different points, of 1.6 µm or less, and an initial wear height of less than 0.3 µm. Furthermore, the piston ring should exert a pressure on the cylinder liner of the order of 0.03 MPa to 0.2 MPa.

The patent document JP2004116707 refers to a combined sliding member formed by a piston ring and a cylinder liner. The piston ring comprises a sliding surface having a roughness Rz of 0.5 µm to 1.0 µm and the cylinder liner has a roughness Rz of 0.5 µm to 1.5 µm, an initial wear height of 0.05 µm to 0.2 µm (based on the standard DIN 4776), an effective load roughness (Rk) of 0.2 µm to 0.6 µm, and an oil sump depth (Rvk) of 0.10 µm to 0.35 µm.

The external lateral surface of the piston ring is formed of a layer of metallic chromium, a laminated layer of metallic chromium, a nitrided layer or a layer applied by the physical vapour deposition (PVD) process. The surface of the cylinder liner, in turn, is preferably formed of cast iron, cast iron with boron or cast steel.

Finally, the Japanese patent document JP2003254156 refers to the combination of a cylinder and a piston ring, wherein there occurs a low degree of sliding friction, reduced scuffing wear, and a reduction in the

loss of the combustion gases through the passage between the rings and the sliding surface of the liner and burning lubricating oil (blow by). The cylinder is made from an alloy based on aluminium and the piston ring has a base of austenitic stainless steel, the external lateral surface being coated by a film of hard chromium constituted by two or more layers wherein microcracks are distributed, each thereof including a part which opens at the external surface and has a depth corresponding to the layer itself remaining and extending partially in the direction of a deeper layer. This constitution ensures an excellent degree of oil retention in these microcracks, ensuring the durability and reducing the consumption of lubricant through blow by.

There had still not been developed a sliding combination achieving the desired gains of durability and strength through the use of a ring with a metal nitride coating applied by the physical vapour deposition (PVD) process and a cylinder liner with a DLC (diamond-like carbon) coating. Studies carried out by the applicant demonstrate that the utilisation of other types of coating on the piston ring, such as chromium ceramic or chromium nitride applied by the thermospray process did not provide the expected results.

Objectives of the invention

The present invention has the objective of providing a sliding combination achieving increases in durability and strength through the use of a ring having a coating of metal nitride applied by the physical vapour deposition (PVD) process and a cylinder liner having a coating of DLC (diamond-like carbon).

More specifically, the present invention has the objective of providing a sliding combination wherein

the compression ring has a coating of CrN, CrCN/C or TiN and the liner has a coating of DLC (diamond-like carbon).

The present invention moreover has the objective of providing a sliding combination achieving increases in durability and strength without the counterpart of an increase in the manufacturing cost thereof which would render it economically unviable.

Brief description of the invention

The objectives of the present invention are achieved by a sliding combination for use in an internal combustion engine, comprising at least one cylinder liner of cylindrical shape defining an internal sliding surface and a ring defined by at least one external lateral sliding surface, the external sliding surface of the ring sliding in relation to the internal surface of the liner, wherein the surface of the ring has a first coating of metal nitride applied by the physical vapour deposition (PVD) process which slides over a second coating of DLC (diamond-like carbon) applied over the internal surface of the liner.

Summarised description of the drawings

The present invention will be described below in greater detail, based on an example of embodiment shown in the drawings. In the figures:

Figure 1 is a cross sectional schematic view of the region of the upper groove (1 to 3) of the sliding combination of the present invention.

Figure 2 is graph showing the measured wear after 1000 hours of a cylinder liner having a coating of DLC against a piston ring having a coating of chromium nitride applied by PVD and, for comparison, against a

ring having a coating of chromium nitride applied by HVOF.

Figure 3 is a graph showing the wear of a conventional sliding combination and the wear of the sliding combination of the present invention.

Detailed description of the figures

The sliding combination 1 of the present invention has been developed as a response to the increasingly severe requirements for increase in performance and reduction in consumption and emission of pollutants to which internal combustion engines are subject.

The sliding combination 1 of the present invention comprises at least one cylinder liner 2 of substantially cylindrical shape defining an internal sliding surface 3 and a ring 4 defining at least one external lateral sliding surface 5, such that the external lateral surface 5 of the ring 4 slides in relation to the internal surface 3 of the liner 2.

The ring 4 is preferably a first groove ring or compression ring, however it is clear that it may assume any other possible configuration such as, for example, a second groove ring or even an oil scraper ring, without the resulting invention ceasing to be included within the scope of protection of the appended claims. In the same manner, the specific geometry thereof is irrelevant in terms of the scope of protection. Finally, the base material constituting the ring may vary freely, provided that it permits the application of a coating which shall be detailed below. The ring 4 is preferably constituted by cast iron or stainless steel.

The cylinder liner 2, in turn, may also assume diverse specific configurations having internal diameters and

an external perimeter which may vary freely, recalling that this latter presents, as a rule, elements which facilitate the affixing thereof to the engine block (these not being illustrated). The base material of the liner is preferably, but not obligatorily, cast iron, the specific composition whereof may vary as a function of design and operational parameters of the engine wherein it will be installed.

Any other materials may be utilised provided that they are functional such as, for example, cast steel, without the resulting liner ceasing to be included within the scope of protection of the claims.

Whatever the specific constitutions may be of the ring 4 and of the liner 2, the surface 5 of the ring has a first coating 6 of metal nitride applied by the physical vapour deposition (PVD) process which slides over a second coating 7 of DLC (diamond-like carbon) applied over the internal surface 3 of the liner 2. In this manner it is clear that the material constituting the ring and the liner may freely vary provided that they render viable the application of the respective coatings.

Following diverse studies, the applicant has observed that the isolated study of the piston ring and of the liner was insufficient to ensure the two in operation when the ring slides axially within the interior of the liner over the billions of cycles of operation of the engine.

The various layers 5, 5’ of the coating 3 are applied by a process known by those skilled in the art as physical vapour deposition (PVD).

It should be noted that the physical vapour deposition process involves purely physical processes, such as high temperature, vacuum evaporation or plasma

bombardment. Furthermore, a gas may be added such as, for example, nitrogen (N_2), such that this combines with the metallic material which is being deposited to form nitrides. Among the processes employed to evaporate the metallic material from the source (target cathode), one of the most well known is the cathodic arc wherein a high power electric arc is directed at the material source, evaporating it and generating ions which are deposited on the part. In the presence of gases such as nitrogen (N_2), the nitride of the metallic material is deposited on the part.

That is to say, the process of deposition by cathodic arc is a technique of physical vapour deposition wherein an electric arc is employed to vaporise material from a target cathode. The vaporised material then condenses on a substrate, forming a thin film.

In essence, control of the pressure of the nitrogen (N_2) gas and of the vaporised metal permits precise control of the coating which it is desired to obtain. In the case of the present invention, the coating 6 of the ring 4 is preferably composed of CrN, CrCN/C or TiN, it being more preferably composed of CrN.

The coating 6 of the ring 4 preferably has a hardness of between 1000 HV and 2300 HV, a thickness exceeding (>) 5 µm, preferably between 20 µm and 40 µm, and presents columnar morphology.

The coating 7 of the liner 2 has a hardness of between 10 GPa and 20 GPa, a thickness exceeding (>) 1 µm, preferably between 2 µm and 15 µm, and presents gradient morphology.

The present sliding pair displays a more reduced wear of the components thereof, thus ensuring greater durability of engines within the original parameters or functional principles thereof.

The graph of figure 2 illustrates the average wear of the cylinder liner 2 having a coating 7 of DLC, after 1000 hours, against the piston ring 4 having a coating 6 of chromium nitride applied by PVD and, for comparison, against an unspecified piston ring having a coating of chromium nitride applied by the HVOF process. The test was executed in an engine having 6 cylinders in line, wherein the linings were of pearlitic cast iron with the DLC coating.

In average figures, after 1000 hours of operation of the engine, the use of piston rings having a coating applied by HVOF gave rise to wear of the linings of approximately 16 µm at the top dead centre (TDC) position whilst the use of rings 4 having a coating of CrN applied by PVD led to the wear of the liners of identical configuration being reduced by approximately 3 µm at TDC.

The graph of figure 3, in turn, shows the comparative wear between two sliding pairs, a first sliding pair being formed by a conventional liner allied with the ring 4 having a coating of CrN applied by PVD, and a second sliding pair formed by the liner having the coating of DLC allied with the ring 4 having a coating of CrN applied by PVD.

The graph illustrates wear measurements on each of the components taken after 500 hours and 1000 hours and makes it clear that, after 500 hours of testing, the combination of the present invention presented wear being 23.4% lower in comparison with the combination employing a conventional liner. After 1000 hours the results are even more advantageous, with the wear being 29.5% lower. It is sufficient to observe that the sliding combination 1 of the present invention demonstrated, after 1000 hours of testing, a degree of

wear which the combination provided with the conventional liner demonstrated in half the time.

These results challenge that which is to be expected, according whereto the greater the hardness of the coating of the ring, the greater will be the wear of the liner. The result was unexpected since, as the surface hardness of the liner is increased, greater wear of the ring is to be expected, and the result obtained was surprisingly the opposite to that expected because a greater surface hardness of the liner resulted in less wear of the rings. This reduction is illustrated in the graphs of figures 2 and 3, corroborating the tribological studies disclosed by the applicant.

An example of preferred embodiment having been described, it shall be understood that the scope of the present invention covers other possible variations, being solely limited by the content of the attached claims, the possible equivalents being included therein.

CLAIMS

1. Sliding combination for use in an internal combustion engine, comprising at least one cylinder liner (2) of cylindrical shape defining an internal sliding surface (3) and a ring (4) defined by at least one external lateral sliding surface (5), the external sliding surface (5) of the ring (4) sliding in relation to the internal surface (3) of the liner (2), the combination being characterised in that the surface (5) of the ring has a first coating (6) of metal nitride applied by the physical vapour deposition (PVD) process which slides over a second coating (7) of DLC (diamond-like carbon) applied over the internal surface (3) of the liner (2).

2. Sliding combination according to Claim 1, characterised in that the coating (6) of the ring (4) is preferably composed of CrN, CrCN/C or TiN.

3. Sliding combination according to Claim 2, characterised in that the coating (6) of the ring (4) is more preferably composed of CrN.

4. Sliding combination according to Claim 1, 2 or 3, characterised in that the coating (6) of the ring (4) has a hardness of between 1000 HV and 2300 HV, a thickness exceeding (>) 5 µm, preferably between 20 µm and 40 µm, and presents columnar morphology.

5. Sliding combination according to Claim 1, characterised in that the coating (7) of the liner (2) has a hardness of between 10 GPa and 20 GPa, a thickness exceeding (>) 1 µm, preferably between 2 µm and 15 µm, and presents gradient morphology.

6. Sliding combination according to Claim 1, 2, 3 or 4, characterised in that the ring has a base of stainless steel or cast iron.

7. Sliding combination according to Claim 1 or 5, characterised in that the liner (2) has a metal base.

8. Sliding combination according to Claim 7, characterised in that the liner (2) has a base of cast iron.

9. Sliding combination according to Claim 7, characterised in that the liner (2) has a base of aluminium alloy.

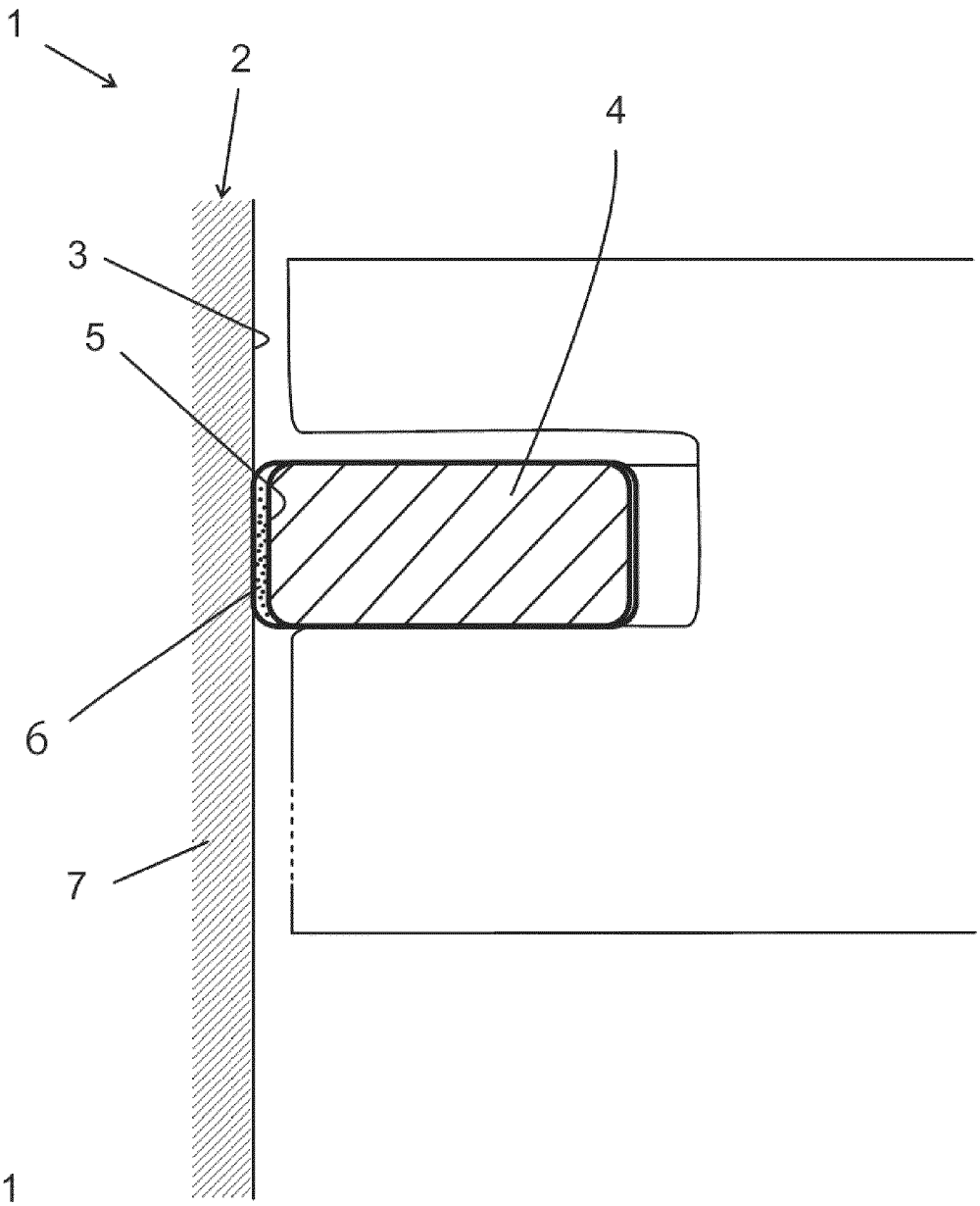

Fig.1

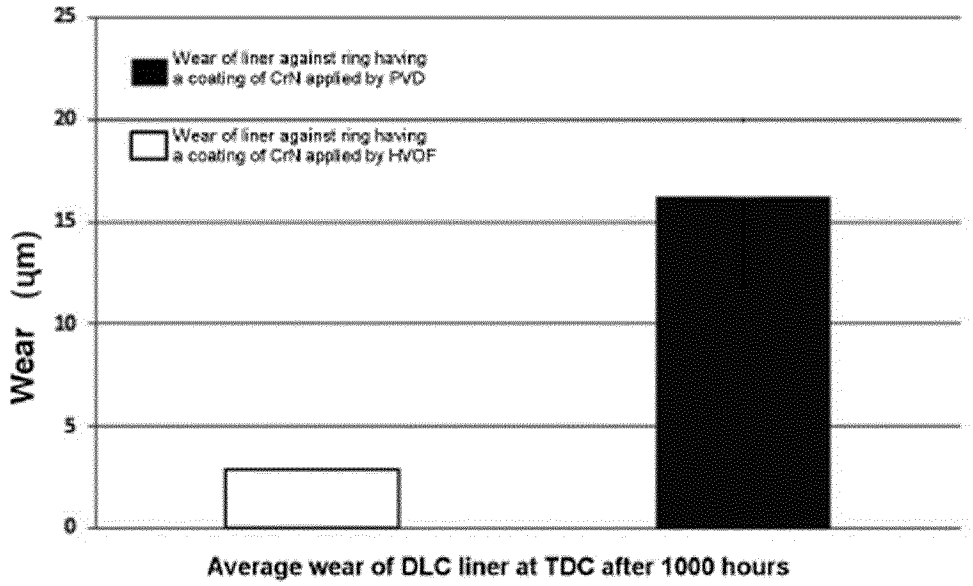
25
20
15
10
5
0
Wear (µm)
Wear of liner against ring having a coating of CrN applied by PVD
Wear of liner against ring having a coating of CrN applied by HVOF
Average wear of DLC liner at TDC after 1000 hours

Fig.2

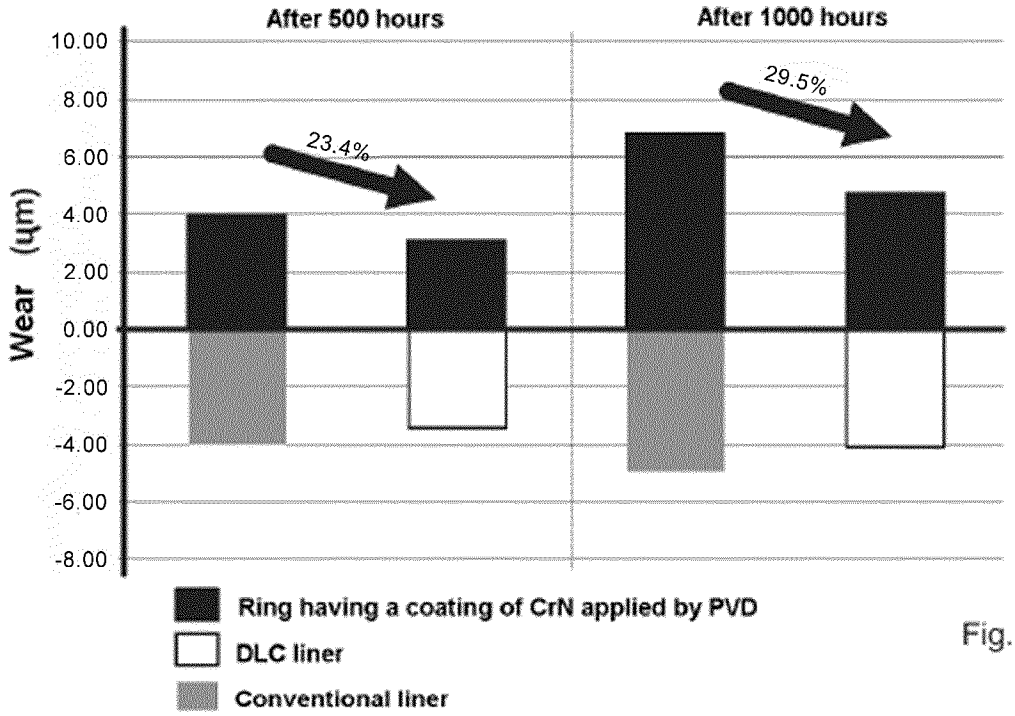
After 500 hours
After 1000 hours
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Wear (µm)
23.4%
29.5%
Ring having a coating of CrN applied by PVD
DLC liner
Conventional liner

Fig.3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/075290

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16J9/26
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F16J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 578 908 A1 (NIPPON PISTON RING CO LTD [JP]) 10 April 2013 (2013-04-10) paragraphs [0053] - [0054], [0057]; claims 9-11; figures 1-2, 8	1-9

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 February 2015	20/02/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Regaud, Christian

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2014/075290

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2578908 A1	10-04-2013	CN 102939482 A	20-02-2013
		EP 2578908 A1	10-04-2013
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		WO 2011151927 A1	08-12-2011
		WO 2011152114 A1	08-12-2011