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A MODEL SCALE TEST METHOD FOR THE PISTON RING – CYLINDER LINER TRIBOSYSTEM OF INTERNAL COMBUSTION ENGINES

Rising technical standards of customers, legal requirements and the trend to minimize maintenance effort raise the thermal, mechanical and tribological loads on components of combustion engines. In this regard, emphasis is laid on improving the piston ring – cylinder liner tribosystem, one with the highest energy losses. An efficient performance has to be guaranteed during its lifetime. Tribological investigations could be carried out on engine test benches, but they are highly cost-intensive and time-consuming. Therefore, a damage-equivalent test methodology was developed with the analogous tribological model, "ring-on-liner". The research was carried out under two characteristic operating conditions. One with a "standard" operating system, modelled in line with ideal lubrication conditions, and the other "extreme abrasive" operating system, typical to a system running on a lubricant contaminated by abrasive particles. To optimize the tribological loading capacity of the cylinder liner, with focus on these two operating conditions, numerous nitride coatings have been investigated. The key aspects being seizure resistance, running-in characteristics and long term wear behaviour.

1. Introduction

In today's world, environment, climate and energy related issues are at their forefront and hence, future developments related to the combustion engines, independent of their operational principle and applications, are steered and strongly affected by them. In order to comply with the national and international emission laws, and also keeping in mind the rising customer demand for a better fuel efficiency and higher reliability, the overall system must be adapted and modified. In this regard, each of the components must be tuned in to meet their ever-rising mechanical, thermal and tribological

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loads. Hence, the tribological system of piston ring – cylinder liner, an area with highest energy loss in the combustion system, is of particular interest [6].

Apart from the system related "problematic areas", such as the boundary friction in the upper dead centre, frequent inclusion of abrasive particles in the system could be considered as critical, too. These contaminations, like coking as a result of the engine oil entering into the combustion chamber or, burning of polluted gas and abrasive-acting gases, have a negative effect on the functioning of the system [7]. In order to withstand these loads, the components must be developed continuously to obtain higher wear resistance, thus increasing their efficiency and reliability. Spontaneous failures should, if possible, be reduced to ensure a continuous functioning of the system thus safeguarding the costs and resources. For the tribological investigations of the piston ring – cylinder liner system, engine test benches can be used but they are highly cost intensive and uneconomical [4, 5]. In this paper, a damage-equivalent test methodology is presented, with which one can compile characteristic results for an optimization, quite economically and in lesser time [9]. The system was modelled in scale, and the tribological analogous model "ring on liner" was used for the tests [1].

2. Tribological and material fundamentals

A schematic of the piston ring-cylinder liner system investigated in this present study is depicted in Fig. 1. The piston ring consists of a low alloyed tempered spheroidal cast iron coated with a chrome ceramic layer which acts as the running surface [8]. Lamellar cast iron (EN-GJL-250), known for its superior tribological characteristics and high damping capacity, was used as the material for the cylinder liner. Hard phases (steadit) are formed in the base material as a result of selective alloying, and these hard phases are about three times harder than the base material itself. Due to running-in and wear processes in the cylinder liner, base material can be degraded, leaving behind the hard phases in the contact zone. The goal here is to obtain low energy and wear resistant contact conditions. The desired surface topography of the cylinder liner is achieved through a multilevel honing process. The surfaces show smooth, steady plateaus with fine secondary hone-scores, which bear the load and assume sliding function. The deep, irregularly arranged primary hone-scores store the lubricant, thus facilitating constant lubrication.

In order to be able to increase the functional reliability of the system, predominantly in abrasive operating conditions, the system must be optimized and adapted to the nonideal, polluted conditions. As a first step, the running surfaces of cylinder liners were thermochemically modified. The specimens

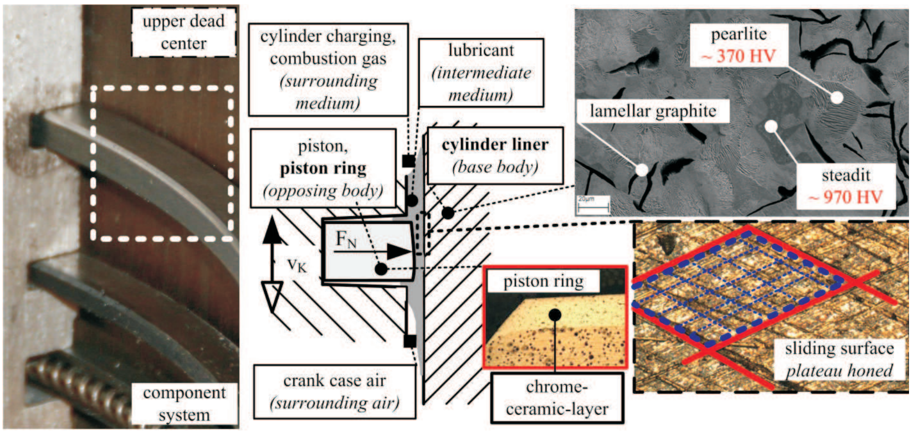

Fig. 1. Schematic of the tribological system piston ring – cylinder liner [1]

were nitrated with selective parameters, whereby nine different layers were produced and finally investigated [2, 3]. In Fig. 2 the EDX-analysis of nitrated cylinder liner surface is shown.

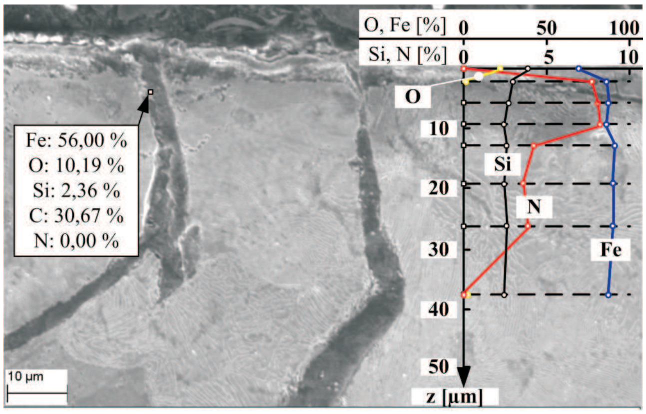

Fig. 2. EDX-analysis: cross-section of the nitrided surface zone [1]

3. Test methodology: configuration and strategies

The test rig TE 77 from Phoenix Tribology with the analogous “ring-on-liner” test model was used for the tribological investigation of the described system. Fig. 3 shows the Tribometer with a detailed schematic of the test configuration.

The oscillating linear movement (25 mm stroke) is produced with the help of a DC motor and a double-eccentric transmission system. The normal

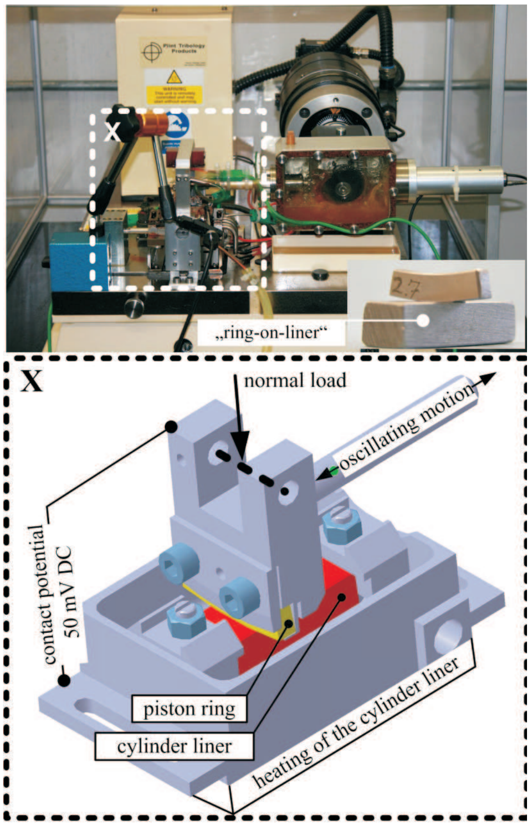

Fig. 3. Test rig TE 77 with detailed drawing of the test configuration [1]

load (max. 1000 N) is applied with a servo-actuator and a lever-mechanism. Both of the specimens were cut out from a real components. An important point in all of these investigations is the conformity between the two specimens. To guarantee conformity, a light-gap-method was applied. The cylinder liner is mounted in a case. The piston ring is fixed to the driving rod with the help of an adapter. The reciprocating movement is supplied by this rod, and so is the application of normal load. The lubricant is drip-fed close to the right edge of the cylinder liner. To ensure temperature conditions equivalent to those in a combustion engine, the cylinder liner is heated with the help of four heating cartridges located beneath the case. Visualization of the thermal conditions is carried out by measuring the specimen temperature (T_1) of cylinder liner and contact-near-temperature (T_2), measured as close to the contact by means of a hole drilled in the piston ring. The contact potential represents the electrical resistance between the mating surfaces and is used as qualitative measure of the boundary layers or the tribofilms formed.

The described component scale test configuration allows conducting damage-equivalent investigations of the piston ring – cylinder liner system. In order to be able to guarantee the transferability of results of tribological model-tests on to real engine system, reference tests have been carried out. With these tests, the mechanical, kinematic and thermal characteristics of the system were determined and accordingly adjusted. Fig. 4 shows the results (3D, microscopy) of a test with stepped parameters.

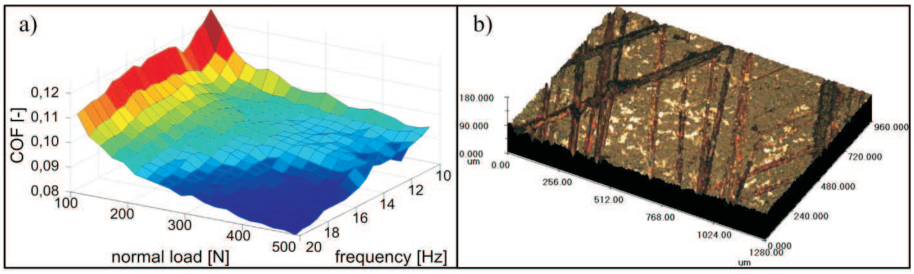

Fig. 4. Analysis of the interdependence of coefficient of friction, frequency and normal load; a) three-dimensional analysis; b) microscopy of the cylinder liner [1]

Tribological investigations and evaluations of individual system characteristics require different test strategies in addition to a suitable test configuration with an analogous test model. A test strategy is a suitable test program, which is adapted to the system requirements and operating ranges. The following strategies are proposed for the tribological characterisation of the system:

- ***Test with stepped parameters:*** Analysis of coefficient of friction, frequency and normal load.
- ***Seizure test:*** Investigation of the thermal stability of the system.
- ***Long-time test with ideal lubricating conditions:*** Test with constant parameters. Investigation of running-in and long term sliding and wear characteristics at ideal lubricating conditions.
- ***Long-time test with lubricant contaminated by abrasive particles:*** Test with constant parameters. Test methodology to replicate the operating condition with an oil of insufficient purity. An exactly defined quantity (based on used oil analysis ISO 4406) of abrasive particles (Arizona Dust ultrafine grade) is mixed to the lubricant.

4. Results of the comparative tribological investigations

In this chapter, the results from the tribological tests and damage analysis are presented. The results with base material (untreated GJL-250) are considered as our benchmark. Similar tests were carried out with nitrated cylinder liners and, in this short version only one significant variant is presented.

4.1. Cylinder liner: untreated

The tribometric data from tests on untreated specimen are shown in Fig. 5. The test with ideal lubricating condition (top measurement) shows quite stable behaviour. A quick running-in process is followed by a drop in the coefficient of friction, which remains low and an increase in the contact potential to its maximum value is seen. In this test an energy efficient contact condition with no instabilities is observed. On the other hand, the untreated cylinder liner with a low surface hardness is strongly affected by insufficient and abrasive lubricating conditions and this is seen in Fig. 5 (bottom measurement). The coefficient of friction is very hectic and at a relatively higher level. In contrast, the contact potential is close to zero, indicating the absence

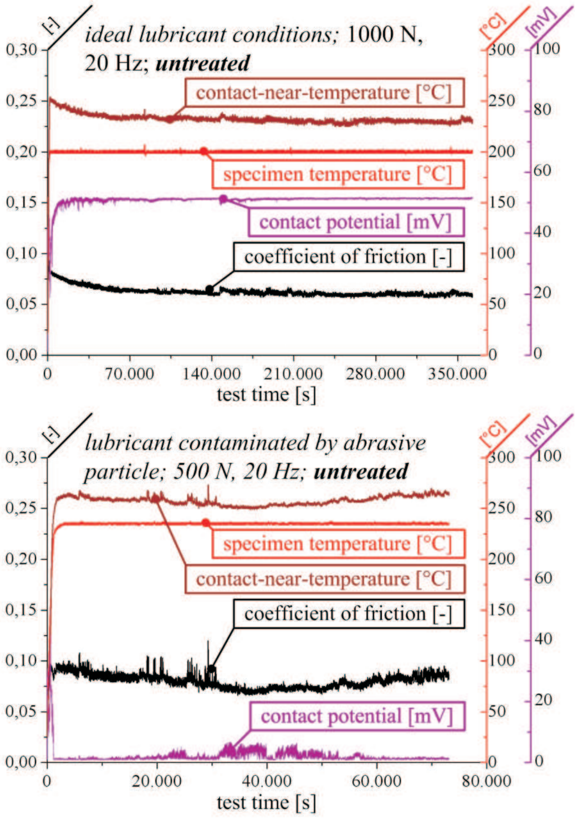

Fig. 5. Measured data: untreated cylinder liner [1]

of boundary layer formation, thus resulting in extreme grooving with high wear. A stable operating condition cannot be obtained at any point of time. This system behaviour needs to be improved.

Fig. 6 shows the microscopic images of the cylinder liner and the piston ring. The large plateaus bear the load and the deep primary hone-scores store the lubricant. Due to the running-in and wear of the cylinder liner, base material is degraded and hard phases (Steadit) remain in the contact zone. A low-energy contact is formed.

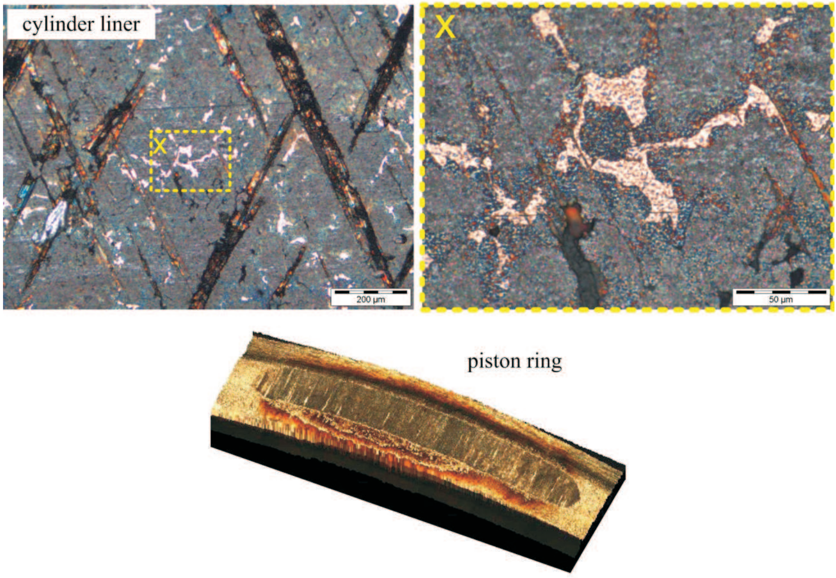

Fig. 6. Microscopy images of the specimens: long time test with ideal lubricant conditions [1]

4.2. Cylinder liner: nitrated

The tribometric result from one of the nitrated cylinder liner test is presented in Fig. 7. The test under ideal lubricating condition shows that during the running-in process, which is longer than in the test with the untreated cylinder liner, a stable contact can be formed. The system stability (in terms of contact potential) is disturbed by wear particles. The reason being that, nitrating process in the graphite lamellar and steadit regions leads to an inhomogeneous surface topography with defects. These faulty layers extend the running-in process and may break off due to fatigue, thus interrupting the stable system running. The test with abrasive particles shows a stable, safe behaviour, indicating a mild and fine wear process. The hard nitrating layer forms a barrier and increases the resistance to abrasive wear.

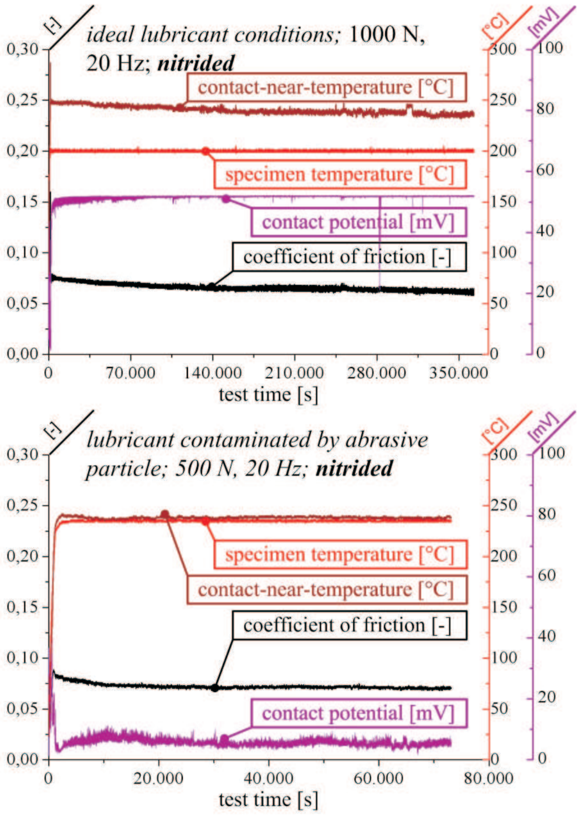

Fig. 7. Measured data: nitrated cylinder liner [1]

The microscopic images (Fig. 8) of the nitrated cylinder liner show a homogeneous, intact nitride layer with a detailed hone structure. The surface bears just a few defects and can ensure high system stability under ideal as well as abrasive conditions. With increased loads, additive layers can be formed.

5. Conclusion

The test methodology presented here, encompassing component-like test configuration and systematically defined test strategies, makes it possible to accomplish damage-equivalent tests with high quality results. Significant differences between different specimen variants can be compiled by comparative parameter investigations. The results with the untreated cylinder liner (base

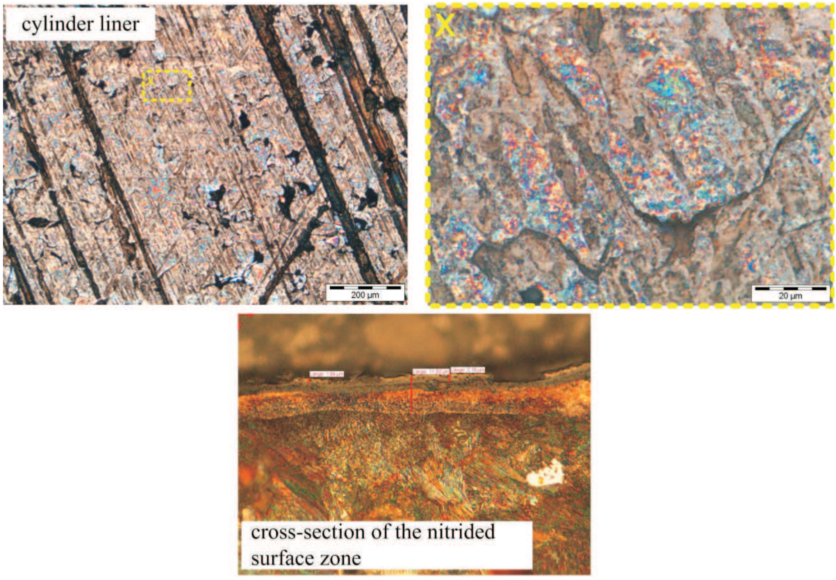

Fig. 8. Microscopy images of the specimens: long time test with ideal lubricant conditions [1]

material GJL-250) are our benchmark. With ideal lubricating conditions, the untreated cylinder liner shows the best results, as expected. The supporting hard phases (steadit) on the sliding surface, allows for a low energy system with stable running.

Furthermore, the difference in behaviour and performance of the system, when using abrasive lubricant in long term tests was characterized. The untreated standard specimens cannot withstand these aggressive conditions. The nitrated variants show clear advantages in terms of an increase in the surface hardness, which acts as a hard-facing. The abrasive wear resistance is higher and the test runs more smoothly. The disadvantages of the nitrated specimen at ideal lubricating conditions are, for instance, extended running-in phase and the system instability during the test. This can be reduced or eliminated by systematic changes in the overall system. Further optimization of the system w.r.t. topography, base material and optional thermal treatment is possible.

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REFERENCES

[1] Schiffer, J.: Schadensorientierte Prüfmethodenentwicklung für das System Kolbenring-Zylinderlaufbahn, Diplomarbeit, Montanuniversität Leoben, 2009 (excluded from public use by 2014).

[2] Schiffer, J.; Gódor, I.; Grün, F.; Krampl, H.; Eichlseder, W.; Dibiasi, W.; Strobl, V.: Anwendung einer Prüfmethodik zur tribologischen Untersuchung des Systems Kolbenring-Zylinderlaufbahn von Großmotoren, Fachtagung der Gesellschaft für Tribologie (GfT), 2009, Göttingen, ISBN 978-3-00-028824-1.

[3] Schiffer, J.; Gódor, I.; Grün, F.; Dibiasi, W.; Strobl, V.; Eichlseder, W.: Schädigungsäquivalente tribologische Untersuchungen zur Erhöhung der Zuverlässigkeit des Systems Kolbenring/Zylinderlaufbahn, Symposium der Österreichischen Tribologischen Gesellschaft, 2009, Waidhofen/Ybbs, ISBN 978-3-901657-34-4.

[4] Czichos, H., Habig, K-H.: Tribologie Handbuch, 2. Auflage, Friedr. Vieweg & Sohn Verlag, Wiesbaden, 2003, ISBN 3-528-16354-2.

[5] Truhan, J.J., Qu, J., Blau, P.J.: A rig test to measure friction and wear of heavy duty diesel engine piston rings and cylinder liners using realistic lubricants, Tribology International 38 (2005), S 211-218.

[6] Küntscher V., Hoffmann W.: Kraftfahrzeugmotoren – Auslegung und Konstruktion, 4. Auflage, Vogel Verlag, Würzburg 2006, ISBN 978-3-8343-3000-0.

[7] Bölter J., Scherge M.: Die Auswirkungen von Dieselruß auf das tribologische Verhalten von Motorkomponenten, Fahrzeugtechnik 69/1.

[8] Esser, J.; Hoppe, S.; Linde, R.; Münchow, F.: Kompressionskolbenringe in Otto- und Dieselmotoren – Stand der Technik und Ausblick, MTZ 7-8/2005 Jahrgang 66.

[9] Galligan J., Torrance A.A., Liraut G.: “A scuffing test for piston ring/bore combinations, Part I. Stearic acid lubrication”, Wear 236 (1999), S 199-209.

Metoda badania w skali modelowej systemu trybologicznego pierścień tłokowy – tuleja cylindra silnika spalinowego

Streszczenie

Rosnące wymagania techniczne ze strony odbiorców, wymagania prawne i trend w kierunku minimalizacji wysiłku związanego z konserwacją prowadzą do wzrostu mechanicznych, termicznych i trybologicznych obciążeń elementów silników spalinowych. Z tych względów kładzie się nacisk na poprawę jakości systemu trybologicznego pierścień tłokowy – tuleja cylindra, w którym występują największe straty energii. Wydajna praca tego systemu powinna być zagwarantowana przez cały czas jego życia. Badania trybologiczne można prowadzić na stanowiskach do prób silnikowych, lecz są one bardzo kosztowne i czasochłonne. Z tego względu opracowano metodologię badań, równoważną badaniom niszczącym, przeprowadzanych na analogowym modelu trybologicznym typu „pierścień w tulei”. Badania były prowadzone dla dwu charakterystycznych rodzajów warunków roboczych. Pierwszy, „standardowy” system działania, jest modelowany przy założeniu idealnych warunków smarowania; system drugi, z „ekstremalnym ścieraniem”, jest typowy dla pracy w warunkach, gdy środek smarny jest zanieczyszczony cząsteczkami ściernymi. Koncentrując się na dwu wymienionych systemach działania, optymalizowano obciążalność trybologiczną tulei cylindra badając różne rodzaje pokryć azotkowych. Aspektami kluczowymi były odporność na zatarcie, charakterystyki docierania i długookresowe charakterystyki zużycia.