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SRV®-Testing of the Tribosystem Piston Ring and Cylinder Liner Outside the Engine

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Abstract: An OEM driven working group started in January 2004 to elaborate the philosophies, concepts and test procedures for testing piston ring and cylinder liner materials as well as engine oils outside the engine using the SRV® test equipment. The different SRV® test philosophies in use by OEMs are compiled. The working group focuses on a.) ASTM sequence VIB (Fuel economy by aging oils), b.) friction and wear in the top dead region under mixed/boundary lubrication, c.) extreme pressure load under mixed/boundary lubrication and d.) hydrodynamic friction. Tribological test results and precision data are presented.

Keywords: SRV, piston ring, cylinder liners, engine oils, ep, extreme pressure, wear, friction, power cylinder components, lubrication, oil

Introduction

Industry seeks to use test systems that enable a qualitative or even semi-quantitative correlation between cheap model tests and expensive and time-consuming component or product testing. There is a strong demand today for test procedures that can rapidly screen potential lubricants and materials before system-level life tests are performed.

In the last decade costs in the US to complete all the engine tests for the principal heavy-duty diesel (HDD) engine oil category have increased five fold, while passenger car motor oil (PCMO) costs have almost doubled, as each:

a. new set of specifications is more technically complex than the previous,
b. the frequency of issue is increasing and
c. Cost are escalating or spiralling.

In Europe, the picture is also of increased costs but related more to stringent and different, individual OEM specifications (MB 229.31, or VW injection pump) and the need for regular OEM re-approvals. The European sequences contain nine, eight and six engine tests respectively, which are developed through the CEC which ensures acceptable test precision and then monitors the test and test methods, whereas the test used for in-house specifications are controlled by the OEMs. These engine tests are related to wear, extreme pressure, fuel economy (friction) and soot, detergent behaviour or engine cleanliness.

To complete all the engine tests required for actual US-API PC-9 oil, assuming only one test on each test type, an additive company spends around $500.000, same as for the European ACEA E7 HDD oil. To complete all the engine tests required for actual PCMO ACEA A5/B5-04 oil, assuming only one test on each test type, an additive company spends around $ 223.000, followed by the specific OEM tests.

In consequence, industry should seek out and remove test redundancy and repetition. Another way to reduce costs and shorten time is to develop a significant wear test outside of the engine using samples prepared from production parts or certified engines and have these tribologically stressed in a tribometer. This alternative requires an extensive exchange of OEM wear test data achieved in engine sequence tests (like CEC-L-51-A-98 using MB OM602A or CEC-L-54-T-96, using M-111) to be compared with those from the test rigs (tribometers) in order to identify the "correct" or transferable test parameters in order to ensure lubricant performance is correctly evaluated. The input coming from OEMs and component suppliers crucial here to ensure success. Also, tribometer-based test procedures need to be consistent and effectively monitored across all test laboratories.

SRV® Test Procedures

Today, several DIN and ASTM test methods [1] prove the high technological level and versatility of the SRV® test philosophy. The precision statements in the test methods underline "best in class", which are annually or biannually verified by round robin tests. The SRV® test principle was developed in 1968. After more than 37 years of experience with more than 260 test machines worldwide, a number of test procedures [2] have been developed and standardized. These are summarized in Table 1. In China and Japan, SRV® related working groups were established in 2004/2005 in order to transfer and extend these standards to Asian methodologies. Due to all of these efforts, more and more OEMs base their technical requirements on tribological tests with SRV®.

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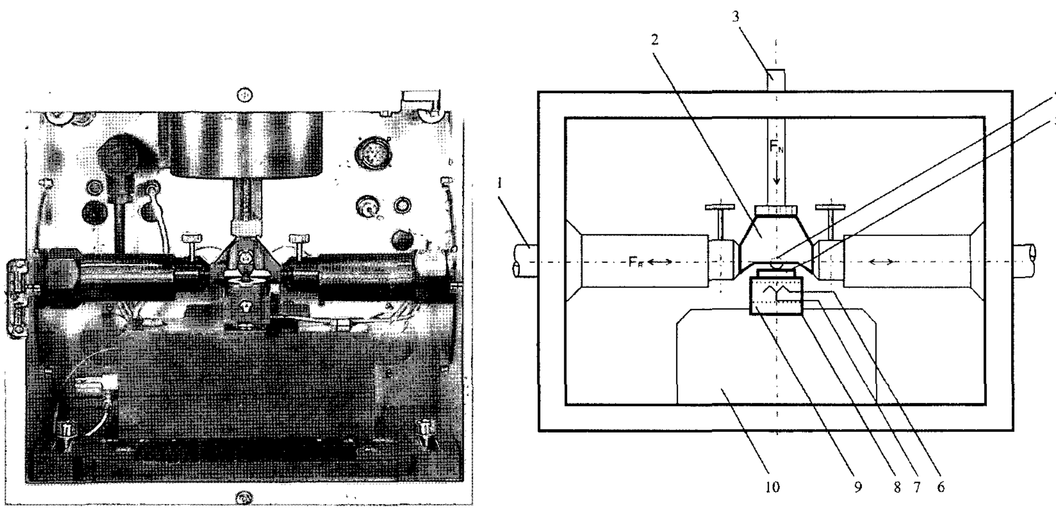
Table 1. Standard Test Procedures Referring to the High-Frequency, Linear-Oscillating Test Machine

Type of Lubricant	DIN	ASTM
Oils, fluids	51834, part 2 (white print)	⇒ D6425-05
	51834, part 3 (white print)	
	51834, part 4 (under preparation)	
	51834, part 5 (under preparation)	⇒ WK D xxxx
Greases	51834, as future part 6	⇐ D5706-06
	51834, as future part 7	⇐ D5707-06
Needle and Sinker Oils	62193, part 1	
Plastic Socket Suspension Joints	51834, part 9	⇒ WK Dxxxx
Solid Bonded Films (former DIN 65593, yellow print 2001, EP and film life)	51834, part 8	⇒ WK D7422
Friction and Wear of Piston Ring Cylinder Liner	(under preparation)	
Extreme Pressure Properties of Engine Oils	(under preparation)	
Fuel Economy under Aged Oils	(under preparation)	
Hydrodynamic Friction	(under preparation)	
Reciprocating wear test for ceramic coatings [CEN/TC 184/WG5 Document N148]	EN 1071	
Test apparatus	51834, part 1 (white print)	



1. Oscillation drive rod
2. Test Ball Holder
3. Load Rod
4. Test Ball
5. Test Disk
6. Electrical Resistance Heater
7. Resistance Thermometer
8. Test Disk Holder
9. Piezoelectric Measuring Device
10. Receiving Block

Fig. 1. Schematic view of the SRV® Test Arrangement and the Test Chamber.

Test Equipment

In the basic test configuration applying for all machine generations, an upper test specimen is rubbed against a lower specimen (see Fig. 1). A few milligrams of lubricant (0.,3 ml) or grease may be placed into the tribo-contact. After lubricant has been placed on the test specimen and these have been installed in the test chamber, the normal force is applied mechanically to the upper specimen in a direction normal to the direction of motion at a given test frequency and stroke.

The friction force is measured continuously by means of a piezoelectric load cell under the lower specimen holder, which is attached to a rigid test block. The wear scar and track dimensions are determined after a given test duration by optical microscopy, 3D laser microscopy or stylus profilometry.

The test block and the holder can be heated to +295°C (optionally up to +900°C) and cooled to control the temperature of the lower specimen.

From the beginning, the SRV® test machine is, in contrast to competitors, driven by a linear, electromagnetic actuator drive with sinusoidal or other selectable motions. As fully electronically operating test equipment, it enables dynamic testing by designing custom made test cycles.

The SRV® test machines covers in the market actual five generations of models: SRV® 0, SRV® I, SRV® II, SRV® III and

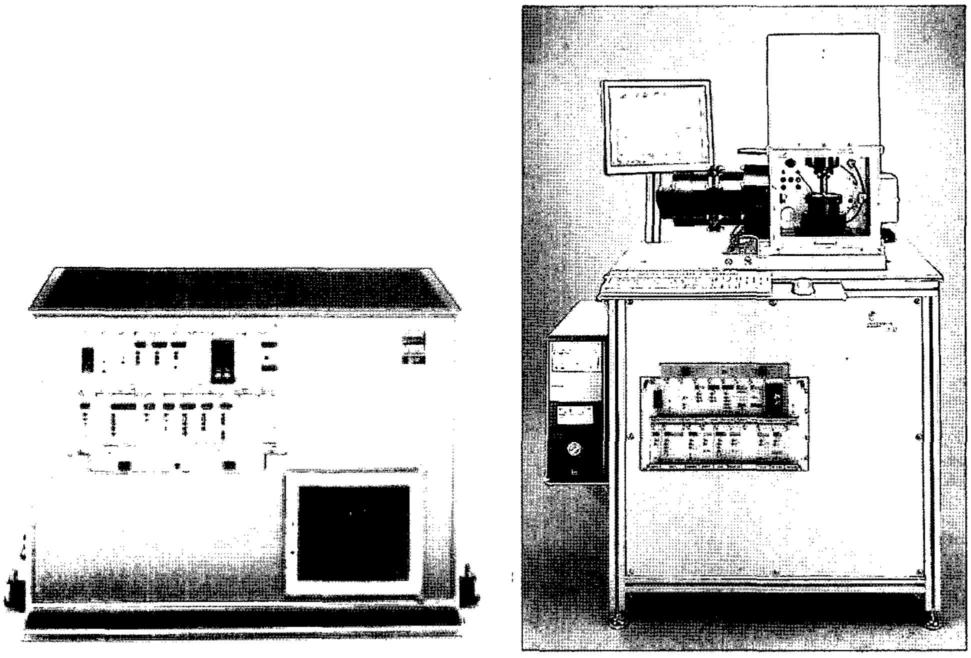


Fig. 2. SRV® Test Machines (left: model III; right: model 4).

SRV® 4. The latter two are illustrated in Figure 2. The SRV® I and II models have proven in nine international round robin tests the same precision as SRV® III or SRV® 4 models.

Benchmark of OEM-based SRV® tests

The working group has compiled in detail for internal uses the test procedures in use within DaimlerChrysler AG, Volkswagen AG, BMW AG, FIAT AUTO, GM, FORD, TOYOTA, NISSAN, TEKNIKER, Tsinghua University, Lanzhou University, Tribology Testing, BAM, AC^{2}T, VTT, Federal Mogul, NPR, TARABUSI and many others. Some of the test geometries are presented in Fig. 3. The consensus is clearly visible, that only test specimens prepared from liners and rings are under use.

The amount of oil in the contact differs from 0,5 ml over a bath of 30 ml to an oil circuit, which injects the oil from a heated nozzle into the contact. The latter lubrication system is also suited for radionuclide wear evaluation.

The test temperatures varied from 135°C to 200°C within a mean of around 160°C. The stroke for friction and wear testing is selected from 2 mm to 4 mm and the test frequencies from 30 Hz up to 100 Hz. The selected normal loads depended on the set-up of an inline or anti-parallel run (see Fig. 5) of piston ring in the cylinder liner bore. The anti-parallel test set-up makes the procedure independent of the influence of the piston ring profile on tribological wear results.

Working area

In a number of meetings and the discussions the working group came to the conclusion that it should focus on the following areas:

a. ASTM sequence VIB (Fuel economy by aging oils),
b. Friction and wear in the top dead region under mixed/boundary lubrication,
c. Extreme pressure load under mixed/boundary lubrication and
d. Hydrodynamic friction,

where the working group feels, that the OEMs have enough in-house engine data available to correlate with SRV® test results.

Round Robin Tests

The discussion lead to the start of the first round robin test which was to determine the friction and wear behavior of materials and lubricants. To this end, it was agreed to prepare the liner samples from certified test engines M107 and M272 supplied by DaimlerChrysler AG. From the 4-cylinder M107, liner samples in GGL26Cr were machined and from the 6-cyliner M272 the AlSi25Ni4 liner samples (SILITEC). The matching ring specimens were supplied by Federal Mogul Burscheid GmbH.

This first round robin test aims to

a. clarify the influence of test arrangement (in-line or anti-parallel),
b. elaborate first hints about the influence of
   -temperature and
   -load.

Another purpose is to compare the different wear evaluation techniques on piston rings. Stylus profilometry as described in DIN 51834, part 3, eases wear quantification of wear tracks on liner samples.

Test results

The following test results were achieved on different SRV® machines according to the in-house test procedures. The materials and oils tested in to are described in detail in references [3] and [5].

-Extreme pressure

The test procedure for determining the results under extreme

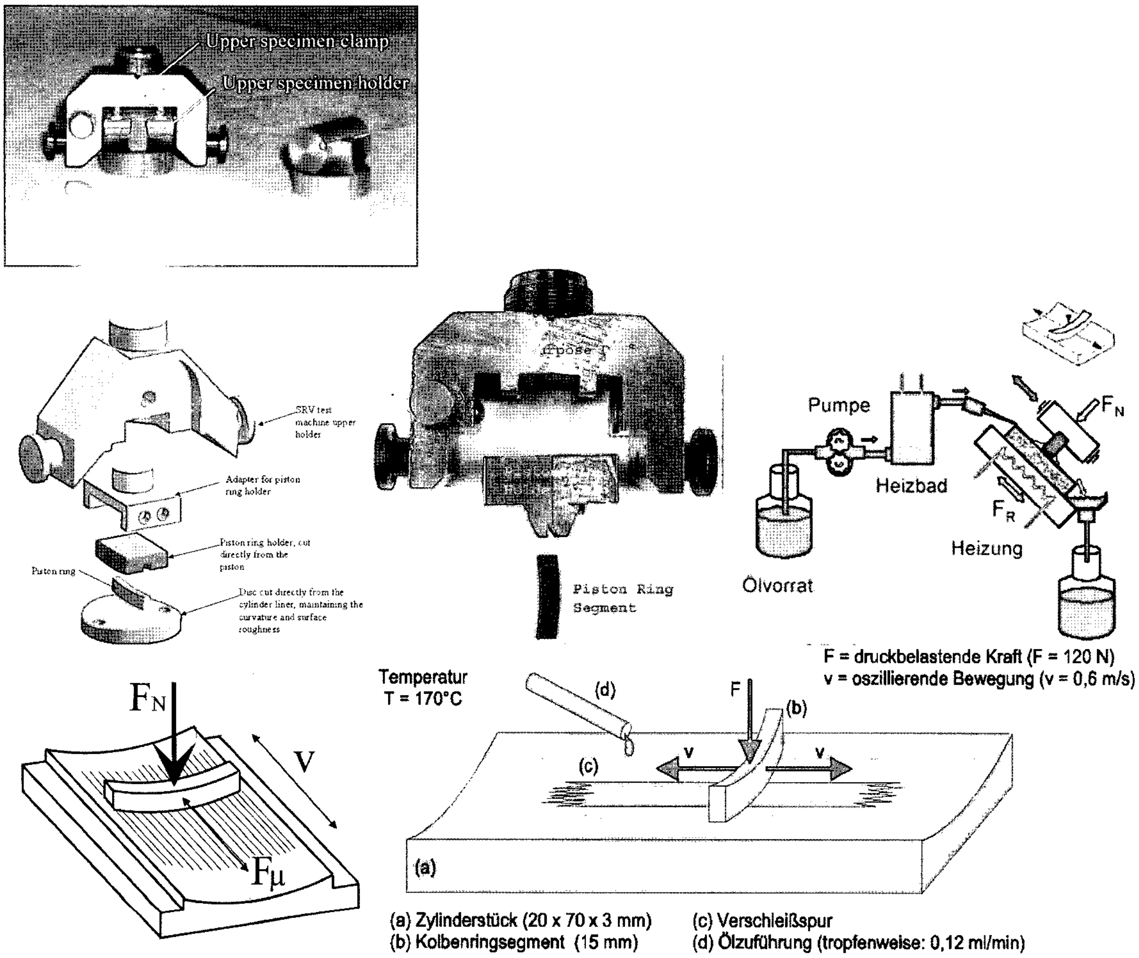


Fig. 3. Examples for testing piston ring/cylinder liner using the high-frequency, linear oscillating" test machine SRV®.

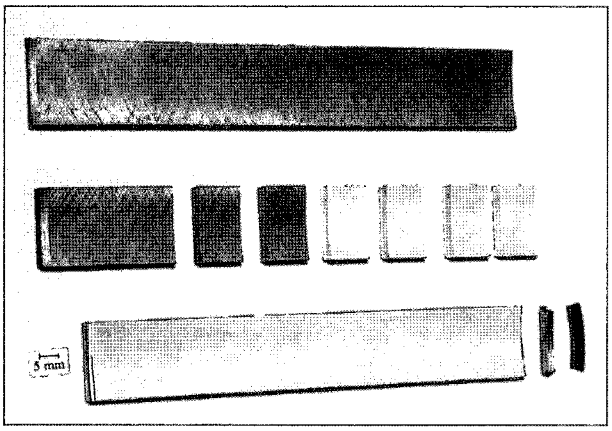


Fig. 4. Steps for machining of the GGL26Cr and SILITEC test samples from liners.

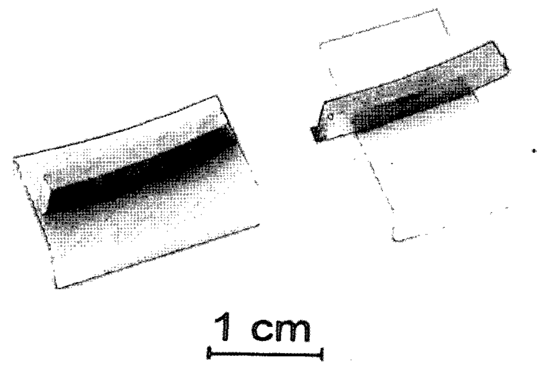


Fig. 5. Test geometries in use by OEMs (inline (left) and anti-parallel (right)).

pressure conditions shown in and are based on a modified ASTM D5706-05. Cam systems normally don't exceed 1,300 MPa of Hertzian contact pressure, except for the BMW Valvetronic or the VW "pump injection system", which reach 2,000 MPa.

Hertzian contact stress determines the adhesive wear mechanism for tribologically stressed surfaces. Therefore, the Hertzian contact pressure at the O.K.-load has to be considered. As the O.K-Load can only be determined as the last load step before failure, a second test has to be run and stopped at the previously determined O.K.-load.

The Hertzian contact pressures before adhesive failure (see Fig. 6) of different oils and bionotox prototype oils based on 100% ester, blends of esters with hydrocarbons and polyglycols compete with high-end factory fill engine oils and

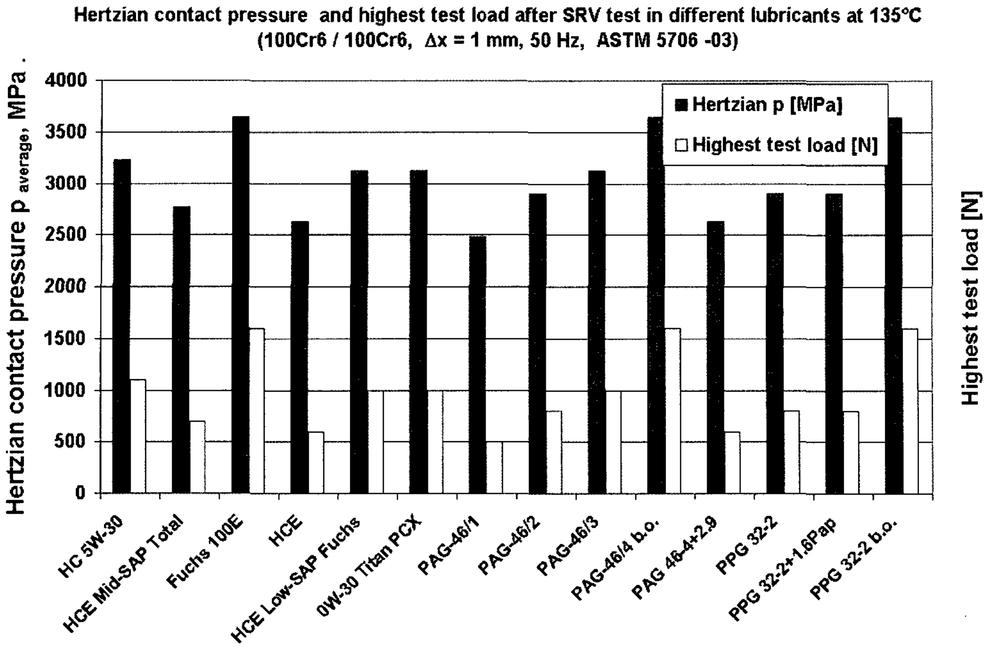


Fig. 6. Hertzian contact pressures calculated using the pass load using the SRV® step load test according to modified ASTM D5706-03 (100Cr6H = AISI 52100 balls and disks).

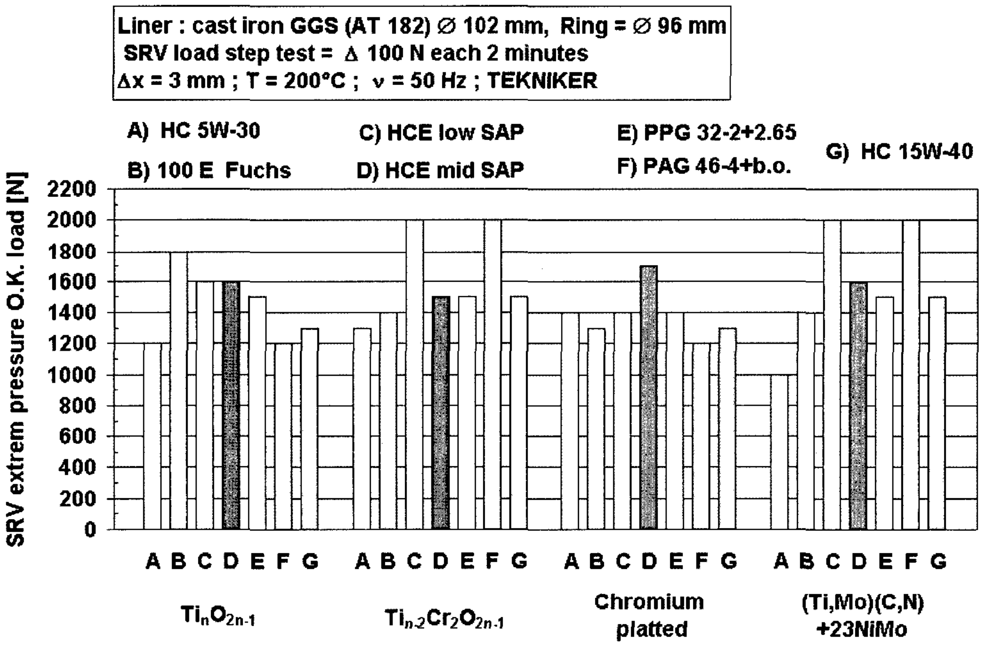


Fig. 7. SRV®-EP step load test using samples prepared from engines [4] and piston rings (www.tekniker.es).

all exceed 2.500 MPa at 135°C. The EP-O.K.-load for the PAG46-4 and PPG32-2 base oil is as good as or better than that of fully additivated engine oils.

The presents results of extreme pressure testing (O.K.-load before failure!) of piston rings coated with triboactive materials sliding against uncoated globular cast iron elaborated in the SRV®-EP step load test modified by using test pieces prepared from engines. A fully formulated, low-ash engine oil "HCE midSAP" and the PAG 46-4 polyglycol base oil reached the 2.000 N resulting in pass Hertzian pressures of >3.500 MPa when lubricating the novel ring coatings HVOF-(Ti,Mo)(C,N)-23NiMo and APS-$Ti_{n-2}Cr_2O_{2n-1}$. Using triboactive materials, all polymer-free, bionotox and low SAP alternative formulations gave better pass loads than hydrocarbons-based factory fill formulations. This trend was confirmed by other formulations (not shown here).

-Friction and Wear

Meaningful friction and wear results [5] determined with SRV® test rig under linear, oscillating sliding motion for mixed

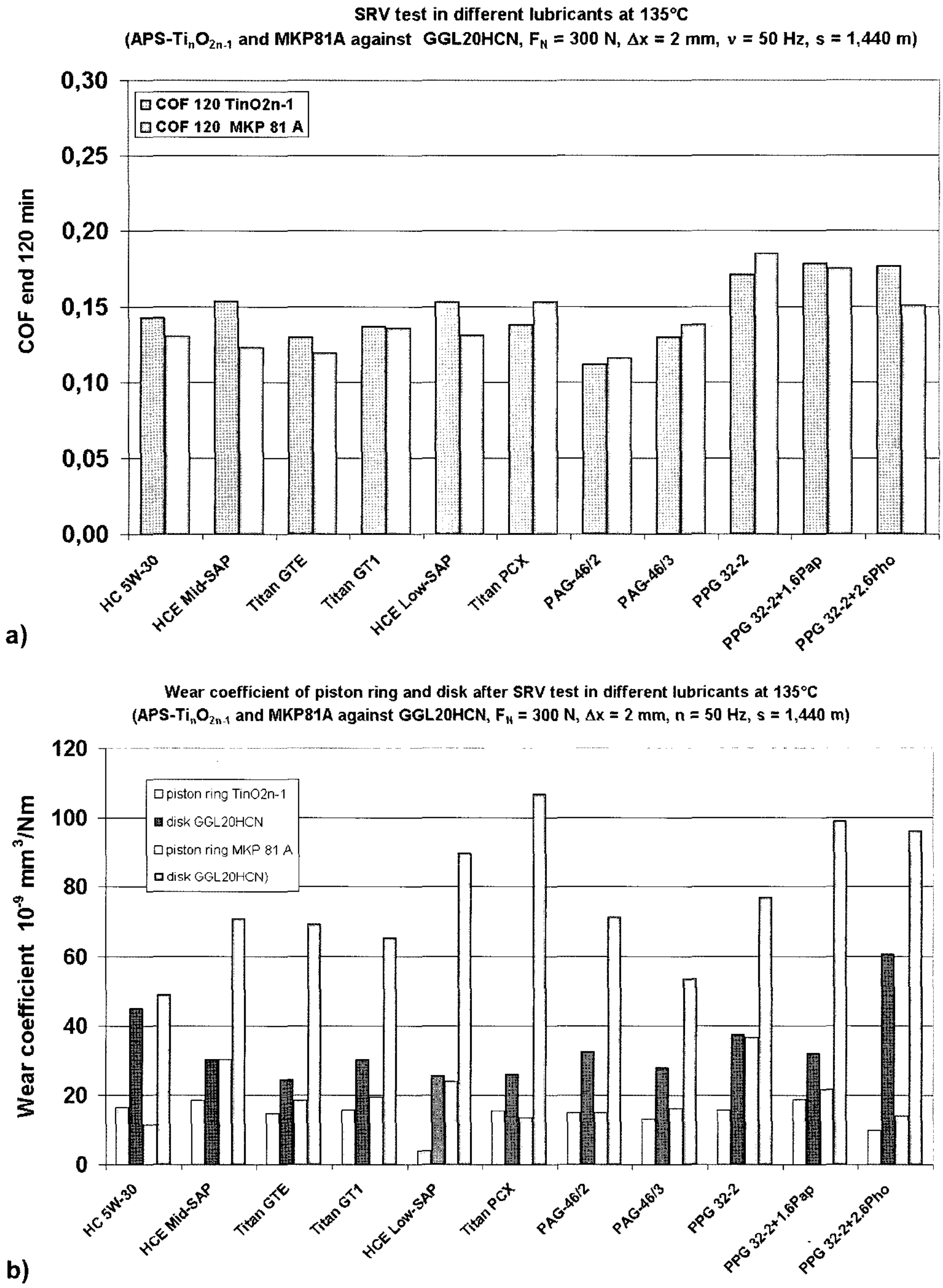


Fig. 8. SRV® test results for MKP81A® coated and Ti_nO_{2n-1} coated piston rings against GGL20HCN in different lubricants [a) coefficient of friction and b) wear rates].

lubricated conditions are compiled in for APS-Mo (MKP81A®) and APS-Ti_nO_{2n-1} coated piston rings running against GGL20HCN cylinder liner material (lamellar cast iron with high carbon content). The SRV® procedure applies a higher load of 300 N associated with a lower oil temperature of 135°C than the BAM test procedure using 50 N and 0.3 m/s at 170°C oil temperature.

With a small scatter of about D0.01, the coefficient of friction is generally not affected by the used Mo and Ti_nO_{2n-1} piston ring coatings. Nevertheless both piston ring coatings exhibit the same dependency for the coefficient of friction in different lubricants. The lowest coefficient of friction was measured with polyalkylene glycoles, which corresponds to the results with unidirectional sliding motion. Compared with the factory fill hydrocarbon-based HC 5W-30, the ester-containing GT1 and GTE can reduce the coefficient of friction under oscillating and unidirectional sliding motion by about 0.01-0.03. PPG32-2 and modified PPG32-2 have a higher coefficient of friction in SRV® tests. Under oscillation sliding, FUCHS Supersyn SL PCX exhibits a higher coefficient of friction as it was not found under unidirectional sliding according to BAM test method.

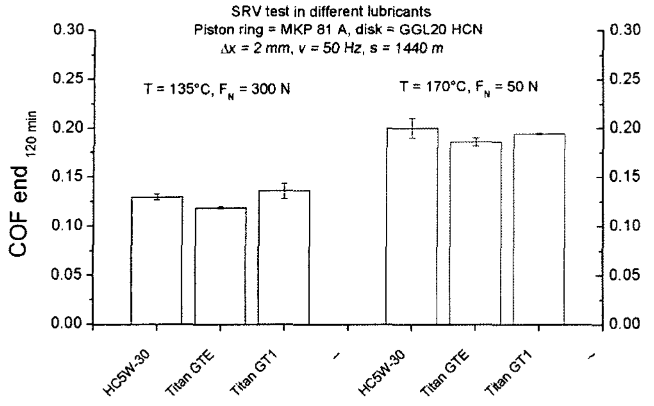


Fig. 9. Repeatability and influence of test conditions on friction using SRV® for piston ring cylinder liner evaluation.

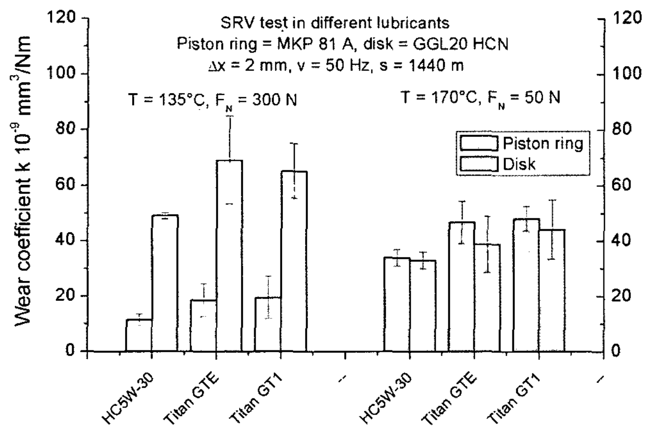


Fig. 10. Repeatability and influence of test conditions on wear using SRV® for piston ring cylinder liner evaluation.

The wear data under linear oscillation show that the molybdenum coating can be substituted by the Ti_nO_{2n-1} coating, since the wear rates of the Ti_nO_{2n-1} piston ring coating are comparable or lower than those of the Mo-coating. The ranking was confirmed by BAM tests. Furthermore, the Ti_nO_{2n-1} piston ring coating promotes a beneficial wear reducing action when lubricated with alternative bio-no-tox oils such as Titan GTE, PAGs 46 and PPG32-2 with 2.6 Phopani.

-Repeatability

Figure 9 and Fig. 10 present the influence of two different test conditions on friction and wear with the associated standard deviation from five consecutive tests. Both load and temperature were changed. For these comparisons in a two-hour SRV® test, stroke and frequency were identical.

The standard deviation bars indicate a high repeatability for these SRV® tests which is superior to those known from engine tests.

Conclusions

On the basis of past and present experience of OEMs and Tier1-suppliers as well on tests regarding precision, the SRV® has proven to be a valuable simulation tool for developing tribological tests performed outside of engines.

At least four test procedures aiming to determine different tribological operating conditions and performance of the tribosystem "piston ring/cylinder liner" are to be developed. The OEMs will correlate the results from the upcoming international round robin tests with the experience from engine tests.

The SRV® represents an ideal technical platform for the issues of piston ring cylinder liner testing outside of the engine - especially as there is active OEM support and standardization working groups ensuring highly valuable and transferable test results.

Acknowledgments

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