



Serbian Tribology
Society

SERBIATRIB '15

14th International Conference on
Tribology



University of Belgrade,
Faculty of Mechanical Engineering

Belgrade, Serbia, 13 – 15 May 2015

UP-TO-DATE TRIBOLOGY EQUIPMENT FOR STANDARD QUALIFICATION OF GREASES

Alexander MINEWITSCH^{1,*}, Aleksandar MARINKOVIC²

¹TTZH Tribologie & Hochtechnologie GmbH, Germany

²University of Belgrade, Mechanical Engineering Faculty, Serbia

*Corresponding author: alexander.minewitsch@ttzh.com

Abstract: Tribotesting of greases as a range of standardised procedures, which are complementary to laboratory analyses of physicochemical grease properties, is in some cases conducted, using classical tribometers, but generally requires more specific techniques complying with the standard qualification procedures since years recognised by major manufacturers of greases and bearings. The authors concentrate on the popular range of up-to-date equipment for grease testing, including some mistakes in the older constructions, and the novelties of the new designs, eliminating any inconsistency between the requirements of the standards (DIN, ISO, ASTM, etc.) and the tribological conditions with the goal of providing a reliable adequateness between the real conditions in the machinery and those in the test rigs.

Keywords: four ball tests, dynamic rust, water washout characteristics, roll stability, low temperature torque, solid matter content.

1. QUALIFICATION GREASE TESTS IN INDUSTRIAL APPLICATIONS

Lubricating greases as an important construction element and “third body” between interacting machine components since years have been a subject of fundamental and applied research [1-2]. Consisting of base oils, thickeners and additives, the commercially available greases range from simple metallic soap thickened mineral oils to complex soaps, containing two or more thickeners as well as organic and mineral thickeners in combination with mineral or synthetic base oils. The latest trends in development of bio based lubricants involve a wide range of vegetable oils, like soy, palm, rapeseed, sunflower, corn, safflower, etc. [3].

Independently from grease nature and composition, some statistics of their application show that more than 80 % of bearings in exploitation are grease lubricated against those oil-lubricated, coated, or used without a lubrication [4-9]. Greases have several advantages against oil lubricated rotating machinery, they provide sealing, decrease of dripping, splattering, leakage, reduce noise. Apart from that bearing orientation becomes irrelevant and they could be lubricated for life. Of course, less flowing versus oils can cause in some special cases a lack of lubricant in hard to reach points, e.g. in chains, absence of cleaning and cooling effects belong to the disadvantages in some applications. Improper lubrication causes more than 40 % of bearing failures, most of them because of specific lubrication problems.

Insufficient (or overfilling) quantity or improper viscosity of lubricants are doubtless significant reasons, but among others there are also deterioration of greases after the years of exploitation in the lubricated for life bearings, excessive temperatures and contamination with foreign particles, water, etc. [5-7,10].

Tribotesting of greases as a range of standardised procedures, which are complementary to laboratory analyses of physicochemical grease properties, is in some cases conducted, using classical tribometers, but generally requires more specific techniques complying with the standard qualification procedures since years recognised by major manufacturers of greases and bearings [10,15].

The authors don't set as a goal of this paper giving a comprehensive description of the qualification tests, but concentrate on the popular up-to-date equipment, implementing the following procedures:

- four ball weld tests acc. to ASTM D2596, DIN 51350-T4 employs 4 half inch balls of steel 100Cr6; the tests run 60 s for welding load;
- four ball wear tests acc. to ASTM D2266, DIN 51350-T5, IP 239; the tests are running under 1450 rpm (DIN) or 1760 rpm (ASTM);
- dynamic rust tests acc. to IP 220, DIN 51802, ISO CD 11007 are carried out in distilled water or other aqueous media with 80 rpm speed;
- water washout characteristics acc. to ASTM D1264, DIN 51807-2, DIN ISO 11009 with two speeds 600 and 3780 rpm and the temperature up to 80°C;
- roll stability tests acc. to ASTM D1831, MIL G 10824, incl. The tests under the temperatures up to 200 °C;
- low temperature torque tests acc. To IP 186 in axially loaded ball bearings under the temperatures down to – 73 °C;
- determination of solid matter content of lubricating greases for particle sizes above 25 µm acc. to DIN 51813.

Some older descriptions of qualification

tests of greases are available from industry [4,10,16-17] and from the authors [18-19]. We dwell on the latest developments in the chapters below.

2. FOUR BALL TESTS OF GREASES

The four ball machines are known since 1940's as the standard bench tests for evaluation of friction, wear and extreme pressure properties of greases. Four ball weld load stays in accordance to DIN 51350/4, ISO 11008, ASTM D2596, IP 239 for evaluation of extreme pressure properties. A critical load, where welding point of sliding balls (Fig. 1) occurs, is determined during 60 s tests with the speed 1450 rpm in Europe or 1760 rpm, 1200 rpm according to ASTM. The tests employ 100Cr6 half-inch special balls RB 12.7/310955 [16]. The stated in DIN load steps are 200 N, and the load maximum in the available machines is 12,000 N. Greases with a weld point above 2800 N belong to full EP greases, while those above 2000 N are considered to have basic EP characteristics [10].

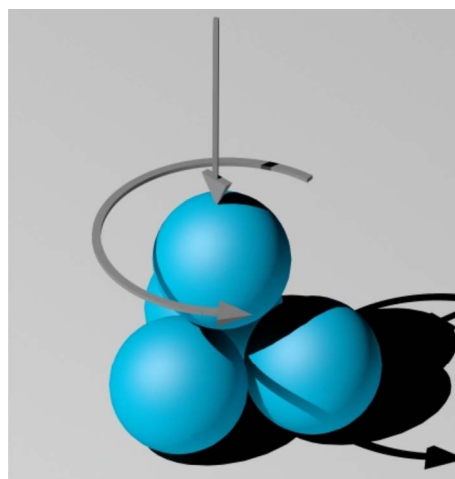


Figure 1. Scheme of 4-ball grease testing machine

Extreme pressure properties under high Hertzian contact characterise load carrying ability of lubricating layers, and wear protection at increasing loads, the tests show the transition from elastohydrodynamic to boundary lubrication and metal to metal contact. In the 4-ball wear scar tests (DIN 51350/5, ASTM D2266, IP 239) greases are compared using an average size of the scar

diameters worn on the three lower balls. For classification of the levels of EP / anti-wear characteristics of greases applicable are the following criteria: below 1.0 mm – very good, below 1.6 mm – reasonable, over 2.0 mm – poor [10,20].

In terms of characterising the real tribo-systems, these tests correlate with nothing in the industry [15], but historically widely spread in testing laboratories worldwide, they remain being a useful simple instrument for tribology. Some parameter deviations between aforementioned standards exist and therefore universality of the testing machines and a possibility of quick rearrangements to meet requirements in different countries is of importance in practical work.

Another aspects in development of capabilities of testing equipment involve an increase in the specimen load accuracy which produces a higher level of reproducibility and repeatability in the test results, automatically control of step load, speed of rotation and temperature, evaluation of the wear rate during the tests and comparison of wear in a real time versus the indicated variables such as torque, friction coefficient, load, speed, temperature, specimen cycles and test duration, computerised control, data acquisition and processing.

Instrumental implementation of these tests is possible and presently commerce-ally available in several executions of 4-ball machines, special units to universal tribometers and simplified designs of rotary tribology rigs.

3. ROLL STABILITY TESTS

During this test (ASTM D1831, MIL-G-10924) the lubricating grease is undergone to stresses similar to those in the ball bearings. Further tests (i.e. cone penetration according to ISO 2137) reveal changes in the shear stability of the lubricating grease and allow an assessment of its durability, determine the oil separation and change in consistency. Depending on the test programme the typical duration of the tests could be 2 h, 50 h, 100 h.

The machine shown on the Figure 2 is designed for long test runs at temperatures up to 200 °C. It is equipped with a high accuracy digital temperature controller. Digital timer with two presets allows unattended operation. The tester demonstrates a low noise operation not only at standard 165 rpm, but in the whole range of speeds from 100 to 200 rpm. A uniform heat distribution is provided by aluminium fan and shielded heaters. The machine is protected against overheating. For higher productivity it possesses 4 simultaneously rotating cylinders with caps, seals and 4 stainless steel rollers respectively. Standard mass of the rollers is 5000 ± 50 g.



Figure 2. Roll stability tester

Grease and/or well mixed and homogenised test composition is rolled for a certain time at preselected temperature. For greases with a density of 0.9 g/cm^3 filling quantity is 55 cm^3 or 50 g.

Due to the friction between cylinder and roller the air inside the test space is constantly warming up. This is why a test at room temperature as described in the ASTM method is virtually impossible. Solution of this problem is employing a room temperature cover (venting hood) as shown on Figure 3 [21]. The venting hood increases the volume of testing space and permanently exchanges the air inside by means of a small fan. So it makes possible to conduct the tests at a stable ambient temperature and meet the requirements of the above standard.



Figure 3. Roll stability tester with room temperature cover

Different cases of bearing applications in industry, as described in [3,7,8,10,13], arise the specific challenges for new testing procedures, which are to provide possibly very similar conditions in the grease stressing to those in real rotating machinery. For example, mechanically stressed greases could be in the meantime undergone to influence of atmospheres. Special design of the roll stability tester offers an additional option of pumping a controllable flow of gas through the test cylinders during their rotation. It provides an adjustable testing atmosphere in direct contact with the grease sample. Combining mechanical stress and adjustable atmosphere creates realistic conditions for examining various grease properties and thereby a unique possibility for analysing the degradation process of grease.

Taking the samples and/or using gas analysis a more intimate approach to the chemical processes (oxidation, decomposition, etc.) occurring during the tests is possible. Results obtained by this method are good applicable for efficient optimisation of greases.

The test rig is designed to process two grease samples simultaneously. Due to its rugged design the oxidation roll tests could run 300 hours or more. The air flow can be regulated in the range 0 – 200 ml/min during the test period.

4. SOLID MATTER CONTENT OF LUBRICATING GREASES

Solid particles in greases cause severe problem during the operation of lubricated units. They influence on the noise behaviour of ball bearings and enhance the wear rate of interacting components. Solid matter content in lubricating greases is given in DIN 51813 [22]. The method employing the hydraulic grease press (Fig. 4) we describe here is applicable to greases not containing any solid lubricants. Operating pressure of hydraulic grease press is up to 150 bar, and the test load at the piston is ca. 60 – 70 kN.

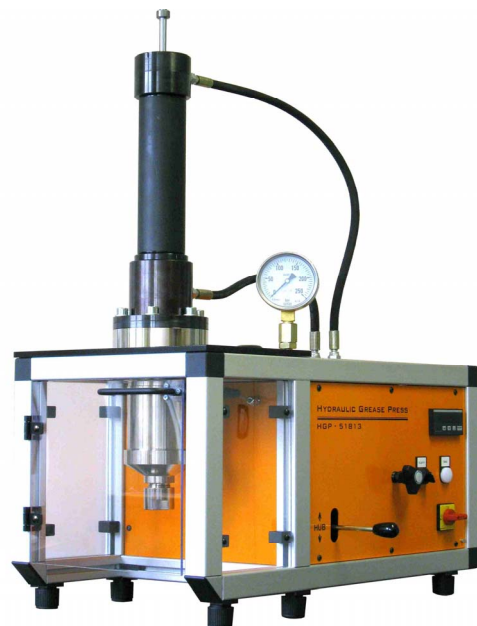


Figure 4. General view of hydraulic grease press

Mean quantity 500 g of a grease sample is pressed through the test sieve (Fig. 5). The squeezed grease is dissolved in a solvent mixture and in acetic acid and then filtered. After washing out and drying the filter crucible a mass difference is used to determine the fraction of solid particles contaminating the grease.

Test sieve with a mesh size of 0.025 mm is made of stainless steel, e.g. according to DIN 4188, and could be used not more than for two tests. Base fabric on the sieve bottom is of the same steel whereas its mesh size is 0.5 mm (Fig. 5).

Precision of the method is characterised by repeatability and comparability as it is shown in the following Table 1.

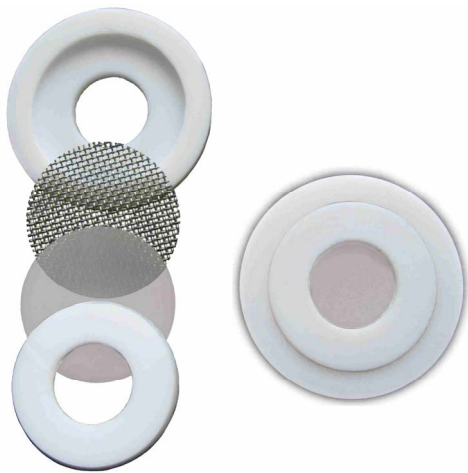


Figure 5. PTFE holder and sieves

Table 1. Repeatability and comparability of the test method (mass fraction in mg/kg)

Solid matter content	Repeatability	Comparability
< 10.0	5.0	10.0
≥ 10.0	7.5	15.0

Some additional controls integrated into the hydraulic grease press make also possible testing the filterability of greases. These include adjustment of the flow rate at the test sieve and the pressure within the grease cartridge. The adjustment range of both characteristics is based on the range of parameters prevailing in filters. Results of such tests show user whether a grease is suitable for an application. Adjustable flow rate at the test save ranges from 0.5 to 1.5 m/min; adjustable maximum of filtration pressure is 60 bar, whereas pressure measurements at the test sieve lie in the range from 0 to 60 bar.

5. LOW TEMPERATURE TORQUE TESTS

The test method IP 186 describes the determination of the starting and running torque of an axially loaded angular contact ball bearing [23]. The principle of this method is shown on the Figure 6, the test allows depending on the used chiller to examine performance of the greases at the temperatures down to $-42\text{ }^{\circ}\text{C}$ and $-73\text{ }^{\circ}\text{C}$ [16,19,23].

The Low Temperature Torque Tester LT3 is used to determine the resistance caused by

the grease in an axially loaded ball bearing at temperatures down to $-73\text{ }^{\circ}\text{C}$ in accordance with IP 186/93 mostly in automotive and railway applications, civil and military aviation. The tests are running under standard axial loads 50 N in the range of torques 0 – 2000 Nmm.

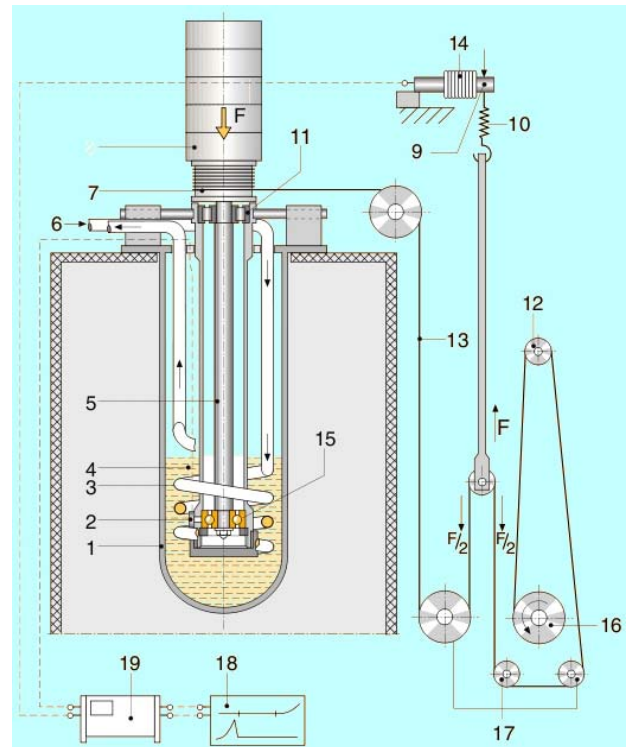


Figure 6. Principle of operation of LT3 – low temperature torque tester (designations: 1 – insulating receptacle; 2 – temperature sensor; 3 – cooling spiral; 4 – cooling bath; 5 – test spindle; 6 – cooling by means of cryostat; 7 – drive cable drum; 8 – axial loads; 9 – weighing cells; 10 – dampening spring; 11 – auxiliary bearing; 12 – tensioning roll; 13 – Bowden cable; 14 – force-measuring roll; 15 – test bearing; 16 – motor with cable drum; 17 – return roller; 18 – plotter; 19 – measurement amplifier [16])

As compared against the conventional devices the Low Temperature Torque Tester LT3 includes several improvements as electronically controlled high precision direct drive, sophisticated torque sensor with high accuracy, semi-automatic operation with electronic data acquisition and closed loop cooling jacket.

The test rig presented on the Figure 7 is an up-to-date tester, accumulating the latest technology developments against the first variant of LT3, designed in 1960's.



Figure 7. General view of LT3 – low temperature torque tester

The tester includes an apparatus with the drive and measuring unit, cooling jacket for hook-up with existing cooling device, stand-alone controller unit with PLC and touch panel, PC Software for data acquisition and analysis. The housing is suited for different bearing sizes, reuse of existing cooling devices and tailor-made solutions. Overview of the test parameters is given in the Table 2.

It involves the following novelties and advantages:

- precision controlled drive with trouble-free, direct power transmission;
- high precision electronic torque measurements;
- quick and simple assembly/disassembly of the test rig;
- extensive automation of the entire test procedures;
- electronic data recording of measured values and boundary conditions;
- integrated closed cooling;
- minimisation of errors during operation and testing.

6. DYNAMIC RUST TESTS (EMCOR METHOD)

The EMCOR machine is designed for determination of the anticorrosion properties of greases when steel bearings have a contact with water or condensed humidity [10,16,24]. Despite mostly electrochemical nature of the environmental influence onto metallic

components, in some cases the changes could be of chemical or metallophysical origin. One of the functions of greases is to protect bearings from rust in extreme situations both in running and standing conditions.

Table 2. Overview of the IP 186 test parameters

What is measured?	Rotational resistance of a grease lubricated angular contact ball bearing at low temperatures
Test bearing	Precision angular contact ball bearing RHP 7204 TU EP 9 d 20 mm, D 47 mm, B 14 mm
Temperature range	Down to $-73\text{ }^{\circ}\text{C}$ ($\pm 1\text{ }^{\circ}\text{C}$)
Load	Axial (4.5 kg)
Grease quantity in the bearing	2.6 ± 0.1 ml
Cooling time	1 to 1.5 h
Holding time at the test temperature	2 h
Running time of Bowden cable drive	60 min = 60 revolutions (1 rpm)
Force measuring range	0 to 98 or 9.8 N (10 kg or 1 kg)
Result	Force required to loosen test bearing during start-up (starting torque) and after 1 h running time (running torque) in Nmm
Reporting	Geometric mean value of each pair of determinations
Precision	Repeatability: 70 % of the lower value Reproducibility: 250 % of the lower value

The principal scheme of the tester is demonstrated on the Figure 8.

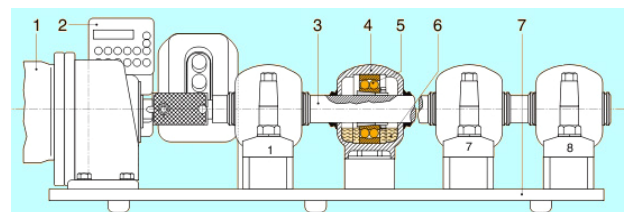


Figure 8. EMCOR machine (designations: 1 – electric motor; 2 – automatic timer; 3 – shaft with nylon lining; 4 – pedestal plain bearings, 8 units; 5 – test bearings, 8 units; 6 – test medium; 7 – support)

The testing procedures are described in German standard DIN 51802 [24], and also in international ISO 11007, British BS 2000 (IP 220), French NFT 60-135, ASTM D6138, etc.

Specimen is normally 1306K/236725 special bearing with stamped steel cage (sometimes researcher use a bearing with polyamide cage). Two bearings in test are run the tester partially immersed in water. Total duration of the test 168 hours (one week) includes 80 rpm speed during the first 8 hours followed by a stop. The sequence is as follows: 8 h run, 16 h stop, 8 h run, 16 h stop, 8 h run and finally 108 h \pm 2 h stop.

No loads applied and the tests run under ambient temperature. Grease fill is 11 cm³ or 10 g, and as a test medium used is distilled water, brine or other aqueous media.

The tests result in visual corrosion rating on the outer bearing surface, as seen on the Figure 9 above. No corrosion in the unchanged rating "0" sufficiently indicates, that the protective properties of the tested grease are good.

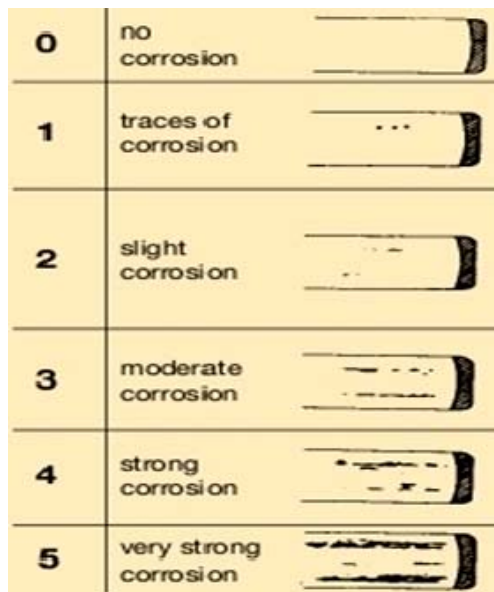


Figure 9. Qualification of corrosion degrees of rust inhibition (description: 0 – unchanged; 1 – max. 3 corrosion spots with a diameter max. 1 mm; 2 – max. 1 % of the surface is corroded, but more and larger corroded spots as with corrosion degree 1; 3 – $>$ 1 % but not more, than 5 % of the corroded surface; 4 – $>$ 5 % but not more, than 10 % of the corroded surface; 5 – $>$ 10 % of the surface is corroded)

Some discrepancies in the above standards exist, e.g. DIN standard speed is 80 rpm, while

ASTM standard speed is 83 ± 5 rpm. The machine could be used for testing the bearings different from the recommended by DIN / ISO, it brings some special features into analyses of the results. Optionally, the test bearings could be subjected to flow of aqueous test fluid during the 8 h running periods this way washing out the corrosion inhibitors, this useful option has a name of EMCOR washout test.

7. WATER WASHOUT PARAMETERS

Standard tests for determining resistance of grease in the bearings against of water washout runs at test temperatures of 38 °C and 79 °C under defined laboratory conditions [25]. The tests differ from other field tests in the operating conditions. The principal scheme of the test rig conforming to the standards DIN ISO 11009, DIN 51807/2 and ASTM D1264 is shown on the Figure 10.

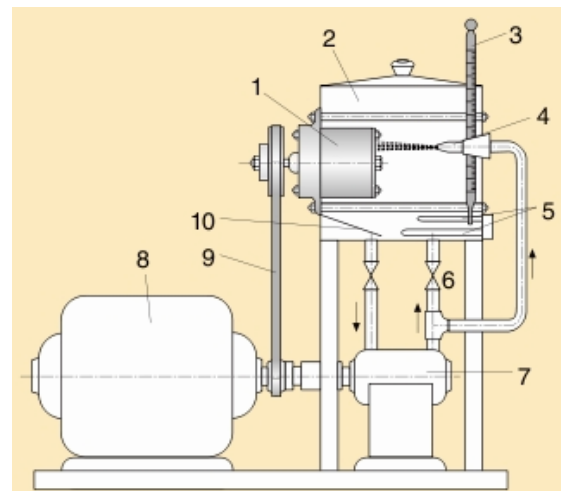


Figure 10. Scheme of the test rig (description: 1 – bearing housing with the test bearing inside; 2 – water tank; 3 – thermometer; 4 – nozzle; 5 – heating; 6 – valve; 7 – pump; 8 – motor; 9 – V belt; 10 – cooling pipe)

For running the 60 min. test a grease lubricated open deep groove ball bearing 6204 is mounted into housing and rotates at 600 rpm. Amount of grease in the test bearing is 4 ± 0.05 g. Water jet is sprayed onto the bearing with the flow rate 5 ± 0.5 cm³/s. The average of the duplicate tests amount of washed-out grease is a measure of its water resistance. General view of the new design of the machine implementing these tests is shown on the Figure 11.

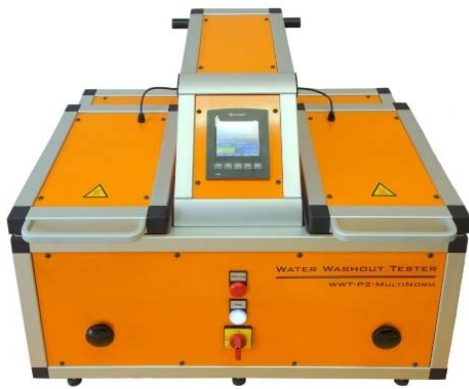


Figure 11. Water washout tester

The up-to-date tester possesses the following features and advantages: advanced control and sensor technique; electronic data acquisition; user friendly operation and maintenance; two separated water tanks (Fig. 12) for duplicate or independent testing; two speed levels 600 rpm and 3780 rpm, while variable speed control is optionally possible too; test temperature up 80 °C enables both tests at 38 °C / 79 °C and 40 °C / 80 °C and this way facilitates all the ASTM/DIN standardised procedures; water tanks are equipped with control heating unit, so no preheating is necessary; the machine parts are resistant to brine corrosion; spacious and easy to clean water tank; separate drive for pump and bearing makes the belt as in older design (Fig. 10) unnecessary; magnetic bearing drive for easy disassembly and removal; volume flow setting by a precise manual control valve.



Figure 12. Two separate water tanks, nozzles and bearing housings

For rating of the water washout test results the below Table 3 is applicable [16].

Table 3. Water washout rating levels

Rating level	Loss in weight [%]	Change
1	< 10	low
2	> 10 but < 30	moderate
3	> 30	high

8. CONCLUSIONS AND FUTURE TRENDS

The customised options make the new executions and modern designs of the known testers not only more flexible and convenient in operation, but also bring some testing conditions well beyond the aforementioned standards. This way the up-to-date qualification equipment is challenging new testing procedures and future revisions of the existing standards.

ACKNOWLEDGEMENTS

The authors gratefully appreciate helpful and motivating discussions with Dr. T. Lazovic, Dr. S. Markovic, Mr. P. Albers, Dr. B. Lawiszus and other colleagues about bearing applications, grease testing and related questions.

REFERENCES

- [1] V. Stepina, V. Vesely: *Lubricants and Special Fluids*, Elsevier, Amsterdam, 1992, p. 704.
- [2] T. Mang (Ed.): *Encyclopedia of Lubricants and Lubrication, Vol. 1–4*, Springer, Heidelberg, 2014, p. 2403.
- [3] L.A.T. Honary, E. Richter: *Biobased Lubricants and Greases. Technology and Products*, Wiley, Chichester, 2011, p. 216.
- [4] *Lubrication of Rolling Bearings. Principles, Lubrication Methods, Lubricant Selection and Testing, Storage and Handling*, TPI 176 GB-D, Schaeffler Technologies, Herzogenaurach-Schweinfurt, 2013, p. 212.
- [5] *SKF Maintenance and Lubrication Products*, PUB MP/P1 03000 EN, 2012, p. 168.
- [6] M. Albert, H. Kötritsch: *Wälzlager. Theorie und Praxis*, Springer, Wien, 1987, 482 S.
- [7] M. Las: Poruchy valivých ložísk v rôznych konštrukčných aplikáciách, in: *Proceedings of the International Tribology Conference "Failures of Rolling Bearings"*, 21-22.10.2010, Bratislava, Slovakia, pp. 63-67.
- [8] A. Marinkovic, S. Markovic, A. Minewitsch: Lubrication and maintenance of thrust ball bearing in bucket wheel excavators, *Tribologie & Schmierungstechnik*, No. 4, pp. 44-48, 2014.
- [9] T. Lazovic, A. Marinkovic, D. Skoko: Influence of abrasive wear on ball bearing internal geometry, in: *Proceedings of the 11th International*

- Conference on Tribology – SERBIATRIB '09*, 13-15.05.2009, Belgrade, Serbia, pp. 233-237.
- [10] P.M. Lugt: *Grease Lubrication in Rolling Bearings*, Wiley, Chichester, 2013, p. 444.
- [11] P.M. Lugt: The grease lubrication mechanisms in rolling bearings, in: *Proceedings of the 25th ELGI Annual General Meeting*, 20-23.04.2013, Amsterdam, Netherlands, p. 10.
- [12] G.W. Stachowiak, A.W. Batchelor, G.B. Stachowiak: *Experimental Methods in Tribology*, Elsevier, Amsterdam, 2004, p. 354.
- [13] H. Czichos, K.-H. Habig: *Tribologie- Handbuch. Tribometrie, Tribomaterialien, Tribotechnik*, Vieweg + Teubner Verlag, Wiesbaden, 2010, 757 S.
- [14] G. Plint: *Introduction to Tribological Testing, Cambridge Tribology Course*, Phoenix Tribology Ltd, Newbury, 2011, p. 28.
- [15] G. Plint: Sliding Hertzian point contact tests, *Benelux Smeeroliecongres*, 23.09.2014, Fort St. Gertrudis – Geertruidenberg, Netherlands.
- [16] *Lubricant Testing, Focussing on Mechanico-Dynamical Tests*, Klüber Lubrication München KG, edition 09/03, p. 67.
- [17] *Greases. Technical guide. Characteristics and Tests*, TOTAL Lubricants Catalogue 08/03, p. 20.
- [18] A.A. Minewitsch, K.-H. Spies, M. V. Efron: Tribotesting and triboanalysis for im-proved bearing technology, *International Tribology Conference "Failures of Rolling Bearings"*, 21-22.10.2010, Bratislava, Slovakia.
- [19] A.A. Minewitsch: Modern equipment for testing of lubricants and greases, *International Tribology Conference „Lubricants Russia – 2010“*, 10-12.11.2010, Moscow, Russia.
- [20] ASTM D 2266-01 *Standard Test Method for Wear Preventive Characteristics of Lubricating Grease (Four-Ball Method)*, p. 3.
- [21] Testing equipment for greases: available in www.ttzh.de/products/grease-testers,en
- [22] DIN 51813 *Bestimmung des Gehaltes an festen Stoffen in Schmierfetten. Teilchengrößen über 25µm*, 1989, 4 S.
- [23] IP 186/93 *Determination of Low Temperature Torque of Lubricating Grease*, p. 3.
- [24] DIN 51802 *Prüfung von Schmierfetten auf korrosionsverhindernde Eigenschaften. SKF Emcor Verfahren*, 1990, 3 S.
- [25] DIN ISO 11009:2007-07 *Mineralöl-erzeugnisse und Schmierstoffe - Bestimmung der dynamischen Wasserbeständigkeit von Schmierfetten*.