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SRV Method: Lubricating Oil Screening Test for FZG

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Abstract: Governments and institutions have the following sustainable development goals: the improvement of energy efficiency and the reduction of CO_2 emissions, in a "green economy" approach, have currently become the fundamental drivers that push research and development activity toward the optimization of rotating machine components in the industrial sector, with a special focus on lubrication systems too. The activity is directed towards the optimization of tribological testing methods and equipment to better discriminate the performance of lubricants in operating conditions as predictive as possible of real applications. In this context, the present paper describes the results of an experimental campaign based on the use of a well-selected linear oscillation SRV * (*Schwingung, Reibung, Verschleiss*) tribometer procedure as a screening of a rig test, the FZG ** (*Forschungsstelle für Zahnräder und Getreibebau (German: Research Centre for Gears and Gear; University of Munich; Munich, Germany))* test, leading to concrete benefits such as saving time (time duration is 76% less without mentioning visual inspection and mounting/dismounting phase) and operative costs. Four cases for the determination of the failure load stage of SRV have been defined as links to seizure and microseizure phenomena. The procedure was tested for ten oils differing in scope (gas turbine oil, turbine oil, gear oil and circulating oil). The tests have been repeated three times and a procedure was defined for repeatability (± 1 stage difference between the minimum and maximum) for nine out of ten cases a failure stage could be defined. The same oils were also tested using the FZG scuffing test, and it can be seen that the results are very comforting as follows: a good correlation with the FZG rig test has been found for eight out of ten oils.

Keywords: tribological test; energy efficiency; rig test; screening; SRV; FZG

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1. Introduction

The growing attention to CO_2 emissions and the energy efficiency improvement in the industrial sector are pushing manufacturers to develop machines with higher performance, characterized by lower power losses, lower energy consumption and downsizing of components. In this compound, lubricating oils can also provide a significant contribution to energy efficiency [1,2].

Manufacturers increasingly tend to consider the oil as an integral part of the machine, a key element just in the design phase. To support this evolution, it is important to identify and use lubricants with well-selected rheological and chemical-physical characteristics combined with appropriate additive systems; in addition, another important lever that gives lubricants a lower environmental impact is the use of components derived from renewable sources. Tribological experimentation is an extremely important tool supporting the assessment of energy-saving characteristics of products, ensuring at the same time the fulfillment of traditional performance targets.

This paper has the following two goals: on one hand, identify and optimize tribological tests in order to better discriminate lubricants with "energy saving" [3] characteristics before moving on to field testing; on the other side, acquire know-how on the mechanisms underlying tribological couplings, looking for correlations between mechanics (tribological instrumentation), chemistry (lubricating oil and its additives) and material in order to set up a tribo test as predictive as possible of real industrial applications.

As a concrete example of this framework, the evidence obtained by using a tribometer, the SRV, for prescreening a rig test, the FZG test, has been reported in this report.

An SRV procedure [4] has been built up for reproducing very similar operating conditions to the FZG test [5].

The FZG [6] is a power re-circulating rig test based on a wheel and pinion coupling and an increasing step load procedure that lasts till the failure load stage is reached. It is very well known in the lubricant industry as one of the more severe and significant tests for the evaluation of industrial and transmission lubricating oils.

FZG failure load stage in the scuffing test is defined as the stage where the sum of the wear area of all 16 teeth of the pinion exceeds the areas of a single tooth.

A higher failure load stage means higher lubricant performance in terms of load-carrying capability and antiwear characteristics.

The SRV is a well versatile laboratory machine that aims to evaluate friction and wear characteristics of lubricants in many different operative conditions by using couplings of different geometry and materials. In this work, the selected coupling is cylinder on disk, and the procedure is a load-increment step test till the failure load stage occurs.

For SRV, the failure load stage is the stage where the coefficient of friction (CoF) profile shows high and sudden peaks that mean seizure occurs. In this regard, the evaluation criteria defined are deeply discussed in the following chapters.

Using the SRV tribometer to reproduce the same operating conditions as the FZG test rig and try to obtain a good correlation of the results of both tests, could lead to a faster screening among many candidate oils.

In addition, other benefits can be achieved, such as less operative cost, less test duration and higher automation level (SRV is less dependent on the operator).

This paper aims to analyze the “EP lubricants” more used for gear oils and try to reduce the use of time-consuming and expensive tests such as the FZG test. The next step of the activity is to analyze the oils with antiwear additives in the additive package (in this case, it is mandatory to analyze the wear performance even in SRV tests).

In this paper, the results achieved by using only the EP procedure modified will be shown and the corresponding evaluation criteria will be discussed; in addition, the relationship between the results of both machines, rig and laboratory tests, for all of the oils tested, will be investigated.

2. Materials and Methods

A widely used test method to evaluate load-carrying capacity in industrial oils is the FZG test A/8.3/90 according to DIN ISO 14635-1. An example of FZG [7] test rig is shown in Figure 1.

A-type gears, wheel and pinion, are loaded stepwise in 12 load step stages (Table 1) from a Hertzian stress of pC = 146 to 1841 N/mm^2 and in some cases also at higher load if required.

The gear pair type A (Figure 1) shows a considerable profile offset, which causes the tooth flanks to move at higher speeds relative to each other. This in turn increases the percentage of sliding movement on the flanks, which makes the teeth more susceptible to scuffing [8]. They are operated for 15 min at a pitch line velocity of 8.3 m/s and a starting oil temperature of 90 $\pm$ 1 °C in each load stage, under conditions of dip lubrication without cooling.

Hence during the running time of each load stage, starting from the 4th, the oil temperature can rise freely. Gear flanks are inspected after each load stage for scuffing [9] marks. Failure load stage is indicated when the wear area detected on all pinion teeth exceeds the area of a single tooth.

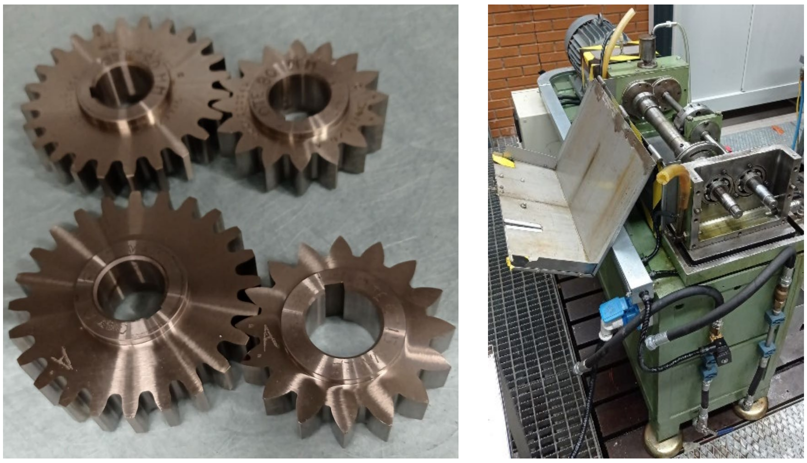

Figure 1. FZG rig test.

For the experimental campaign it has been used SRV5 tribometer (Optimol Instruments Prüftechnik, Munich, Germany; load range 0–2500 N ± 1 N) equipped with OCA software for operation, controlling and test evaluation using the EP procedure modified.

Table 1. FZG load stages.

Load Stage	Pinion Torque [Nm]	Hertzian Pressure [N/mm^2]
LS 1	3.3	146
LS 2	13.7	295
LS 3	35.3	474
LS 4	60.8	621
LS 5	94.1	773
LS 6	135.5	929
LS 7	183.4	1080
LS 8	239.3	1223
LS 9	302.0	1386
LS 10	372.6	1539
LS 11	450.1	1691
LS 12	534.5	1841
LS 13	626.9	1996
LS 14	714.2	2130

The SRV tribometer [10,11] (see Figure 2) is a very versatile device for measuring the coefficient of friction and the wear and EP characteristics of lubricating oils and greases under various operating conditions.

The basic SRV5 system is equipped with an electromagnetic linear drive, which generates a periodic sinusoidal translational movement in the frequency range 0.001–500 Hz with strokes of 0.01–5 mm (oscillation) as the relative movement of the test contact.

The main principle of oscillation motion is the identification of the friction coefficient of a material coupling with or without an intermediate medium, according to the following setting:

- Testing variable chosen frequency, stroke, test force, test temperature and test duration;
- Pressure of the opposite body on the main body with a defined normal force;
- Oscillation of the opposite body on the surface of the main body with a sinusoidal motion;
- Measuring the lateral friction force resulting from the movement of the opposite body on the main body;
- Calculating and recording the friction coefficient during the whole test.

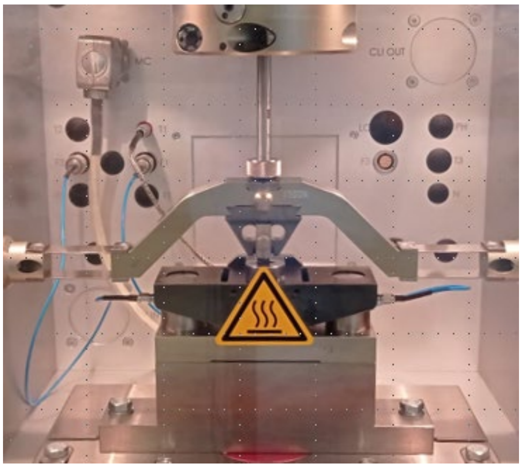

Figure 2. SRV5 tribometer overview.

Thanks to its modular design, it is possible to configure the test with couplings of different materials and geometry, testing them either in oscillatory-translational mode or, with another set-up, in rotational mode [12]. The software is able, during the experiment, to measure and save the following fundamental parameters of the test: load, temperature, frequency, stroke and coefficient of friction (CoF).

The SRV [13] is able to produce results that comply with the reliability and reproducibility statements of ASTM D5706, D7421 [14] and related specifications.

Experimental Procedure

The algorithm of the procedure used consists of a running-in under 50 N for 30 s then there is an increasing step-by-step load up to 17th stage keeping fixed at 90 °C temperature the lower specimen. The test pass to the following step if no seizure and microseizure phenomena occur (or go out the threshold cut-off values below described). The CoF curve saved during the test is then evaluated by the operator and after an accurate analysis is assigned a failure load stage.

The test kinematics involves a periodic sinusoidal translational movement at 50 Hz with a stroke of 2 mm (oscillation).

The aim is to reproduce the same scuff marks [15] as in the FZG test, and to enable this and to have the same operating contact conditions (Hertzian pressure of the FZG system), the specimens selected to reproduce the pinion/wheel are cylinder and disc.

The lower specimen is a disk Ø 24 $\times$ 7.9 mm, made of hardened rolling bearing steel AISI 52100/100Cr6. The upper specimen [4] is a cylinder Ø 6 $\times$ 8 mm. The surface is polished and aligned at 10° to the direction of movement along its longitudinal axis (see Figure 3).

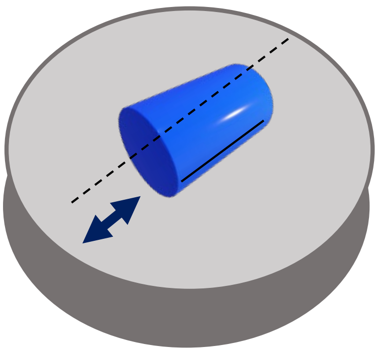

Figure 3. Tribological contact: cylinder on disk.

The surfaces of the AISI specimens were ultrasonically cleaned in ethanol for 5 min.

After the cleaning phase the specimens were mounted and locked with a torque wrench with a load of 30 N. A very small amount of oil sample is needed, and the operator should dry both the upper and lower specimens during the setting phase.

The load steps for the SRV EP procedure are presented Table 2.

Table 2. SRV EP Procedure vs FZG test load stages.

FZG load step	1	2	4	6	8	10	12	14	16	18
Hertzian stress [N/mm^2]	146	295	621	929	1223	1539	1841	2170	2465	2777
SRV normal force [N]	7	28	126	282	489	774	1107	1538	1985	2520

The duration of each step is 217 s, which is a result of prior investigations [16], where it was compared to shorter runs and reflects the following two conflicting physical phenomena: too high step times will lead to too much wear and thereby change the applied pressure, as the system is load controlled; too short times will not let the tribo-system establish itself properly and, therefore, do not allow for distinction between the tested oils.

The conditions for the step test are a temperature of 90 °C (changed from the standard EP procedure to have the same condition as in FZG test), a stroke of 2 mm and a frequency of 50 Hz.

Have been defined threshold values of some parameters for test execution, the so-called cut-off values. In particular, for this experimental campaign the following cut-off values of CoF and stroke have been set: 0.3 as maximum CoF and a stroke deviation of maximum 55%.

Have been chosen these values for the following two main reasons: on one hand for safety operation, as to quickly block test run while high seizure occurs; on the other, the above limits selected allow us to detect also microseizures and seizures (of limited intensity) helping in the qualitative analysis of CoF profile (otherwise impossible for the operator if the test suddenly is aborted).

For the evaluation criteria of oil performances and failure load stage assignment the following four cases have been defined:

- Case 1: during test run the presence of seizure, i.e., a sudden and high increase in coefficient of friction profile has been detected; in other words, there is a consistent peak that lasts for at least for few seconds and leads to test stop, according to the cut-off criteria. In correspondence to the stage where what described occurs, the failure load stage is assigned;
- Case 2: the oil is able to reach the end of test without presenting any seizure or relevant microseizures. CoF profile is linear descending and thin. This oil overcomes the SRV 12th stage.

When seizure does not occur, but the CoF profile presents an anomalous trend, a more interpretative component of the evaluation has to be taken into account and other two cases can be distinguished.

- Case 3: alternation of frequent and close micro seizures (i.e., peaks not so high as the seizure) and thickening of the curve of the friction coefficient, before reaching a very net seizure or without reaching it as follows: from the interpretation of the curve it is possible to the failure load stage of the SRV in correspondence of the stage where this phenomenon has begun and continues (seen in some cases that we will present later); in order to have a more robust and objective evaluation are needed more statistical data and, eventually, also wear analysis on the specimen in order to better investigate the behavior of oil;
- Case 4: halfway through the test there is a drastic change in the profile of the coefficient of friction, microseizures increase and the curve is disturbed although not presenting appreciable thickening. Moreover, in this case it appears very difficult to assign

the failure load stage and are needed at least the FZG result to have a reference to compare to.

3. Experimental Campaign

The SRV EP procedure [4] has been used with the only difference of temperature (T = 90 °C instead of 98 °C).

The procedure is performed for each oil for a minimum of three repetitions.

A good repeatability can be defined with a difference of ± 1 stage.

Ten oils have been tested for a minimum of three repetitions each. The oils used for testing were gas turbine oils from ISO VG 15 to ISO VG 46, a turbine oil ISO VG 46, gear lubricants with kinematic viscosity 320cSt and 460cSt at 40 °C and four circulating products ISO VG 68. Lubes also differ by a mix of base oil (from mineral to more synthetic oil) and EP (extreme pressure) additives.

As can be seen in Figure 4, for all gas turbine oils, gear oils and turbine oils there is a difference between the minimum and maximum failure stage of ± 1. Only for a circulating oil is there a difference of five points, and in this case, it was not possible to assign a failure stage. Presumably, this is due to the different additives' presence in the lubricant, and this variability is assumed to be caused by chemical phenomena that require more detailed analysis. Finally, of the products tested, only one did not demonstrate good repeatability.

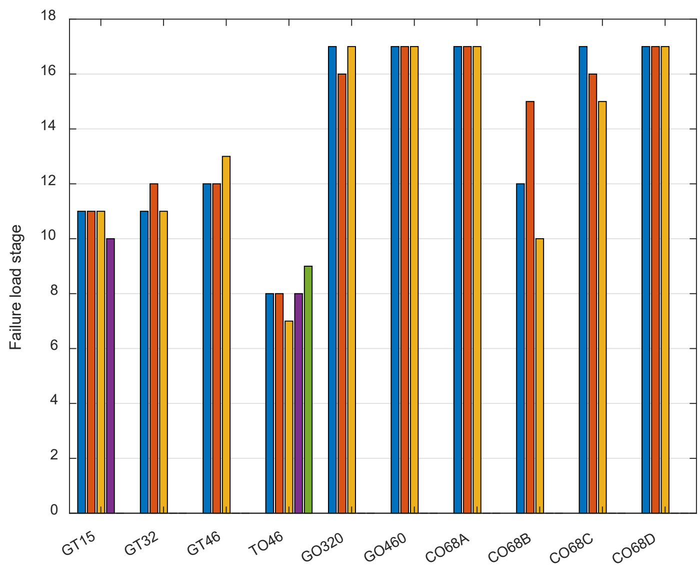

Figure 4. Repeatability of the experimental results.

4. Experimental Results and Discussion

In this section, some experimental results are shown in detail and the relationship between rig test and laboratory test according to the cases we reported in the previous section has been discussed.

The procedure used better reproduces the FZG scuffing test (FZG test method A/8, 3/90 [17]) because there is a gradual increase in load as in the FZG and the temperature is the same, thus maintaining the same rheological characteristics of the oil in the two tests. There is currently no work available in the literature using the SRV EP procedure, as it is fairly new, but other procedures with SRV machines have been used in the past to reproduce the FZG test under different contact geometry conditions [18].

The procedures used in the past [19,20] consisted of a short run-in and the setting of a fixed load to simulate the 12th stage. The 12th stage is a reference value that must be exceeded for special applications (such as gear oil for wind turbines) where higher performance is required, but not all applications require this load capacity.

Figure 5 shows the simplest case (case 1) as follows: during the test, the presence of a clear CoF peak has been detected; in correspondence to this, the tested oil reaches the failure load stage.

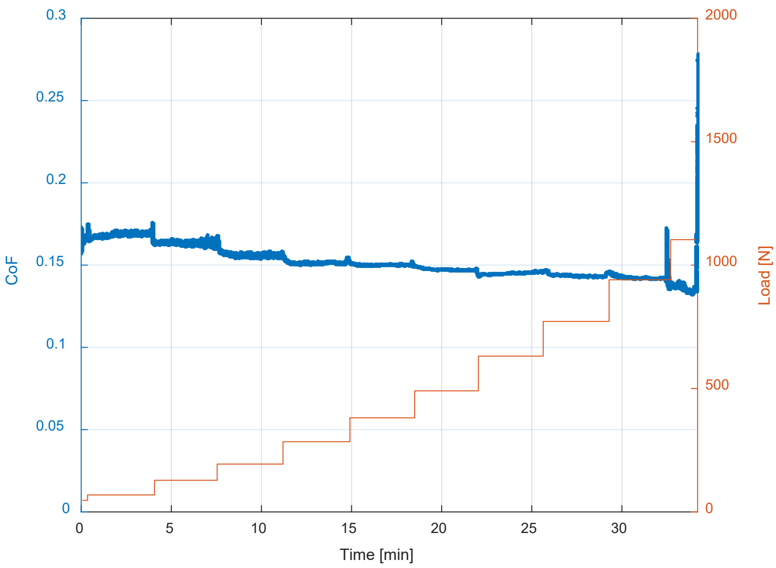

Figure 5. Case 1: example.

The results of case 2 are shown in Figure 6, where in the last steps, we see an increase in the CoF profile without huge peaks or multiple small peaks or any thickening of the curve; for this reason, we can conclude that the oil has passed all steps of the procedure.

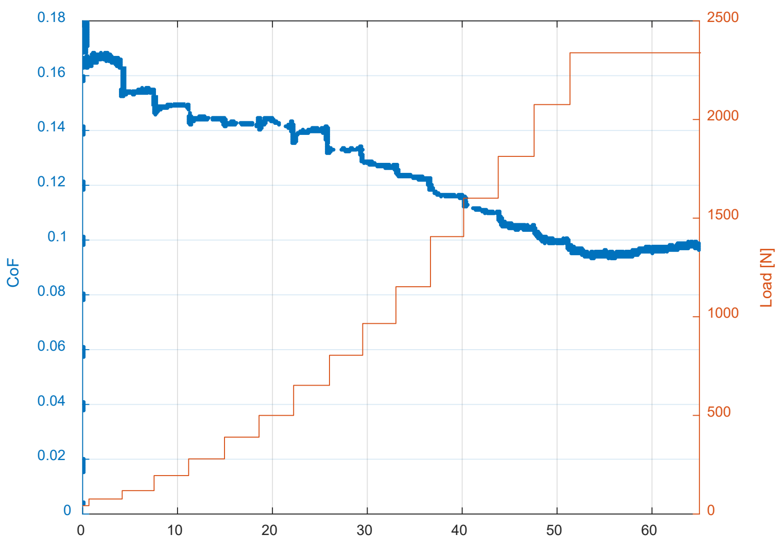

Figure 6. Case 2: example.

In the experiments, it can be highlighted that the oil has an SRV failure load stage of >12, even if the stages of the SRV procedure are 17.

In fact, in order to be comparable to FZG, it is enough that it exceeds the twelfth SRV stage (so that, if the SRV failure load stage is greater than the fifteenth or reaches the end, it would not be so relevant).

The results of case 3 are shown in Figure 7, where a lot of peaks are attributable to microseizures phenomena in the final steps; after the first microseizure, the CoF curve presents other peaks of higher intensity. The failure load stage is assigned at the stage where a series of microseizures occurs and continues for at least a few seconds.

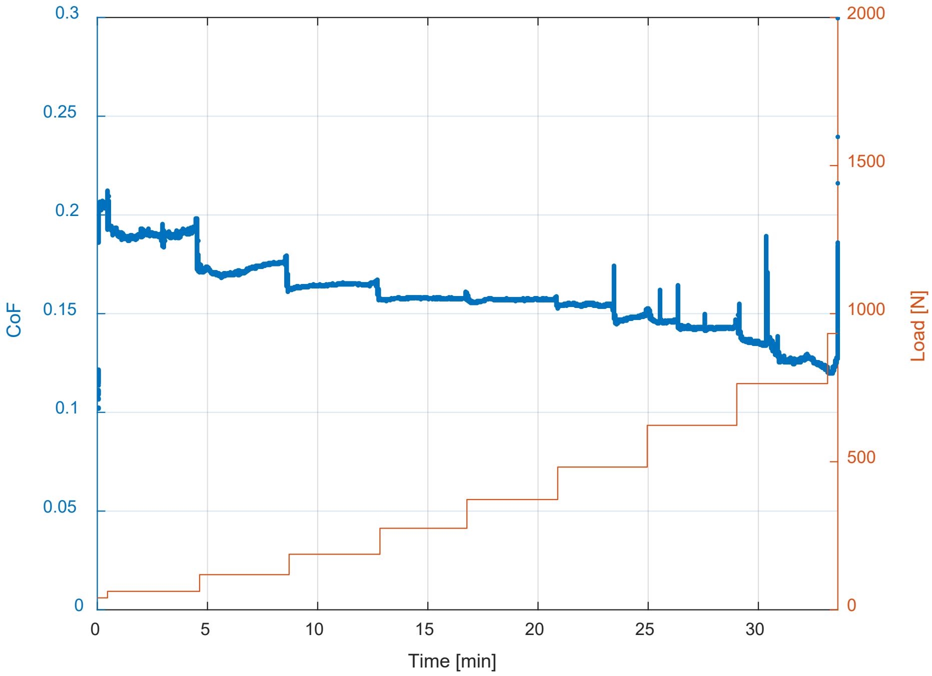

Figure 7. Case 3: example.

The results of case 4 are shown in Figure 8, where a special and unique case can be highlighted. In the middle of the test, the CoF profile changes, becoming flat and reaching high values as in the first steps. This behavior has occurred quite exactly in all the test repetitions.

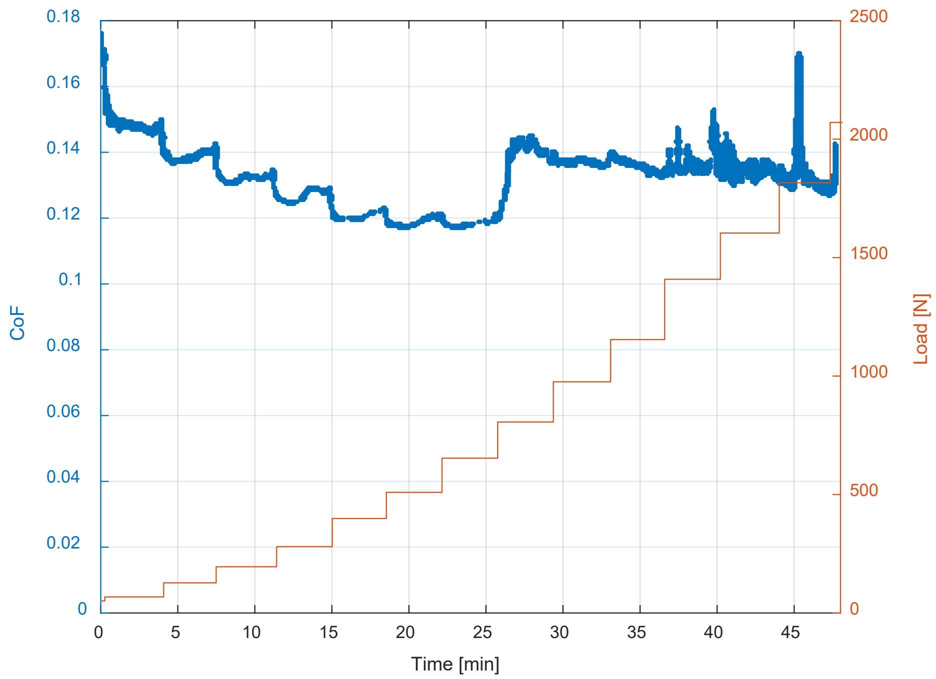

Figure 8. Case 4: example.

The results of the SRV test are listed in Table 3 as an average value between the repetitions we carried out for each oil. The FZG data are also listed in order to have a clear comparison among the results of both machines.

Table 3. Experimental results: laboratory and rig tests.

Oil Name	Oil Type	ISO VG	SRV Failure Stage	FZG Failure Stage
GT15	Gas turbine	15	11	12
GT32	Gas turbine	32	11	12
GT46	Gas turbine	46	12	12
TO46	Turbine	46	8	9
GO320	Gear	320	>12	>12
GO460	Gear	460	>12	>12
CO68A	Circulating	68	>12	>12
CO68B	Circulating	68	N.D.	12
CO68C	Circulating	68	>12	N.A.
CO68D	Circulating	68	>12	>12

For only one of the tested products, no FZG data are available.

Only for one oil, the SRV failure load stage (it belongs to case 4) is not assumed.

For all of the other lubricants, a difference of only $\pm$ 1 stage in the values of the failure load stage obtained by the two machines has been noticed.

Based on this, a good correlation between SRV and FZG tests has been found, appropriately distinguished in the cases previously identified (the oils tested mainly belong to cases 1 and 2).

For lubricants belonging to case 1, characterized by the presence of a net maximum in the CoF profile due to seizure, it is possible to assume a good correlation between SRV and FZG failure load stages, with a tolerance of $\pm$ 1 stage.

For oils belonging to case 2, characterized by a linear, thin and descending CoF profile without any detectable seizure or microseizures, it is possible to assume that lubricants that overcome the twelfth SRV stage can reach or overcomes also the twelfth FZG stage.

For products classified in case 3, a failure load stage has been assigned for the criteria previously explained in chapter 2 but must be defined with a more precise tolerance in order to assume a correlation with the FZG test; in addition, it would be very useful to collect more data and also add further evidence derived from other analysis (wear detection on the specimen, for example).

For the lubricating oil classified in case 4 (the 8th oil reported in Table 3) is very difficult to assign the failure load stage as it presents a unique and anomalous trend. Moreover, in this case, data gained by other types of analysis could help us in the assessment.

In addition, a great contribution to the global evaluation of these tests can derive from the knowledge of lubricant formulation in order to predict, estimate or determine the synergistic/antagonistic effect of oil components.

5. Conclusions

In this paper, the results of an experimental campaign are presented based on the use of a well-selected SRV procedure as a screening of the FZG rig test, leading to concrete benefits such as saving time and operative costs.

Four cases for the determination of the failure load stage of SRV have been defined and, in many cases, a good correlation with the FZG rig test has been found. A very good repeatability of this method has been proven too.

The tests conducted using SRV compared to the FZG scuffing method are as follows:

- Time saving (test time duration is 76% less without mentioning visual inspection and preparation for the following step);

As an example of time saving, just consider that each step of the FZG procedure takes at least 15 min without mentioning the operator's visual inspection and the preparation for the following step, while the SRV takes only 217 s per step.

- Cost/Material saving (smaller specimens and less oil sample);

- Less operator independent (automated machine and no visual inspection needed);
- Create a ranking (With the same failure stage we can rank the wear of the candidate's product).

This method is proposed as a screening tool for the FZG test, thus reducing the use of the FZG rig, which is very costly (the gears are unusable after each test and several liters of lubricant are needed) and time-consuming.

The obtained results are useful preliminary indications of the behavior of the lubricant, thus helping a formulator in the development of lubricating oil. In the case of the development of a new lubricant, where the performances of six or more different candidates are compared, only the two best performers will run the FZG scuffing test (still required to qualify a new lubricant).

Finally, from the work carried out, the importance of optimizing test methods, such as tribological ones, really emerges. These can lead to numerous advantages from the point of view of product development and final machine performance, being an extremely useful tool for the constant improvement of the energy efficiency of modern industrial systems.

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