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WEAR DETECTION IN TRIBOLOGICAL SYSTEMS BASED ON ACOUSTIC EMISSIONS

Gabriel Stadler[1], Philipp Bergmann[2], István Gódor[3], Florian Grün[4]

[1, 2, 3, 4]Chair of mechanical engineering, Montanuniversität Leoben, A;
gabriel.stadler@unileoben.ac.at

1. INTRODUCTION

Novel environmental laws force technical companies to reduce CO_2 emissions in their manufactoring process and products. In the automotive sector may this be done by lightweight constuctions or the increase of efficiency in energy transfer [1]. New engine process technologies like “start-stop”, higher ignition pressures and operation temperatures raise the efficiency level but lead also to a higher wear rates of ICE[1]-components. In order to deal with this problems, the most concerned parts, a large share are found in tribological systems, need to be taken under examination. Tribological systems consist basically of two surfaces in relative motion, supported by lubrication. Such systems can be found in ICE, gear couples, generators and other moving machine parts. To describe them theoretically, several mathematical methods, material parameters and operation diagrams are used. One of the most important graphs to show the frictional interaction between liquid lubricated sliding partners is the “Stribeck curve”, see figure1, plotting the COF[2] against speed. This curve illustrates the liquid lubricated sliding process at different interaction stages. The three main stages are: solid friction (I), mixed friction (II) and lubricant friction (III). In the first stage (I) the high friction coefficient results from solid interactions like interlock or welding. In the second area (II) liquid lubricant gets between the surfaces and starts to separate them partially, reducing the COF. In the last stage (III) the surfaces are fully separated with a continuous lubrication film between the surfaces. The COF starts to rise again, due to rheological friction at higher speeds.

[1] ICE=internal combustion engine
[2] COF=coefficient of friction

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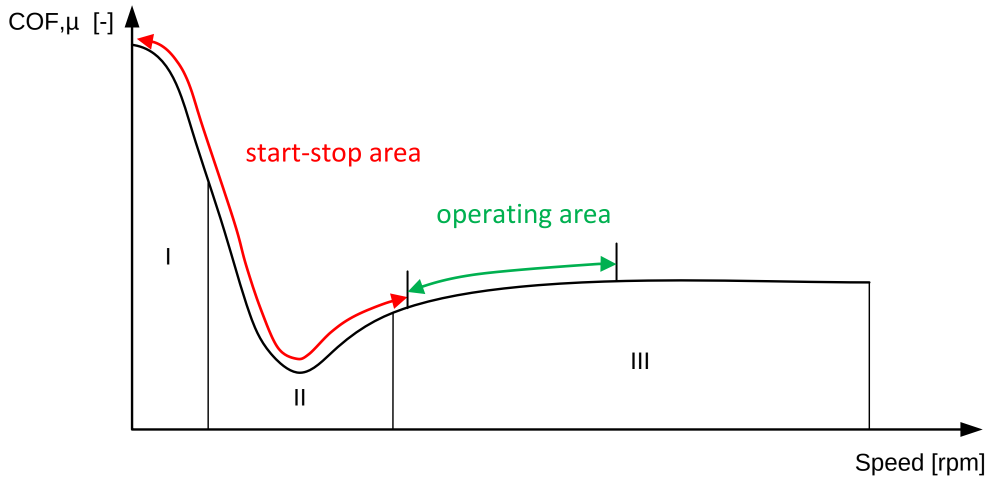

Fig. 1
Stribeck curve

Conventional engines start runs from the left side along the curve till it reaches the area of operation in the liquid friction stage. At this area the system is running with low friction and hardly any wear. As illustrated in figure 1, the main area for start stop is below this point in the mixed lubrication stage with higher friction and wear. In order to investigate the interaction between two sliding surfaces under such conditions, analogous models are used. For research applications, small specimens with structures of practical components are tested because they can be handled easier than whole components and deliver concentrated information about the material interaction in tribological system. Especially for the pair, shaft and journal bearing, different test methods are available. Two test methods which allow detailed investigations are developed at AMB[3] and described in the following. Additional to the existing measurement parameters a novel parameter the acoustic emissions are recorded and interpreted with mathematical methods.

2. TEST METHODS

These methods to analyze the tribological systems are on the one hand “ring on disc“-setup (see figure 2) and on the other test with journal bearing adapters. The ring on disc which is set up on a rotationary tribometer TE92 from Phoenix Tribology, uses a steel disc, coated with a soft bearing material and a ring made of steel representing the crankshaft. The disc is fixed at the bottom of a vertical shaft which is driven by an electrical motor via a V-belt. The ring is inlaid in a pot filled with oil, which is located on a crosshead (Fig. 2). A bellow moves the pot upwards

[3] Chair of Mechanical Engineering, Montanuniversität Leoben

and develops a normal load between the ring and disc. Due to the relative rotation between the two components friction sets in.

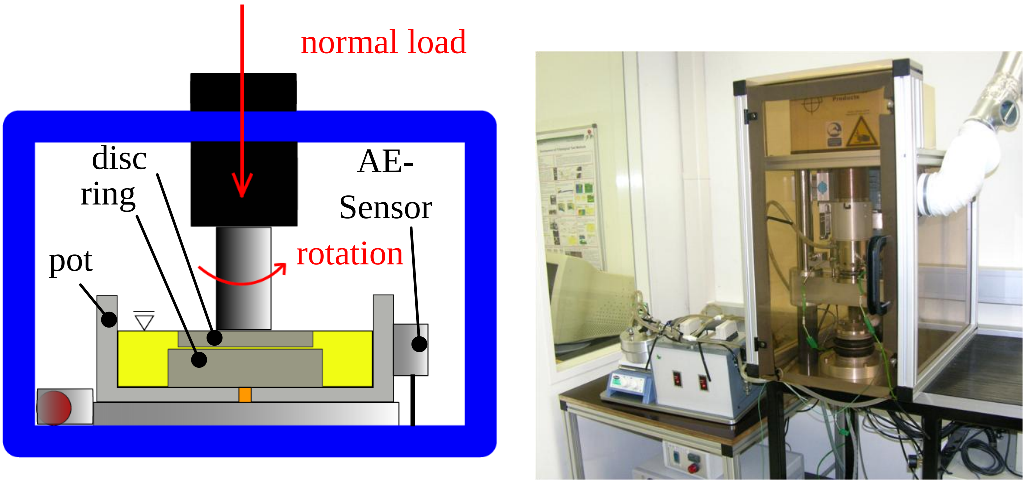

Fig. 2
Ring on disc test rig

This test set up focuses on the material interaction between the friction partners (e.g. journal bearing- crankshaft) and lubricants. The input parameters are the normal load (F_N), system temperature (T_2), and the rotational speed (n), shown in figure 3. Input parameter variations allow the realization of different test modifications, like temperature test or wear test. Figure 3 depicts exemplary a wear test with firstly a running in phase allowing both surfaces to reach a energy optimized state and increasing load stepwise until the system collapses.

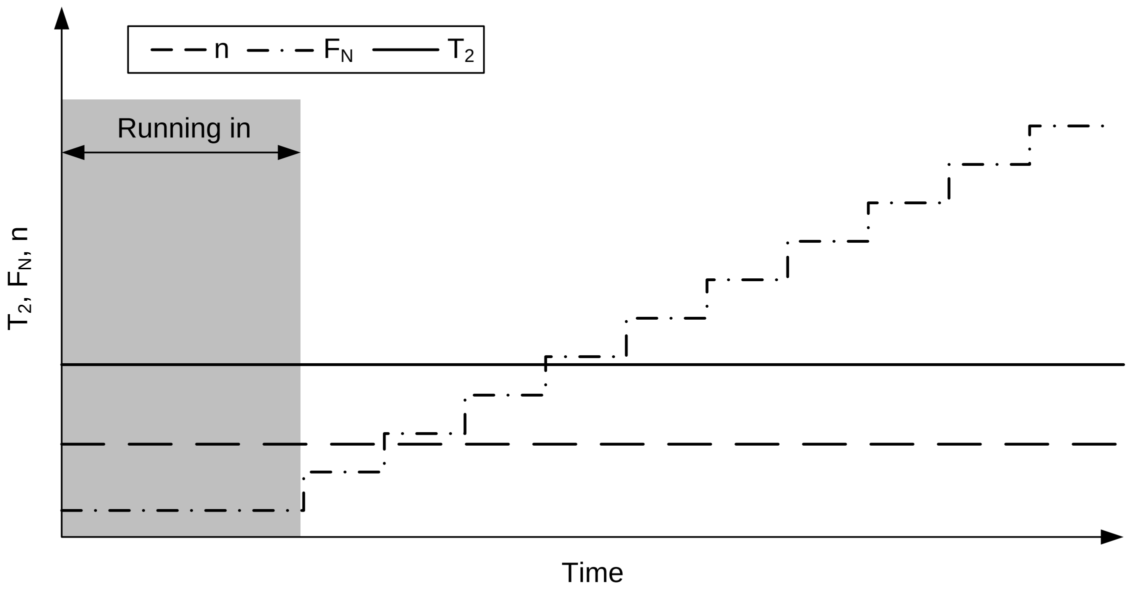

Fig. 3
Input parameter

The result from such a test is a graph with different measurements (see figure 4). The normal load is measured with a load cell between the bellow and the pot. It’s denoted in Megapascal (MPa), because the load is related to the normalized contact area. Two temperatures are detected, a near-contact (T_1) and a system temperature (T_2). The friction coefficient can’t be measured directly, but is calculated from the normal load and the resulting frictional moment. The state of friction is measured via the contact potential which is realised with an electrical flux through these two parts. If they are separated by lubrication, the resistance between both surfaces rises and increases the contact potential. In the case of solid contact the contact potential drops. Consequently this is an indicator to estimate the moment when solid friction and as a result wear occurs. The measurement of the wear rate is determent with electrical induction.

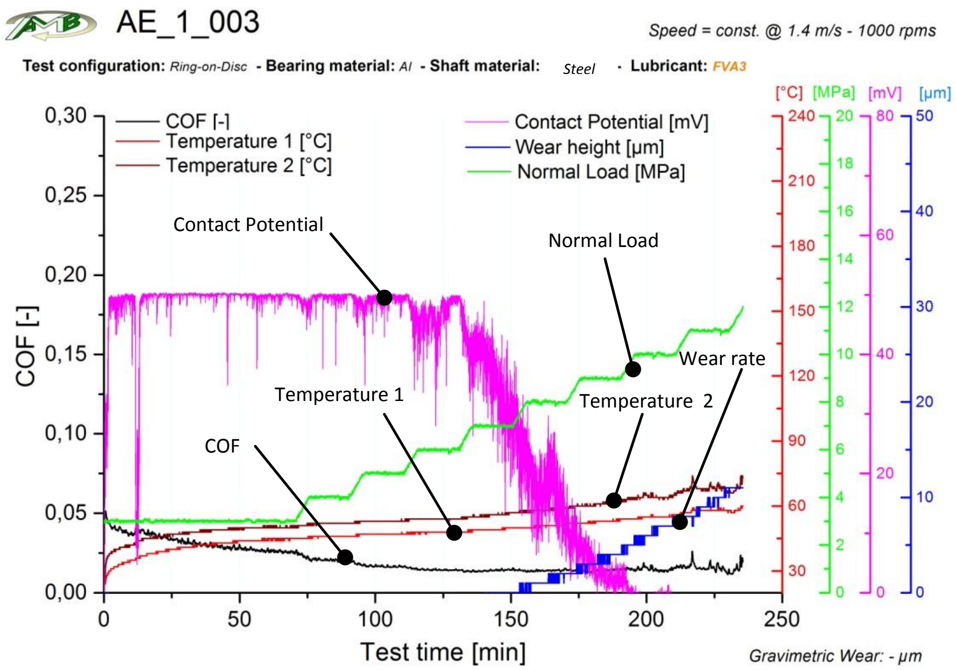

Fig. 4

Test data graph from ring on disc

A typical graph for a wear test shows that the contact potential starts at a certain level and drops shortly before the wear rate starts to rise. The system temperature and the contact temperature are increasing constantly during the whole test time due to heating up caused by friction losses. The coefficient of friction decreases in the first part by the reason of surface adjustment and shows an unstable behaviour when wear occurs, due to the continuous changing surface conditions. This kind of test result is used to determine seizure load limits. The journal bearing test method was developed on a rotationary tribometer TE92 HS with the main difference of a directly driven shaft. The shaft specimen made of steel is directly mounted on the drive shaft. The bearing shells are hold in a journal bearing adapter. The two shells are pushed against the shaft sample via a bellow and set of levers (Fig. 5). One main advantage is the direct driven shaft, which allows it to realize "start-stop cycles".

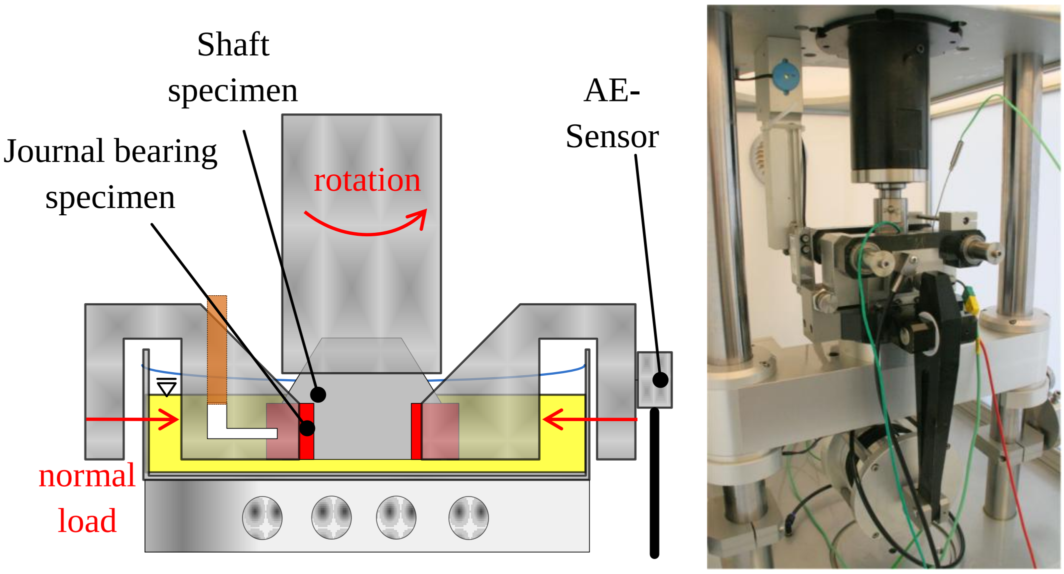

Fig. 5
Journal bearing adapter

This method uses specimens with practical shape. So they are one step closer to real components, but keeping the possibility of good measuring. The focus of this test is to investigate the behaviour of the whole system. The input- and output parameters are the same as the ring on disc method (Fig. 3) delivers respectively needs. A typical graph (Fig. 6) for a temperature test shows the constant load and speed. The system temperature (T_2) and the contact temperature (T_1) are increasing due to heating up. The coefficient of friction is low at the beginning and starts to rise when wear occurs.

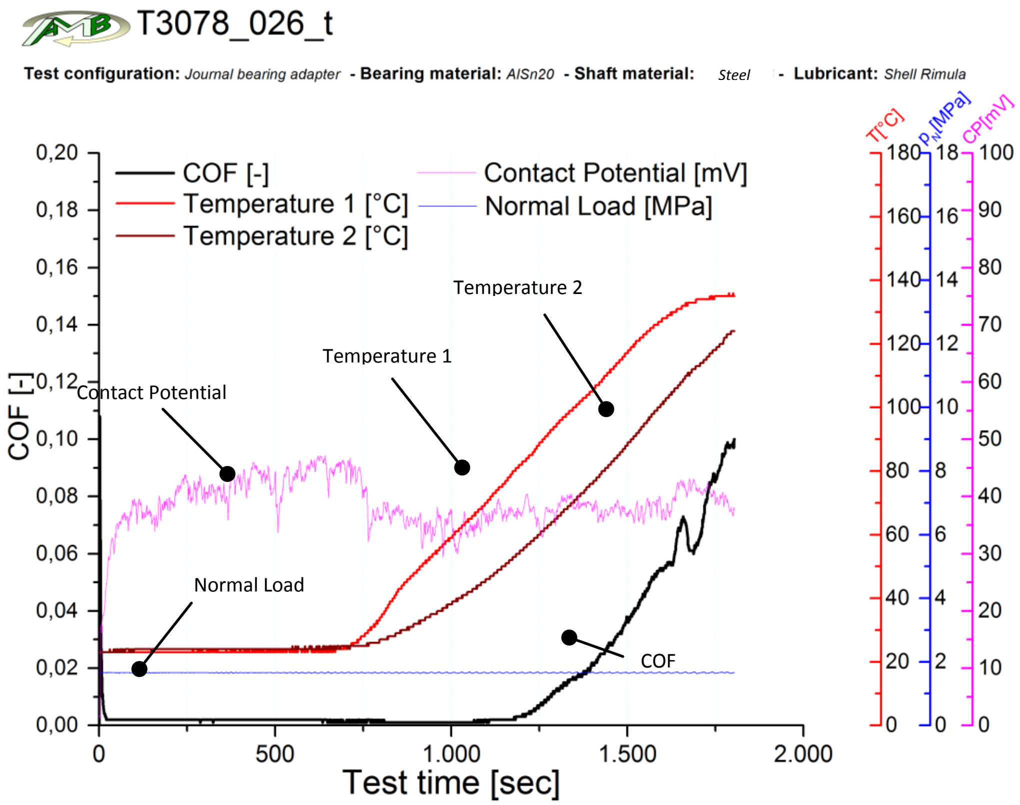

Fig. 6
Test data graph from journal bearing adapter

Additional to the existing test parameters a novel measurement variable, the acoustic emissions have been introduced which lead to promising results in available literature [2, 4, 5]. To lead the possibilities of this measuring method, test in ROD and JBA configuration were conducted. The material configuration for both test methods are aluminium based bearing materials in combination with a typical crankshaft steel. The ring on disc test uses mineral oil (FVA 3) lubrications. The regarded test is a wear test with a stepwise increasing load after a running in part (figure 3). The speed and the temperature are kept at a constant level. The viewed test with the journal bearing adapter ran at a constant speed and load level. After a running in phase, the system is heated up while keeping the other parameter constant. This test uses also mineral oil (Shell Rimula) lubrications.

4. ACOUSTIC EMISSION

Acoustic emissions occur in every dynamic system. Mainly machine elements, like gear couplings and ball bearings are producing characteristic structure-borne sounds but also frictional systems emit detectably acoustic waves [2, 6]. Due to the interactions between frictional partners, the amplitudes of the waves and their frequencies are changing during the operating stages. The lubricant friction stage emittes a low rate of acoustic emissions because of the impedance and the damping effect from the oil. Another point is that no transversal waves can be transmitted in liquids. Partial solid contact increases the friction and the amplitudes of the AE signal [2]. The contact of asperity summits, slip-stick effects and weld surfaces are reasons for this higher AE response. Modern measurement systems allow detecting such waves and converting it into a usable signal. The transformation from an ultrasonic structure-borne noise to an electrical signal happens in an AE Sensor based on the "piezzo effect". The resulting signal is transmitted by wire to an amplifier with integrated filter. Further it's send to an analogue-digital-converter (AD converter) to get a processable signal for the computer. The main advantage of this method is to detect frictional wear, even if a measurement of conventional parameters is impossible. Another benefit is that it can be installed at sealed systems with no entry to the operation space. So it can be installed at different test rigs easily. But several aspects need to be considered to ensure a reliable measurement. In order to satisfy the Nyquist–Shannon sampling theorem, it's necessary to sample with the double frequency of the upper level from the band pass filter. The signal intensity is reduced from the friction area to the sensor due to the specific impedance of steel. Also the quantification from the analogue digital converter (16 bit) needs to be considered. The detection range for this application is located between 0 and 1 MHz. The sensor exhibits its highest sensitivity between 50 and 400 kHz. The sampling rate of 2 MHz causes a high amount of data per sampling, which makes it necessary to trigger data storage at specific times.

5. DEVELOPMENT OF THE METHODS

The following methods are developed by using the acoustic emission signal gathered during the wear test depicted in figure 4. The electrical signal is a quantitative, noisy signal. In order to get useful information, the whole signal needs to be filtered. A common filter for smoothing waves, based on a polynomial regression, is the "Savitzky-Golay-Filter" [3]. This filter uses a polynomial function with a certain order in given points, to smooth the curve between them. Figure 7 depictes the filterd and original signal starting at a time of 120 minutes until the test end. In the phase of stabile contact potential the acoustic emissions show low amplidudes. At the point of wear start the intensity of the original and filtered signal rises.

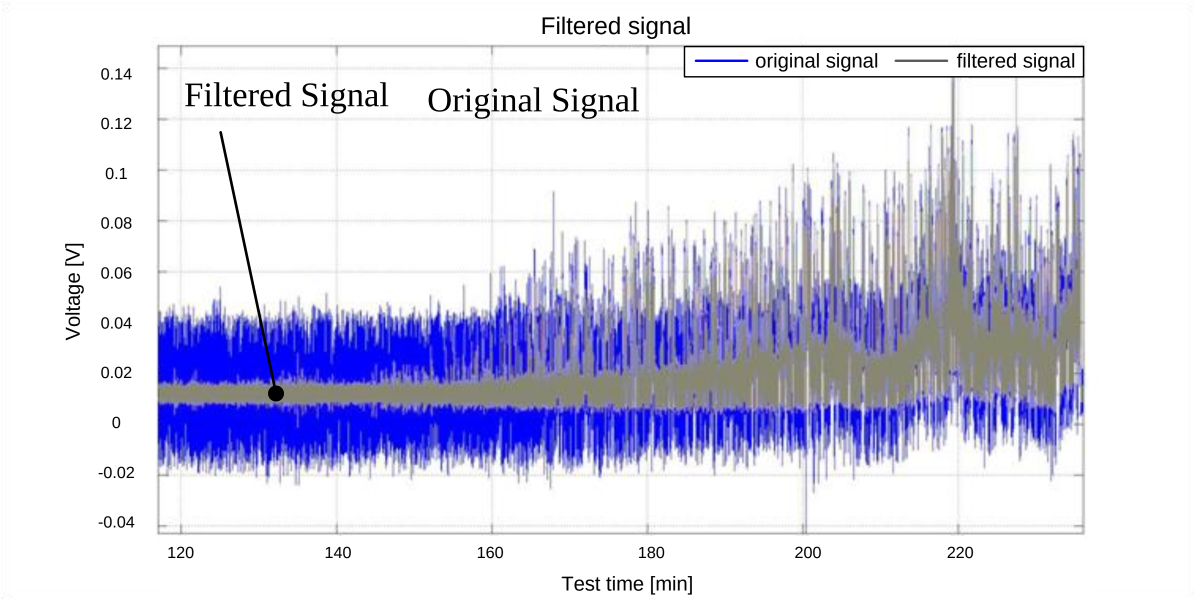

Fig. 7
Difference between original and filtered signal

5.1 SPECTRAL ANALYSIS

During a test run, a certain range of frequencies is activated. FFT transforms the time dependent signal into a frequency spectrum which can be used subsequently to perform spectral analysis. The sequence of the time dependent frequencies spectra results in a waterfall chart (Fig. 8). This chart shows the change of excited frequencies during the test. An intensity change in a frequency area 50-400 kHz can be observed at a start of wear at approximately 150 minutes.

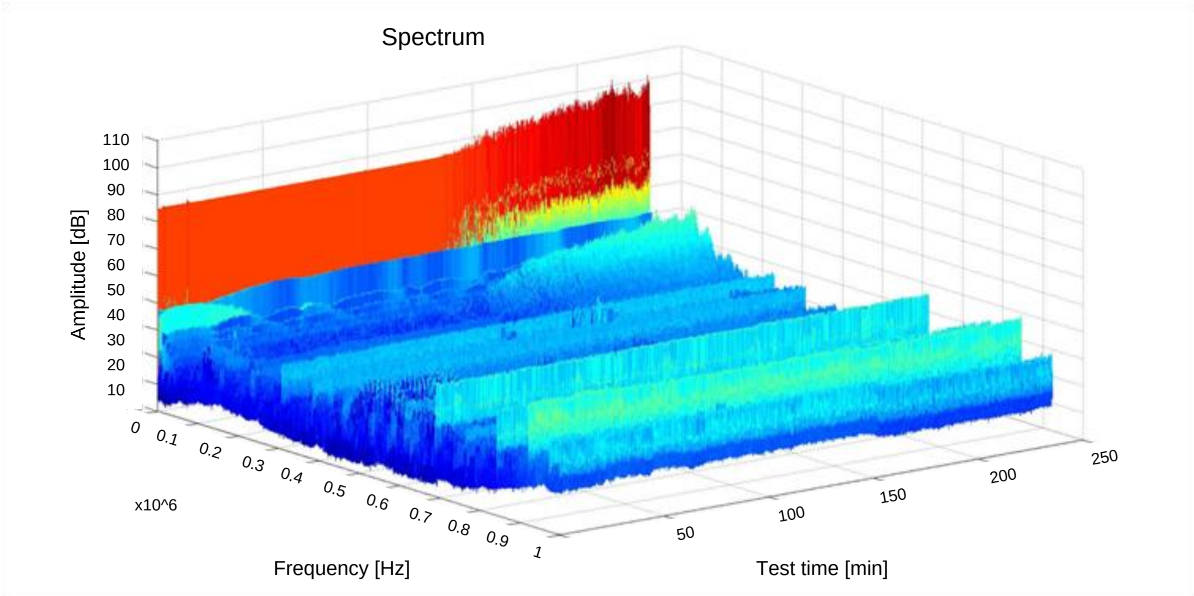

Fig. 8
Diagram of a spectrum

5.2 ROOT MEAN SQUARE

Another meaningful method is the root mean square (RMS) [3].

$$\mathrm{RMS} = \sqrt{\frac{1}{T}\int_0^T A(t)^2 dt} \qquad (1)$$

The root mean square takes the squared amplitudes (A (t)) divided by the number of the considered values (T). An advantage of this method is that the results are all positive. This makes it easy to include the resulting curve into a diagram and compare it with other test parameters. The RMS shows a near zero smooth course in the lubricant friction area. When solid friction sets in, the value of the RMS increases noticeably (Fig. 9).

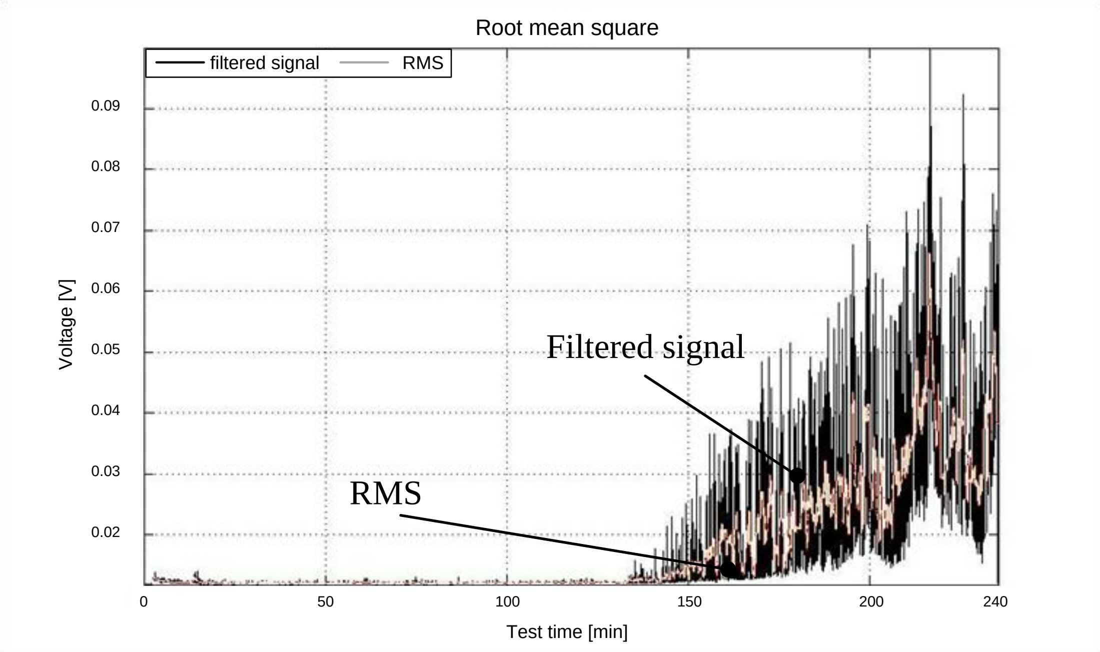

Fig. 9
Root mean square of the signal

The root mean square shows exactly the course of the AE signal during the test without the non relevant amplitudes.

5.3 ENERGY METHOD

During the whole test energy is inserted into the system. Most of this energy is dissipated in form of heat but also in acoustic emissions. So the amount and height of AE amplitudes correlate with the acoustic energy. The energy method builds the sum of the amplitudes A(t) over the whole test.

$$E(t) = \sum A(t) \qquad (2)$$

The result is a representative pseudo energy E(t). Therefore the raise of this curve depends on the amount and value of amplitude peaks in a certain time section. If the curve raises very fast, a huge amount of peaks with a high value occur (Fig. 10).

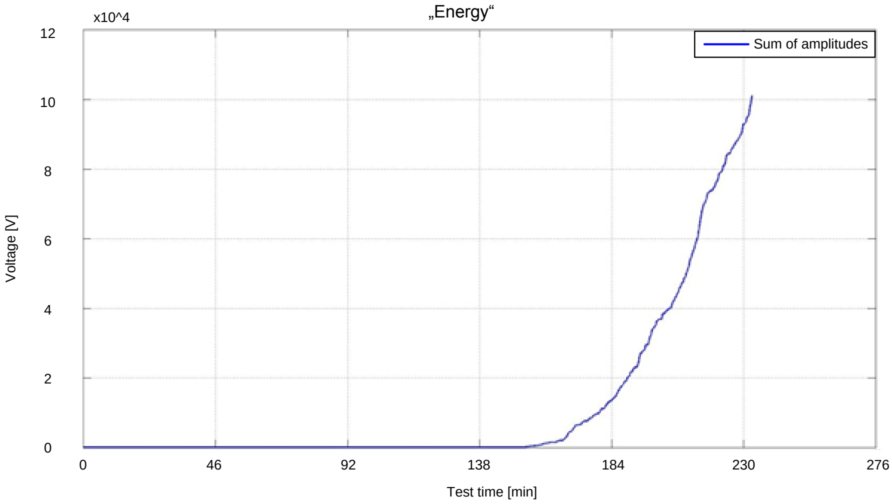

Fig. 10
Sum of the amplitudes

The rise of the curve represents the intensity of wear. In this case there is a viewable difference at the moment when solid friction occurs and wear starts.

6. DISCUSSION AND CONCLUSION

The AE show a strong correlation between COF and occurring wear. The developed methods deliver valuable information about the tribological behaviour. Especially the RMS is suitable for the direct implementation in-situ supervision of tribological systems, see figure 11. This is showing the RMS of the AE implemented in the measuring graph of the conducted seizure limit load test.

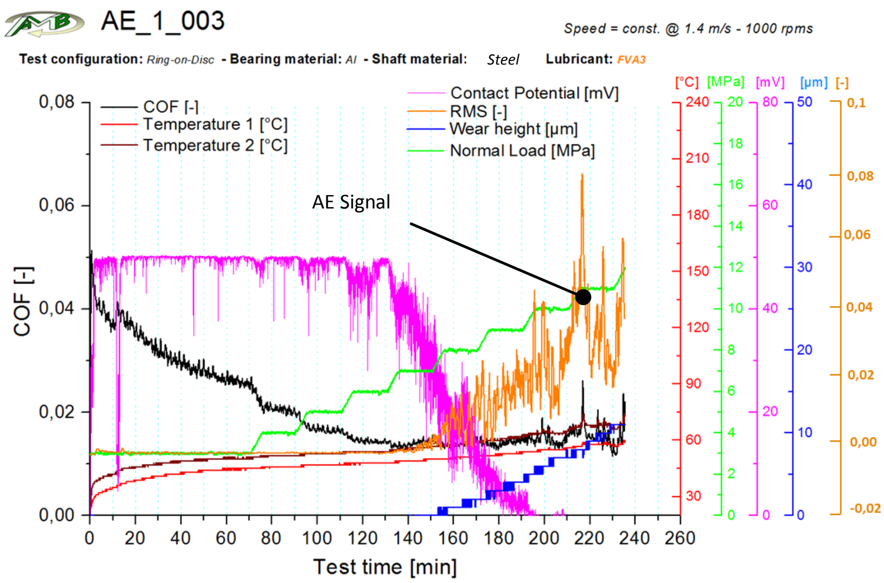

Fig. 11
Test data graph (ring on disc incl. AE-signal)

The AE curve from the ring on disc test shows a comparable raise with the wear rate and a correlation between the AE signal and the coefficient of friction. One result of this graph is that the AE signals conditioned by friction. Additional the response of the signal is higher than the others and so it’s a usable source to evaluate friction.

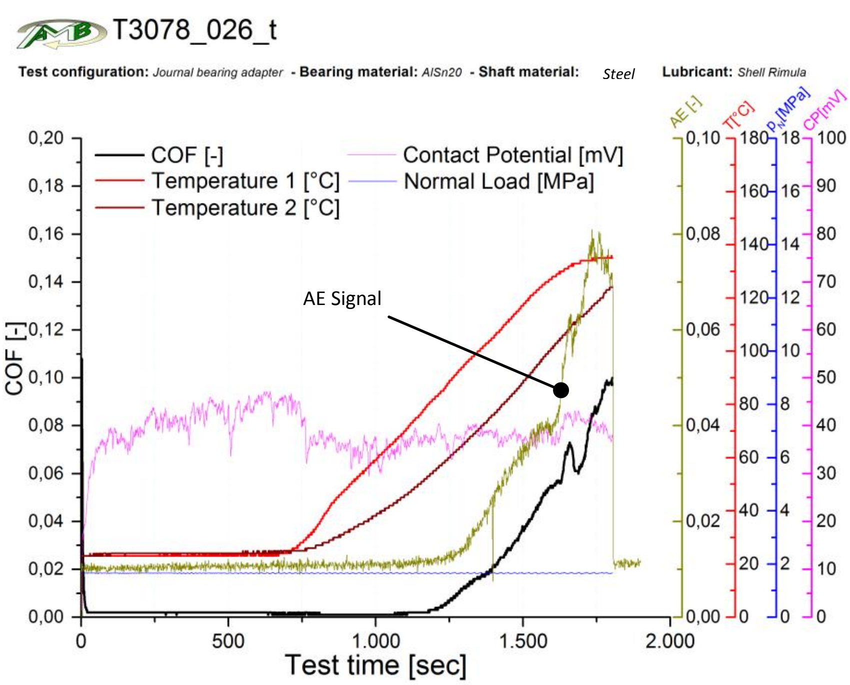

Fig. 12
Test data graph (journal bearing incl. AE-signal)

Having a look at the measure graph form the JBA and the included a similar behaviour to the ring on disc test may be seen (Fig. 12). The essential message is that the two test modifications deliver the same trend referring to friction respectively wear and underline the usability of AE to characterise tribological systems. The spectral analysis shows that several specific frequencies between 50-400 kHz are activated and change during the test. This method is promising for future work. The resulting graph of the energy method turns out to a helpful variable to evaluate wear intensity. The graph (Fig. 10) shows, that the amount of inserted energy, increases significant at the moment when solid friction and wear occurs. AE signals from the tribological test deliver new infomation to describe such a system. The analysis methods are useful for different considerations of friction and wear. In the future the signals may be used to characterise the wear, detect mixture friction earlier or to control the test.

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8. REFERENCES

[1] PROFF, H.; PASCHA, W.; S SCHÖNHARTING, J.; SCHRAMM, D.: **Schritte in die künftige Mobilität,** 2013, ISBN 9783834943071

[2] BURGER, W.; ALBERS, A. ; NGUYEN, H. T.: **Reducing power loss of hydrodynamic journal bearing by means of condition monitoring and automatic lubrication flow control. -** 18 th international colloquium tribology –TAE

[3] SOPHOCLES J. ORFANIDIS.: **Introduction to Signal Processing**, 2010

[4] RASTEGAEV, I.; MERSON, D.; VINOGRADOV, A.: **Enhancement of efficiency of tribological testing by using acoustic emission measurements. -**Journal of AE, Volume 32/2, **-** AEWG**,** 2013. p. 597 – 603

[5] CHACON, J. L. F.; KAPPATOS, V.; BALACHADRAN, W.; GAN, T.-H.: **A novel approach for incipient defect detection in rolling bearings using acoustic emission technique. –** Applied Acoustics 89, 2015. p. 88 – 100. – ISSN 0003–682X

[6] ZELLER,P.: **Handbuch Fahrzeugakustik,** 2012, ISBN 9783834886576