SOME POSSIBILITIES OF AE SIGNAL TREATMENT AT CONTACT DAMAGE TESTS OF MATERIALS AND BEARINGS

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Abstract

This article compares recent application possibilities of the acoustic emission (AE) method for more specific identification of the stages of contact fatigue of materials. It focuses also on examples of results obtained by a new AE analyzer, which allows for continuous AE signal sensing. The results proved that AE techniques enable reliable recognition of running-in period, stabilized run and exact definition of initiation stage of surface damage, leading to pitting. First results obtained during AE signal sensing in the course of durability tests of axial and radial bearings in the contact fatigue laboratories of the Brno University of Technology are also presented.

1. Introduction

Endurance of materials against contact fatigue damage is one of the most important parameters for long-term reliable function of all types of bearings, gears and many other movable machine parts. The tests of contact fatigue of materials and bearing durability are conducted using equipments with test specimens of different form or real test bearing. In most cases the actual degree of damage is detected by sensing vibrations of the whole testing mechanism. After reaching a predefined level of vibrations, the machine is switched off and the sample or bearing is examined in detail. Although these testing machines are equipped with sensitive sensors, the results are not fully satisfactory yet. One potential improvement in the identification of damage degree is the application of acoustic emission (AE) method. This method can provide detailed information about periods of changes of damage mechanism. So far, it is difficult to precisely assign the observed changes of AE signal to the processes in material. One of the reasons is of course the limited knowledge about mechanisms of contact damage, and another one is the range of information available in AE signal.

An important reason of the loss of decisive properties of all types of bearings is the inception of point contact damage, so-called pitting, on some of its elements. Contact damage is caused by cyclically repeating processes in surface layer of material by mutual dynamic load of two bodies. Damage of surface layers causes the inception of microcracks in places of maximum sheer stress, by progressive separation of damaged surface layers and by inception of holes on the surface (Fig. 1). In the beginning, this fatigue damage results in decrease of functional properties of damaged part; however, emerged surface hole may gradually create a center of fatigue crack, which successively enlarges to the whole section of the part.

In frame of the project of Ministry of Industry and Trade of the Czech Republic, “Research of new methods of measuring and evaluation of acoustic emission signal”, a new type of analyzer has been developed that is capable of registering the whole AE signal. In this paper the
information about the processes of contact damage of materials obtained by standard methods and by this new analyzer are compared.

Fig. 1. Example of contact fatigue microcracks (a) and pitting damage (b) on the surface of the specimen from bearing steel (100Cr6) loaded in Axmat testing device.

Compared with classical material testing, contact fatigue is more complicated, as there is always mutual contact of at least two bodies. In case of development of contact damage, AE signal contains not only “standard information” about the activity of the defect itself, but, taking into account the change of quality of contact surface, the vibrations of the system grow and noise in the testing equipment grows as well; all this is reflected in the detected signals. We also cannot forget the important influence of the lubrication of the whole system. With respect to the sensitivity of AE method, the importance of quality of setting is apparent – choice of parameters, sensors, signal amplification, sensor locations, quality of contact between sensor and surface, etc. [1-3].

2. Experimental equipment

Three basic appliances are used for contact fatigue tests of materials and for tests of bearing life (principle of all these stations were described in other contributions [4, 5]):

a) Axmat station – in this case, 21 balls are placed in guiding ring; they roll away on the surface of firmly fixed disc-shaped sample from tested material. This device was modified also for axial bearing tests. In this case, ring, balls and material sample are replaced by the tested axial bearing (Fig. 2a).

b) R-mat station (Fig. 2b) – two rotating discs roll away on the surface of cylindrical sample.

c) SA 64 testing equipment (Fig. 2c) is devoted for tests of radial bearings durability.

Sensed AE signals are amplified in preamplifier and subsequently processed in AE analyzers. Our standard AE analyzers (Dakel Xedo®) enable dividing detected signals into 16 elective energetic classes, so-called levels. In order to highlight the AE signal change, it is possible to choose only suitable levels. The sensing software Daemon® was used for sensing and evaluation of AE signal. After completion of the tests, the signal was processed by software DaeShow®. The examples of AE signal treatment are presented on Figs. 4, 5, 9 and 11.

In a part of experiments, we had the possibility to use the newly developed AE analyzer named DAKEL IPL®. It is a new state-of-the-art system for continuously recording and process-
ing data from the AE sensors. Compared to the commonly used AE analyzers, the major advantage of the DAKEL IPL is the capability of continuously sampling and storing the whole AE signals for as long as there is a disk space to store them. With the biggest currently available fast disks on the market having the limit of about 1 TB, we can store as long as 17 hours of 5-channel recording and when using RAID arrays of such disks it can be much more.

![Image](image1.png)

Fig. 2 a) device Axmat with axial bearing, b) detail of working part of R-mat device, c) testing station SE 64 for radial bearings durability tests.

![Image](image2.png)

Fig. 3 Typical shapes of the tested specimens a) for Axmat device (diameter app. 40 mm), b) R-mat (diameter 10 mm) and c) tested axial and radial bearings.

The device has a total of 5 synchronous analog input channels, simultaneously and continuously sampling at 2 MHz. Out of these, 4 channels are generally used to sample the AE signals and the last channel is used for synchronous monitoring of any external physical parameter that is used to excite the testing object (such as the loading force, pressure, temperature, etc.). This comes handy when you need to correlate the AE signals to some external events in time.

The results obtained from DAKEL IPL device are commented later in the text. Some examples of the processed data from contact loading of material (on Axmat testing device) will be shown in Figs. 6-8. First results obtained on radial bearings are collected on Figs. 13 and 14.

3. Experimental results

3.1 Contact fatigue of materials:

Observed changes of the number of overshoots over adjusted levels of the signal during a test on Axmat and R-mat stations are shown in Figs. 4 and 5 [5].
Fig. 4. Example of observed changes in the number of overshoots over adjusted levels of the signal during a test on Axmat station (bearing steel 100 Cr6).

Fig. 5. Record of the final part of contact damage test of a bainitic steel on R-mat testing station. These “simple” and basic records of AE signals enable us to obtain detailed description of the character of the damage, which emerges either as gradual breaking of the surface layer of the material and “leap” extending of pitting or possibly by widening of number of damaged places in monitored contact trace. When the test is finished, it is possible to determine the type of damage by visual observation.

Figures 6, 7 and 8 show the examples of latest records, which were obtained by DAKEL IPL, which is capable of continuously sampling and storing the whole AE signals. Changes of spectral amplitude (Fig. 6) should be a very important parameter for differentiation of damage stages. The possibility of displaying the progress of the amplitudes on selected frequencies in time is also useful (Figs. 7 and 8). In the present case, it is clear that for the identification of contact damage initiation in steel, it is suitable to observe the change of higher frequencies (in this case above ~180 kHz) in time. For comparison, the record obtained during grey cast iron contact fatigue test is also shown (Fig. 8). In this case the mechanism of damage is considerably different from steel. As a result being a relatively soft material, a deep trail with a plenty of small damages appears. Gradually the contact pressure decreases and the period of stable damage appears.
Records on levels 50 to 70 kHz correspond to this. However, unlike the case of steel, the higher frequencies do not provide any information about damage propagation.

Fig. 6. a) Continuously sampled signal allows us to create a 3D map of continuously evolving averaged spectrograms in time during the whole measurement (or any part of it that we choose). The third dimension on this figure represents the spectral amplitude and is represented by the color according to the displayed scale on the right side of the graph. b) This is a horizontal cut of the 3D spectral map from Fig. 6a at 8 min, 50 min and 100 min in time. This is the common way to display the spectral amplitudes. Testing device Axmat and tested material – carbon steel.
3.2 Tests of bearings durability:

Compared to contact fatigue testing, the tests of real bearings present many technical problems. We have conducted a series of successful experiments with axial bearings on a modified Axmat testing station (Fig. 2a). An example of record of the final part of test of a bearing with pitting on both outer and inner ring is presented on Fig. 9. and Fig. 10 shows details of defects.
Most recent group of experiments was carried out for durability testing of radial bearings (Fig. 2c). Sensing of AE signal is complicated by position of the tested bearing inside the testing station, so it is not possible to place the AE sensors to its direct vicinity. In this case we use waveguides, whose one end touches the outer ring of the bearing, which is fixed in the testing device and the other end is connected to the sensor. Another sensor is placed on the surface of the testing station.

Despite the mentioned complications with AE signal sensing, we have managed to find optimal setting of the measuring chain and to process some records of high-quality and damaged radial bearings. Example of basic comparison of records from the initial stage of loading of both bearings is depicted on Fig. 11a.

Notably higher level of signal is apparent in the case of the second (damaged) bearing. After disassembly it was found that some balls in this bearing were “low-quality” (Fig. 12) and so it was the cause of high AE activity. After further analysis of AE events, differences in their frequency characteristics were found (Fig. 11b). In the case of the high quality bearing the maximum frequencies were ranged approximately between 45 and 120 kHz, while in the case of the bearing with damaged balls the AE events had maximum on the level at approximately 83-87 kHz.
Fig. 11 a) Example of AE signal records from the initial phase of a test of high-quality radial bearing and from a low-quality bearing (with defect), b) typical examples of AE events and their frequency spectra with maximum - Dakel Xedo device and DaeShow software.

Fig. 12 Damaged ball – the “cause” of high activity of AE signal at damaged bearing from Fig. 11 and other defect on the ball surface.

At the end of 2008, the analyzers with continuous sampling and storage of AE signals (DAKEL IPL) were used also for tests of radial bearings on stations SA 64 (Fig. 2c). Because the tested bearing is located inside the testing station, we have to use sensors placed on waveguides. Here, magnetically held sensors were placed on the surface of the station body. That is why it is necessary to amplify the AE signal more than usual and it can contain undesirable noise. Despite that even in this case it is possible to observe significant changes of signal during the initiation and propagation of bearing damage. The changes are perceptible much earlier than they can be recorded by standard vibro-diagnostics. Examples of the records are shown on Figs. 13 and 14.

4. Conclusions

In our experiments, AE method succeeded in distinguishing the characteristic stages of process of material damage by contact loading, which verified the possibility of improving tests of contact fatigue resistance of materials.

The situation with AE diagnostics of real bearings damage is much more complicated, as the bearings are composed from many parts which are in contact and especially it is usually not possible to place the AE sensors directly on the bearing surface. For this reason, the signal contains
Fig. 13 a) Continuously sampled AE signal (3D map) of spectrograms with time (see also Fig. 6a) during the final part of a real bearing (type 6204) measurement. b) The record of the amplitudes on selected frequencies with time for the same part of the measurement as in a).

Fig. 14 Examples of horizontal cuts of the 3D spectral maps from various test times of real radial bearings (type 6204): a) bearing No. 3 from Fig. 13. b) bearing No. 2 with different type of damage.

Fig. 15 Examples of contact damage of the inner ring of a radial bearing.
much more undesirable disturbances, which makes adjusting of measuring chain more difficult. Nevertheless the examples shown in this paper suggest that it is possible to identify bearings with damaged parts. After the evaluation of a number of data files, it would be possible to work out simplified way of signal processing of selected signal characteristics that would correspond with real damage of diagnosed bearing. This simplification will result into one-purpose analyzers that will be a part of permanent diagnostic systems used on some important bearings, e.g. in transport technology, in technological lines and energetic devices – in order to optimize intervals of planned maintenance and temporary stoppage of operation connected with it (e.g. turbines mounting, rolling lines, etc.).

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References