Identification of Contact Fatigue Stages with Acoustic Emission Method

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Abstract. The knowledge with the acoustic emission (AE) method utilisation at tests on contact loaded surfaces is discussed. The results proved the AE technique enables reliable recognition of running-in period, stabilised run and exact definition of origin stage of surface damage, leading to pitting. It is proposed direction of AE analyzers utilisation not only in research area, but the AE technique may be successfully used even in industrial practice.

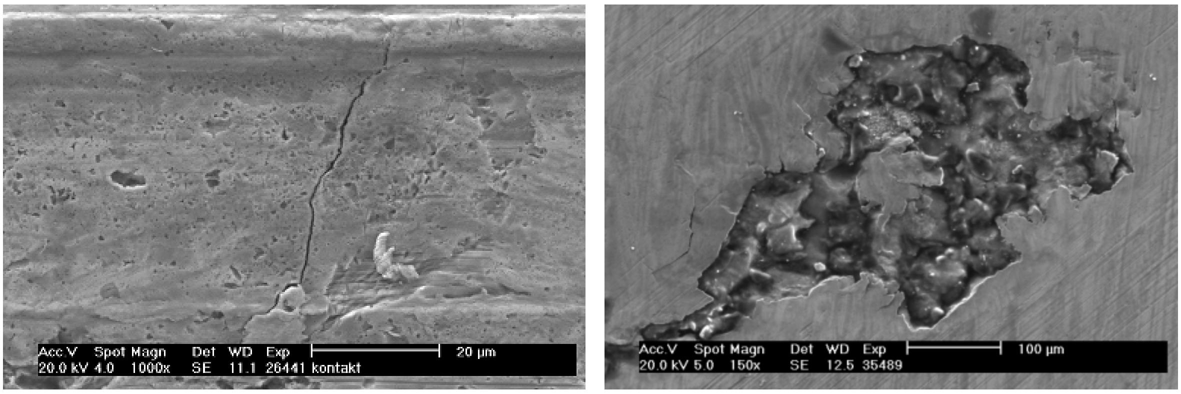
1. Introduction

Most moving machinery parts are bedded in supporting elements – bearings, the task of which is to transfer or catch loading force and moments or conduction of machine parts. From the point of view of construction, there are, before all, sliding bearings and rolling bearings. The main task of all types of bearings is to provide above mentioned functions under conditions of minimizing energetic loss and ensuring maximum lifetime of bedding.

Lifetime of rolling bearings means period in which the bearing carries its function until the moment when it does not meet the requirements of operation and it has to be put out of service. It has been experienced that the lifetime of the same bearings under the same operational conditions is considerably different. The differences of properties are caused, before all, by differences of properties of the materials and by tolerances of dimensions of individual elements of bearings.

An important reason of 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 inception of micro-cracks in places of maximum sheer stress, by progressive separating 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 centre of fatigue crack, which successively enlarges to the whole section of the part. In some applications, damage of these bearing elements might cause considerable material loss and, particularly it might endanger lives of people.

Taking into account the importance of bearings, attention is paid to chosen types; their warming is measured, total level of noise and vibration of the system are analysed. Method of acoustic emission may offer another possibility of deepening of diagnostics of real actual state of bearing; it is, without doubt, one of new perspective areas of automated diagnostics. Some work in this field has been done especially in Japan, USA and UK [1, 2, 3, 4, 5, 6]; nevertheless, important bearing producers are gradually becoming involved. Some experiment were realised also in Czech Rep. [7, 8].



a) b)

Fig.1 Micrographs of short crack in contact fatigue trace (cast iron) a) and developed pitting in carbon steel b)

2. Experiments

2.1 Experimental possibilities

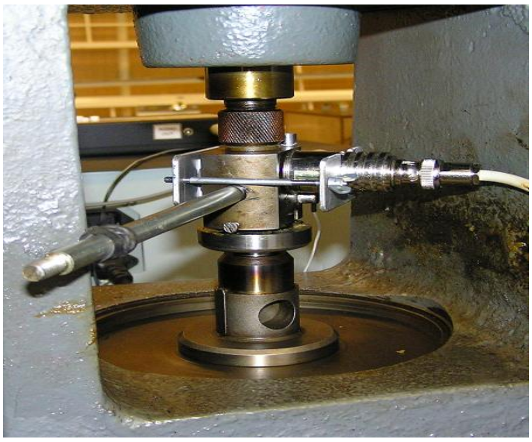
The Institute of Machine and Industrial Design of BUT in Brno has been one of the most important workplaces focusing in research of contact damage of materials as well as bearings themselves. We have been proceeding in this tradition and, except for evaluation of materials; we focus especially in research of possibility of exact identification of stadiums of contact damage of materials and diagnostics of bearings, utilizing application of the method of acoustic emission. For successful application of AE method for bearing diagnostics, several steps have to be realized successively.

2.2 Laboratory tests of contact fatigue of materials

The elaborating of procedure of AE method application on laboratory tests of contact fatigue is an important area. The AE method may significantly contribute to the knowledge of the process of contact damage. Individual stages of this cyclic process - stage of running-in and especially the inception of first pitting in contact trace can be easily diagnosed. Contemporary standard vibro-diagnostic procedures enable to identify only relatively developed pitting.

This type of tests of material characteristics is done on several basic types of testing equipment.

a) *Axmat testing station* – the principle lies in rolling balls in circular track on the surface of testing sample of discoid shape (Fig.2a, b). The balls are, by means of rotating supporting ring, pressed by defined axial strength towards the surface of the sample; contact damage consequently arises in its surface layer.
b) *R-mat testing station.* These stations utilize cylindrical samples (Fig.3a, b); driving and pressure cylinder of precisely defined profile lean towards them.
c) Further stations, e.g. four-ball machines etc.



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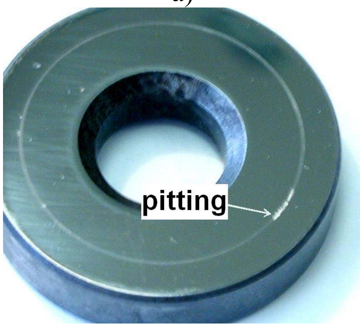
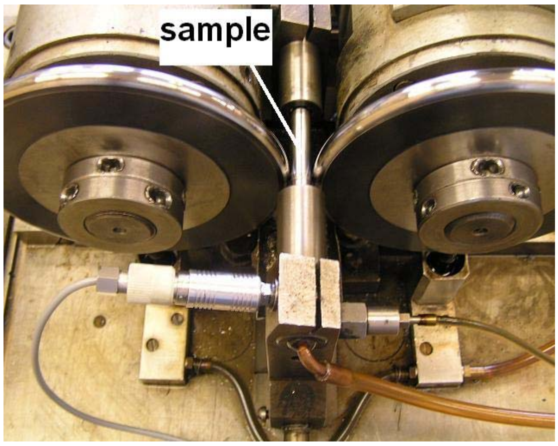


b)

Fig.2 Detail of Axmat testing station (a) and shape of sample with developed pitting in contact trace.



a)

b)

Fig.3 R-mat device (a) and test sample with pitting in traces (b).

Especially station Axmat simulates the state occurring in real ball bearing very well (especially in axial one); moreover, it enables evaluation of the influence of lubricant etc. Acoustic emission helps to give precision to evaluation of contact properties of materials used for bearing elements and to work out methodology of evaluation of sensed AE signal, which may be very useful for evaluation of real bearings. On the contrary, R-mat device enables simulation of contact damage with mutual slip between the discs and the sample, which is useful e.g. for the evaluation of contact properties of materials of rings for railway wheels, dynamically loaded parts of railway turnouts etc. Acoustic emission provides certain diversification of current way of evaluation of materials.

2.3 Laboratory tests of contact fatigue of materials

Results presented hereafter were gained from tests of bearing materials on device Axmat. AE system Dakel Xedo with sensing software Daemon was used for sensing and evaluation of AE signal. After completion of the tests, the signal was processed by software DaeShow.

One AE event corresponds with strongly attenuated set of sinusoidal shape. This set is called emission event. In the course of signal processing, either number of these events or number of overshoots the amplitude of which exceeded pre-set threshold levels of the device (counts). Frequency of these events or counts is often used as a criterion. Furthermore, the time necessary for reaching maximum amplitude of the signal – rise time is used as well.

Taking into account the shape of the signal, it is possible to estimate the structure of AE resource; frequency spectrum defines the basis of AE resource. AE signal frequency provides information about speed of damage inception. Further characteristics can be obtained from the level of deformation of the shape of signal, amplitude distribution of signals etc.

The simplest is the record of the total number of counts in the course of the test. An example of this "summation" curve can be seen in Fig.4. It is quite easy to identify time areas in which the mechanism of damage is strongly changed. In place marked X, the stage of running-in is finished and strong pitting appears in place Y. The standard test system is switched off, by means of vibration sensors, in place Z.

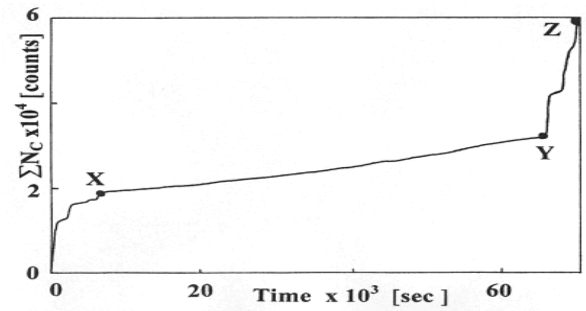


Fig.4 Exemple of summation record of number of AE overshoots (counts) in the course of contact fatigue test of grey cast iron.

The record of AE activity is often thought to be a time unit (so called counts rate) in the course of the tests. Especially combined with the counts level analysis of the signal, these records enable further specification of information about changes of character of material degradation, or degradation of parts. Examples of similar cases gained by contact loading of grey cast iron and carbon steel can be seen in Figs.5 and 6.

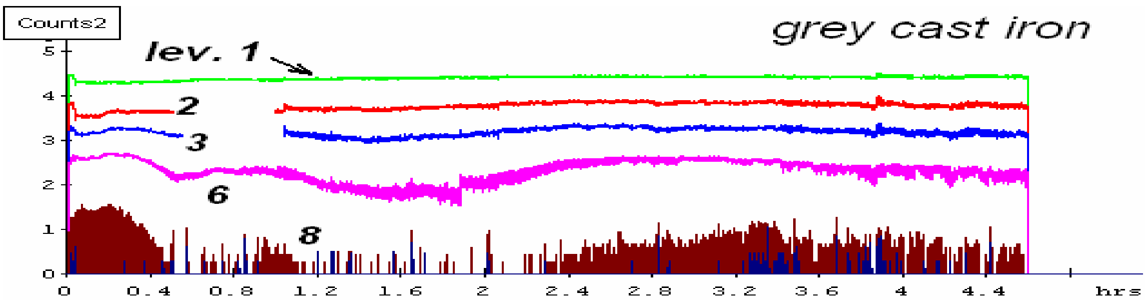
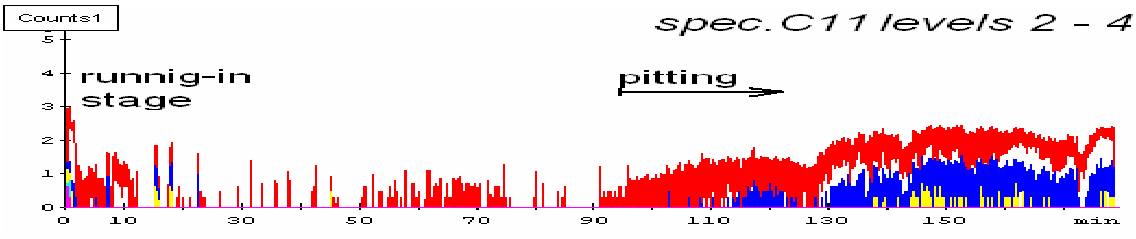


Fig.5 Number of overshoots (counts rate) in measured levels of AE signal in the course of test - example of various measured levels with low energy (grey cast iron). Level 8 will be used for identification of stages.

These "simple" records provide quite good possibilities especially for making the estimate of pitting inception. Nevertheless, possibilities for AE signals processing are much wider and further parameters of signals can be found; the changes would reliably indicate inception of contact fatigue. It is possible to identify the initial period of contact damage, the so called running-up stage. This division of contact damage is very hardly achievable using the classic vibration methods.

Example of relativelly "advanced" processing of signal from initial phase of the experiment, when so called "running" starts (creating of trace) can be seen in picture 7. "Running" proves especially wider ¨scattering of frequency clusters. Four important frequency clusters are evident especially in the field of about 10 kHz, 20 kHz, 50 kHz, and 80 kHz. Processing of AE signal in the phase when the surface starts being destructed



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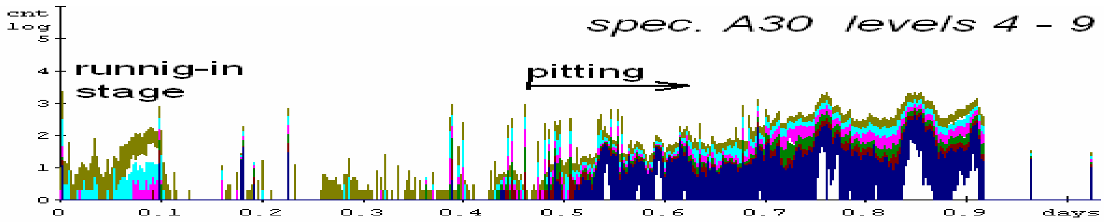


b)

Fig.6 Numbers of counts overshoots in chosen levels of AE signal a) level 2 to 6 in a grey cast iron sample under high contact load (test time app. 3 hrs), b) level 4 – 9 in carbon steel samples (test time app.22 hrs.)

can be seen in picture 8. In this case, the spectrum is significantly shifted to the area of about 100 kHz. Time-frequency transform of both phases of contact damage shows important frequency area about 100 kHz. But in case of initial phase, frequency extent up to nearly 500 kHz shows only the area up to 1.5 ms, than the whole spectrum attenuates to the area up to 200 kHz. In case of the phase of running in, there is the scattering of frequencies up to 500 kHz in the whole evaluated extent. It means that in the initial phase, chosen signal (event) of acoustic emission is inhibited faster.

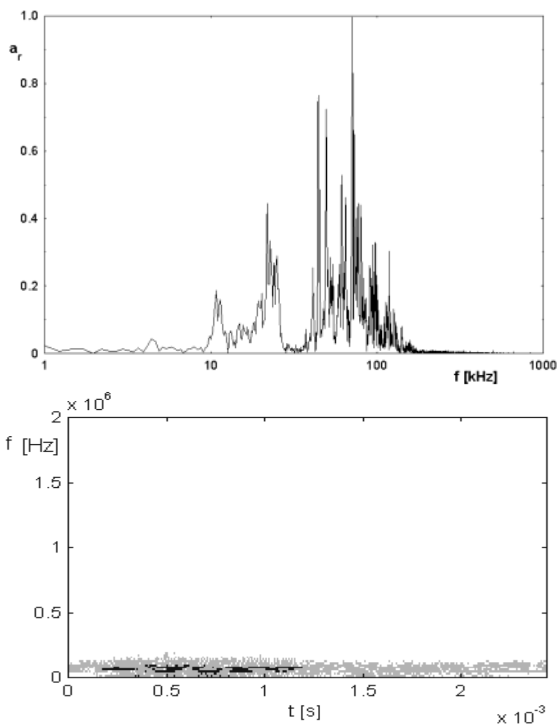


Fig.7 Example of amplitude spectrum in the incipient stage of test and time frequency spectrum of chosen sample in inception stage of test (GCI)

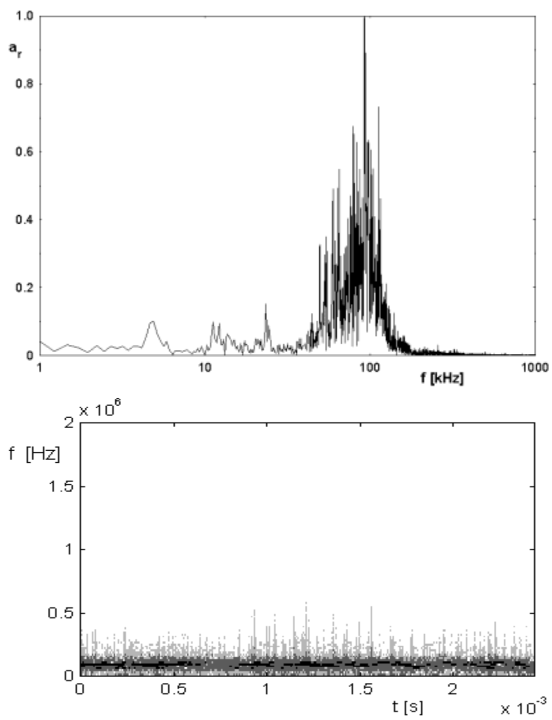
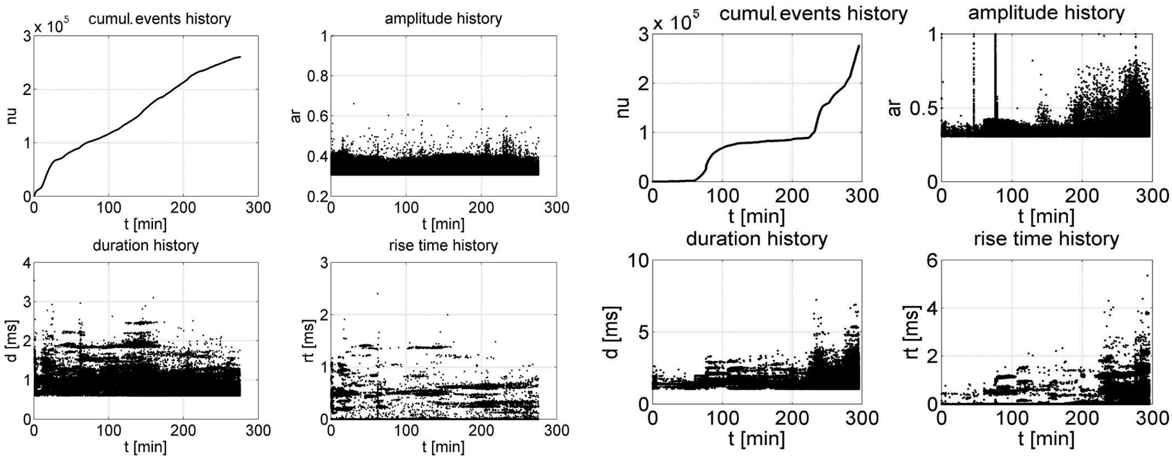


Fig.8 Amplitude spectrum of chosen sample in the phase of pitting and time frequency spectrum of chosen sample in the phase of pitting (GCI)

Figs.9 and 10 represent the selected parameters of AE signal (counts), which were obtained during the contact fatigue test of grey cast iron and carbon steel, are compared. At these images one can see noticable difference in character of some parameters of AE events, which is the result of different mechanisms of contact damage of these materials.



a) b)

Fig.9 Overview of basic AE events parameters treatment – cumulative number, amplitude, duration and rise time history for grey cast iron (a) and for carbon steel (b).

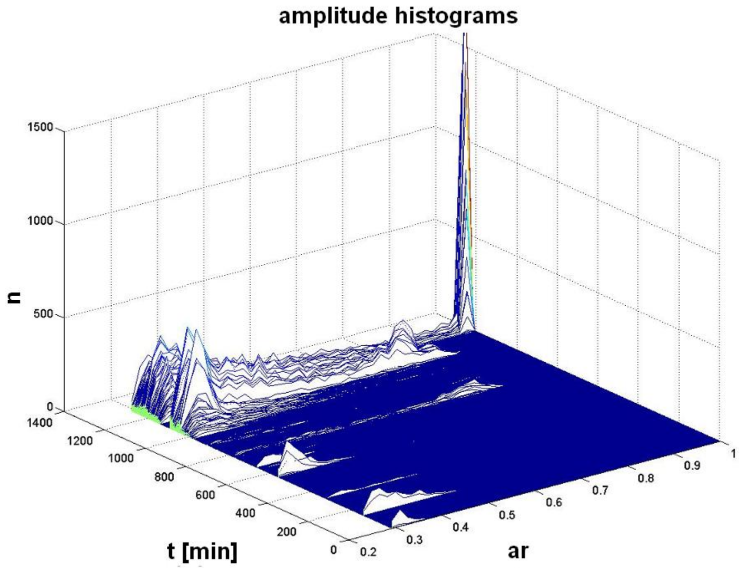


Fig. 10 Example of 3 D treatment of statistical distribution (n) of relative amplitude (ar), evaluated in 1minute intervals (t) for contact loaded carbon steel.

It is necessary to make note to above mentioned records that these are relatively short-time tests with high contact pressure.

3. Experiments on real bearings

3.1 Laboratory testing of bearings

The actual stage of material testing should be followed by tests of real bearings that would verify the information about change of AE signal gained in previous experiments. Our workplace is equipped by a number of stations of type SA 67 and RAH 4 (Fig.11). This means long-term tests of bearings that simulate common operation conditions.

a) b)

Fig.11 Equipment of the laboratory of bearings lifetime a) stations SA 67 b) station RAH 4

3.2 Practical diagnostics of real bearings

After evaluation of a number of data files, it would be useful to work out simplified way of signal processing that would emphasize monitoring of several chosen characteristics that would correspond with real level of 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 (e.g. to restrict the possibility of unexpected damage), in technological lines and energetic devices – in order to optimize intervals of planned maintenance and temporary putting out of operation connected with it (e.g. rolling lines, turbines mounting etc.). The results of AE method may be utilized for optimization of lubrication rate etc. Some prototypes of simplified diagnostic units are being tested currently (Fig.12).

Fig.12 Examples of tested prototypes of devices for bearings damage identification

4. Conclusion

In the initiation phase of experiments, we concentrated our effort to show basic methodology of sensed signal of acoustic emission from device Axmat. Analyzer Dakel.Xedo (4 sensing channels, dividing the signal up to 16 levels) was used for sensing the signal; consequently, the signal was processed by software DaeShow © (v.2004). In the course of repeated tests, characteristic phases of the process of damaging of the material by contact loading were recognized; this substantially improved standard tests of contact fatigue resistance. Up to now, it was evaluated by means of vibration sensors; this device can only detect advanced stages of damage (developed pitting). In recent time the research advances with detailed evaluation of parameters of AE events with the aim to find further parameters, which could correspond with the change of the damage character.

The sensibility of AE method brings a number of problems that have been restricting its practical use. Sensed signals are sensitive to a number of surrounding influences and this is why a number of conditions must be met in order to receive reliable information about processes that are under way in the construction. The fact that every measuring is unique is still a great problem for repeatable application of AE method. This is caused by very difficult ensuring absolutely identical conditions of every measuring (often long-lasting). Before all, various materials differ significantly in their "acoustic activity" and its character. The possibility of mutual comparison of results strongly depends on used sensors, on the way they are fastened to the sample, on the contact medium between the surface of the material and the sensor etc.

For qualified estimate of real sources of acoustic emission in loaded material it is necessary to make use of much more demanding signal processing, using suitable mathematics methods. It is necessary to take off characteristic shapes of events in individual stages of damage and to provide detailed frequency analysis. Following experimental tests in our laboratory will be focused also on the application of signal processing results on testing of real bearings and on simplification of AE signal treatment for practical use.

Work, the results of which are presented in this paper have been carried out in the framework of the project of Grant Agency of the Czech Rep. nr. 106/06/0343 „Research of stages of contact damage using the method of acoustic emission" and partly the project of MPO CR F1-IM3/136 „Research of new methods of measuring and evaluation of Acoustic emission signal (AE) and development of multi-channel Digital apparatus with fully continuous sampling of AE signal and its pre-processing in real time".

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