Aplication of Acoustic Emission Method in Contact Damage Identification

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Abstract - The contribution summarise the experimental experience of authors with acoustic emission method application in the area of improved bearing materials contact damage stages identification on testing stations Axmat and R-mat types. The paper is focused also to the first experimentals results received from measurements on real axial bearings. These results proved the AE technique enables reliable recognition of running-in period, stabilised run and exact definition of origin stage of material surface damaging, leading to the 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. 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.

Keywords: Acoustic emission, contact fatigue, bearing, pitting.

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. Rolling bearings belong to very important and precise machinery parts that enable transfer of loading by mutual rotating or sliding movement of its parts. The loading is transferred by means of rolling elements that are placed in a cage, often between rings; sliding friction is replaced by considerably lower rolling friction.

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. Rolling bearings, as well as other machinery parts, are subjected to degenerative processes - wear, resulting from mutual interaction of loaded and moving surfaces or by influence of operating environment which leads to material decrease. In extreme cases, damage accruement or strong impacts may cause material fracture. Different parts may be damaged: rings, rolling bodies, cages or possibly bearing seals. Under ideal operating conditions, restricted bearings lifespan is usually caused only by material crumbling; it is accompanied by formation of hollows, so called pitting. This 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 mentionned holes on the surface (Figs.1, 2).

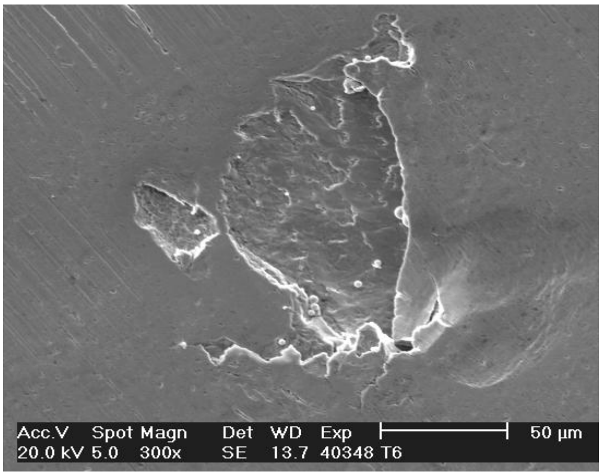

Figure 1 Micrographs of little point contact damage (pitting) on the bearing steel surface

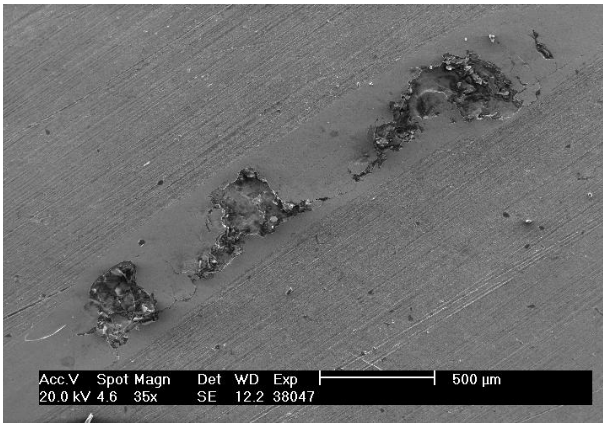

Figure 2 Micrographs of developed contact damage on the surface of bearing steel

2 Bearings diagnostics

Bearings diagnostics is a part of technical diagnostics; it is a discipline which deals with non-destructive and non disassembly diagnostics of technical conditions (condition monitoring). Technical diagnostics is focused on sensing damage, localizing and discovering its size, which gives evidence of the severity of the damage. Technical diagnostics includes detecting causes of damage inception and spreading. Various diagnostics methods are used for evaluation of the state of roller bearings.

The extent of damage is very important; it determines weather the bearing meets required qualities. The speed of spreading of the damage is vital; it determines the lifetime of the bearing. From the point of view of diagnostics, the stage of damage is important. To ensure trouble-free operation of machine, various diagnostics methods are used; they enable not only to detect and localize damage, to trace extent and range of the damage of roller bearings, but it enables to find reasons of damage inception and spreading.

Damage of roller bearings of a machine may be discovered by means of operational parameters monitoring; unfortunately, only late stages of damage can be discovered; at this stage, bearings are loosing their ability to meet required function. Exact diagnosis cannot be specified unambiguously by means of operational parameters monitoring. Number of revolutions, input, performance, efficiency, economy (fuel consumption) and temperature of operational media belong to monitored parameters.

Vibration diagnostics is a basic method for professional technical evaluation of rolling bearings. Mechanical vibrations are mechanical oscillation caused by external or internal driving force by which physical points provide reversible movement around equilibrium position, which is given by zero impact force. The values of vibration depend on the size of driving force, its frequency and direction [1].

Thermodiagnostics - this method is based on body surface temperature measuring. It is used in cases when heat results from friction and degradation processes. Temperature can be measured in individual points by means of contact thermometer, which is advantageous for quick detection by small machines. Thermography is used for larger machines. This method cannot recognize the inception of damage, only its later stages.

Noise diagnostics – vibrations of machine surface caused by vibrations of moving parts of the machine cause noise spreading. Noise is considered to be objectionable in the extent from 20 Hz to 20 kHz of frequency zone and it is a contactless measurable diagnostic value giving evidence of technical state of machine. Noise is partially caused by friction of contacting surfaces of machines. This method may be used for detection of damage in rolling bearings in later stages, when the results of damage are audible; this is why this diagnostics method is not effective for timely recognition of damage inception and for spreading prevention.

Acoustic emission – this method can be used for detection of very small energy loss processes, e.g. friction, cavitations, and contact of rolling bearing parts. Acoustic emission arises in irreversible dislocation and degradation processes in both macro and micro-structure of material. In such cases, energy is released; it is changed into mechanical stress impulse spreading in material in the form of crosswise or lengthwise stress wave which, when reaching the interface of surface and air, partially bounces and partially transforms and spreads by so called Rayleigh wave; it is partially transformed into Lamb waves. Released energy is very small, which requires very sensitive sensors. Piezoelectric sensors are used usually. The waves are detected by piezoelectric sensors with frequency zone from 100 kHz to 4 MHz with resonance frequency above measured scale or by resonance sensors with more resonances and adjustable sensitivity depending on frequency in case of narrow measured zones. This method is especially suitable for continuous diagnostics of rolling bearings; compared with other methods, this one is time saving. Unfortunately, the exact cause of acoustic emission energy origin is not known yet, as this phenomenon is connected with many other factors, such as wave transmission, which is defined by structure and homogeneity of materials, and body shape [2,3,4,5].

3 Experimental equipment and tested materials

A number of "classical" contact fatigue testing equipments are available in the Brno University of Technology. These devices fully meet current requirements from the point of view of mechanics, but their control systems, based on scanning of equipment vibration are rather obsolete. Experimental work in contact fatigue properties laboratories of the Institute of Machine Design are focused into two basic fields.

The first one focuses on identification of AE signal parameter changes by contact damage of different types of materials on Axmat and R-mat equipment. This type of tests of material characteristics is done on two basic types of testing equipment (see papers [6, 7]):

a) Axmat testing station – the principle lies in rolling balls in circular track on the surface of testing sample of discoid shape (Fig. 3). 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.3); driving and pressure cylinder of precisely defined profile lean towards them (Fig.4).

Sensed AE signal is amplified in preamplifier and consequently processed in AE analyzer. Our AE analyzers (Dakel Xedo) enable dividing scanned signal 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.

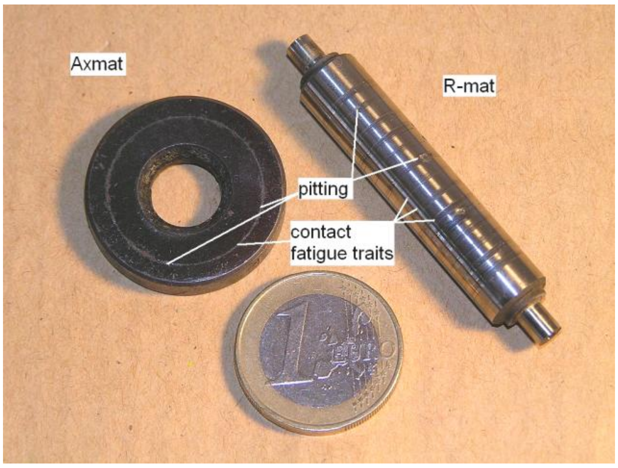

Figure 3 The shape of test bodies for Axmat and R-mat testing stations (with pitting)

The second field - currently, acoustic emission method is being applied also on real bearings. Results presented in this paper result from comparative tests of axial bearings designated for car clutches (Fig. 5) on Axmat testing stands. Inner bearing ring is fastened into upper clamping part (stationary) of loading equipment, which is loaded by constant axial force. Outer bearing ring rests on lower rotating clamping jaw. Magnetic AE signal sensors are placed on fixed jaw (Fig. 6).

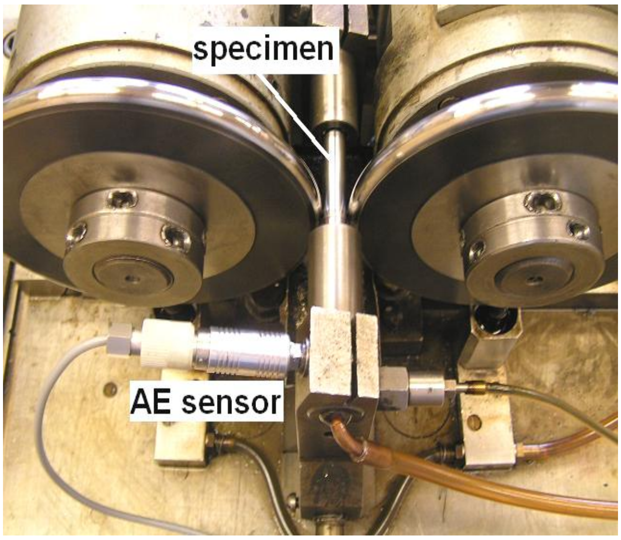

Figure 4 Detail of R-mat testing station.

Figure 5 Tested axial bearing (external diameter 60mm, internal 35mm, 15 rolling elements - balls)

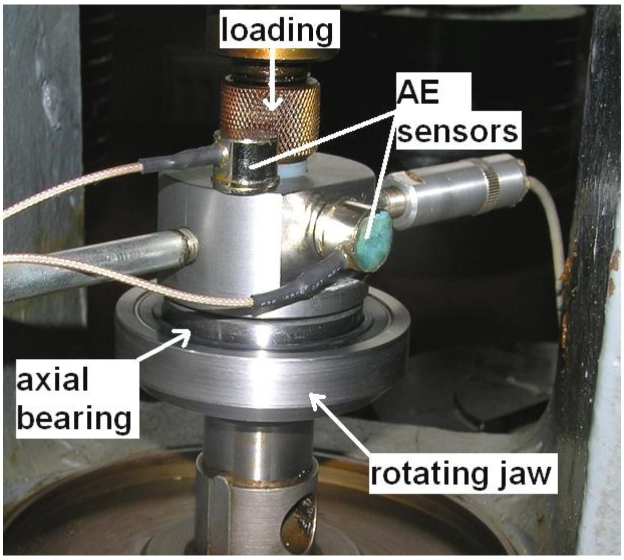

Figure 6 Detail of the operational part of the Axmat loading equipment (with axial bearing)

4 Experimental results

4.1 Contact fatigue of materials

Compared with classical material testing, contact fatigue test 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, of course, noise in the testing equipment grows as well; all this is reflected in scanned signal. With respect to sensitivity of AE method, the importance of quality of setting is apparent – choice of parameters, sensors, signal amplification, sensors location, quality of contact between sensor and surface etc. [2, 3, 4, 5].

The goal of measuring was to compare the possibilities of AE method application on both types of testing equipment. It seems to be clear from a simple analysis of the mechanism of testing equipment that stations Axmat are more suitable. In this case, the sensor is placed very close to tested sample. In an utmost case, a sensor with the diameter up to 3 mm can be placed directly on the sample. In case of R-mat stations, the situation is much more complicated; pitting emerges on a rotating sample, which is placed in ball bearings. These bearings are fastened in fixed jaws on which AE sensors may be placed (Fig.4).

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. At present, we have a lot of experimental results about development of contact damage in different bearing and carbon steels, grey cast and nodular cast irons, etc. at disposal. Examples of the recordings of AE counts rate change during the contact tests of bearing steel using the Axmat device is displayed on figure 7. Examples of similar cases gained by contact loading of grey cast iron and carbon steel can be seen in Fig. 8.

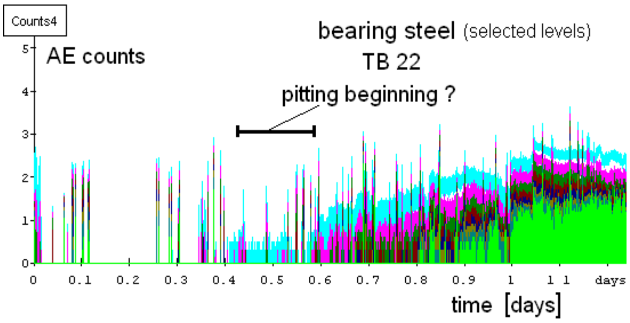

Figure 7 Exemple of plot of AE counts rate in chosen levels of signal in a bearing steel 100Cr6 (test time approx. 30 hrs).

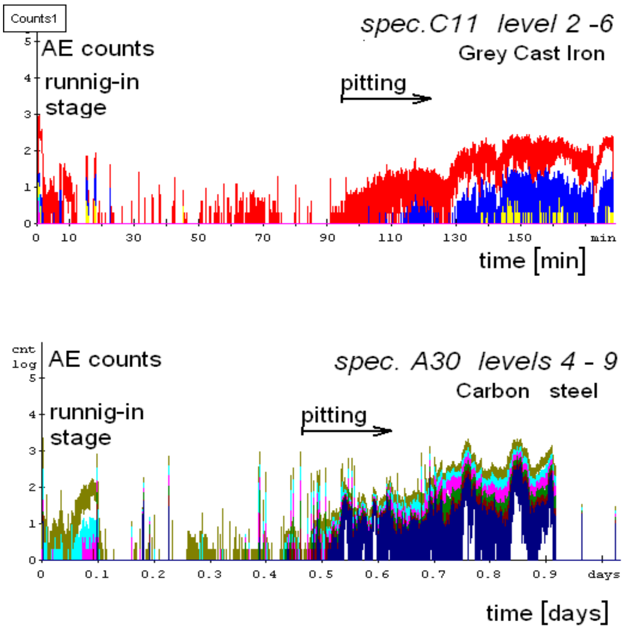

Figure 8 Numbers of counts overshoots in chosen levels of AE signal - level 2 to 6 in a grey cast iron sample under high contact load (test time app. 3 hrs) and level 4 to 9 in carbon steel samples (test time app.22 hrs.)[6]

The importance of finding optimum adjustment of the measuring chain and the choice of suitable place for sensor placing is clear from picture 9. The character of the signal from a sensor with lower amplification (b) (which was placed on another surface of the fixing jaw) is very different from records made by optimally adjusted and placed sensor (a).

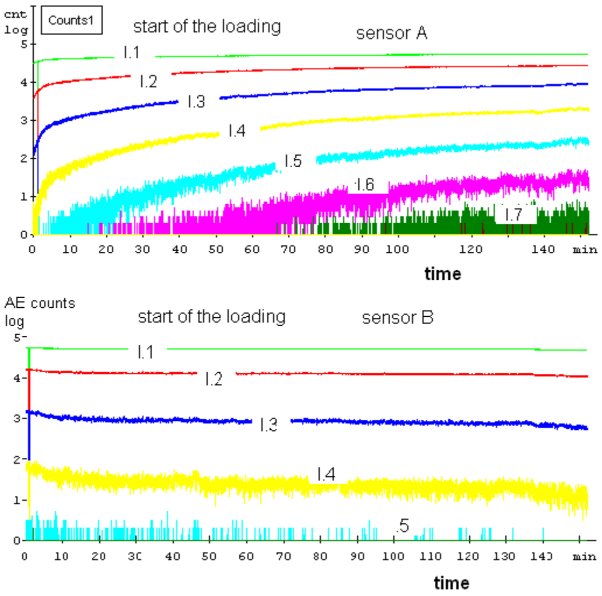

Figure 9 Comparison of record of AE signal from initial period of test of carbone steel from two sensors that are set and placed in a different way on the same specimen – suitable A), unsuitable B) – equipment R-mat [7].

Advanced ways of signal processing enable monitoring of time changes of selected parameters, e.g. relative amplitude history, amplitude duration history, rise time history …. The basic examples of these records can be seen in Fig. 10. On this figure are represented the selected parameters of AE signal (counts), which were obtained during the contact fatigue test of carbon steel. At these images one can see expressive difference in character of some parameters of AE events in time, which is the result of different mechanisms of contact damage.

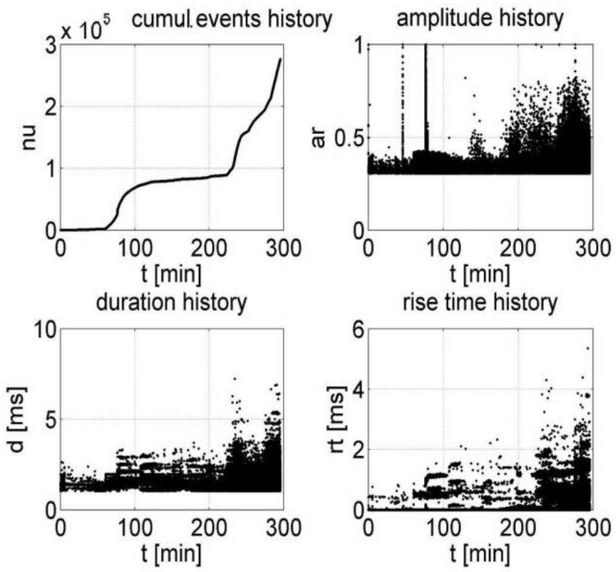

Figure 10 Exemple of basic AE events parameters treatment – cumulative number, amplitude, duration and rise time history for carbon steel in loading time [6].

4.2 Contact tests of real axial bearings

The purpose of the first phase of these tests was only a mutual comparison of the bearing properties of a well established bearing producer (A) and a non-traditional Asian producer (B). Results presented hereafter were gained from tests on device Axmat adapted for bearing testing (Fig.6).

Examples of records taken during the first overloading simultaneous tests of axial bearings from two producers can be seen in Fig. 11 and 12. The first picture shows time dependence of AE signal (counts rate) in initial stage of loading of both bearings – in the running-in period. The following figure 12 shows similar record from the time of pitting inception on the bearing (after three days of loading). At the begining of AE signal registration (time 0) the level of loading was increased. The reaction of bearings on this change can be seen from AE signal.

There are significant differences in the AE signal obtained from the tested bearings. The signal obtained from bearing B is more intensive at the starting period of loading. At time app. 4,5 hours the situation is changed. Signal from bearing A is remarkably discontinuous compared to bearing B. After three days loading and after loading increase the signal from bearing A is higher and also discontinous. That indicates significant difference in progression of damage of the bearings (when using overloading).

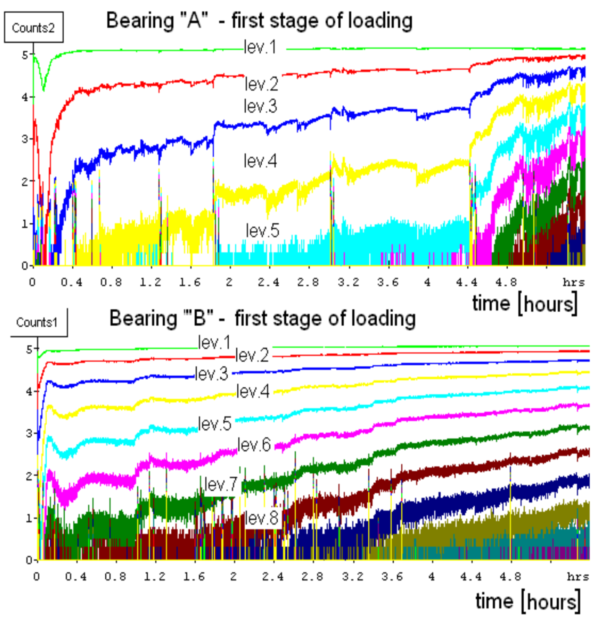

Figure 11 AE counts rate plots from starting part of loading of both bearings. Bearing "A" – traditional producer, bearing "B" – producer from Asia

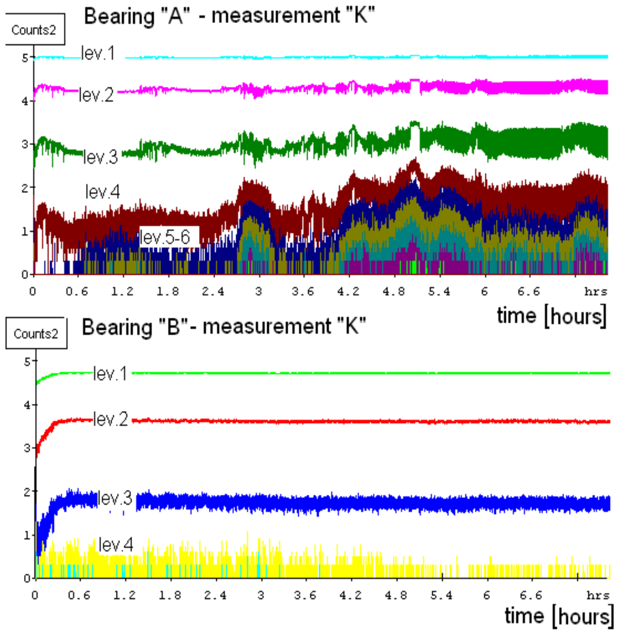

Figure 12 Plot of AE signal from the same two bearings after three days of testing. Note that in time zero the loading was increased

5 Conclusions

Current position and importance of AE method, compared with other methods of non-destructive testing by NDT methods, lies, before all, in their mutual supplementing. AE method provides technically different information, compared with other NDT methods. Acoustic emission uses the method of "wiretapping" of warning activity of damage causing processes, developing in the material as a result of loading of construction. Current research tries to give precision to AE methods in such a way that it would not be used only as supplementary method, but it would be sufficient for gaining necessary information for appropriate evaluation of material status.

In the initiation phase of experiments, we concentrated our effort to create the basic methodology for acoustic emission signal sensing from devices Axmat and R-mat. 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.

Also the first tests of real axial bearings on modified Axmat stations prove the possibility of AE method use for more precise diagnostics of their damage grade.

The situation with radial testing equipment R-mat is, compared with equipment Axmat, much more complicated, as the signal originates from rotating sample and it must go through bearing in which the sample is placed. For this reason, the signal contains much more undesirable disturbances, which makes adjusting of measuring chain more difficult. From recorded values can be seen that in radial loading, AE method provides only supplementary information about changes in progress in the sample. In a number of samples, the moment of change of the character of damage has not been identified unambiguously. Nevertheless, the example shown in this paper suggests that the problem is rather in finding optimal parameters of measuring equipment adjusting and that AE method would be applicable on similar tests after having eliminated undesirable influences.

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 analysis. 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 AE 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. turbines mounting, rolling lines, etc.). The results of AE method may be utilized for optimization of lubrication rate etc.

Above mentioned results are created as a part of the solution of the project of Grant Agency of CR nr. 106/06/0343 „Research of stages of contact damage using the method of acoustic emission", they were partly obtained by equipment that was upgraded under the project of the Ministry of Industry and Trade of the Czech Republic nr. 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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