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Acoustic Emission Monitoring of Landig Gear Fatigue Testing

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Abstract

There is analyzed the use of the acoustical emission (AE) method for non-assembling checking of technical state of complex structures. The control of initiation and development of fatigue cracks by means of different AE systems during fatigue testing of aircraft landing gear component is discussed.
KEY WORDS: *acoustical emission, fatigue cracks, landing gear.*

1. Introduction

The basic advantage of the acoustical emission (AE) method [1] is a possibility of finding different defects in the internal chambers of complex structures. It may be important for aircraft constructions such as aircraft undercarriages, where the ultrasonic method is usually used during fatigue tests. Additionally it is interesting to establish the correlation between AE signals and the parameters of fatigue crack development.

The use of AE method for fatigue crack development exemplified by the technical state of Tupolev Tu-154B main landing gear during bench tests is discussed below. Two stages of fatigue tests are analyzed: crack initiation and development during cyclic loading and object disruption during static loading.

2. Analysis of fatigue crack initiation and development during cyclic loading

The object of investigation is an aircraft snub piston of the main landing gear snubber. The crack concentrator was inserted inside this snub piston – this is a place where a fatigue crack appeared during previous fatigue testing of analogous objects. It is necessary to note that this zone is inaccessible to use the usual methods of non-destructive testing (NDT) during the bench test and aircraft operation without object disassembling.

According this fatigue test the object was exposed to cyclic loading created by a special hydraulic system. Loading parameters were measured by a strain gauge installed to a rod of the snub piston.

The first task of the researches during the cyclic loading was to catch the moment of the crack appearance. The second task was control its growth up to the given size (up to 1,0…1,5 mm where the ultrasonic method can be used for crack detect). It will give opportunity to calculate and check the material behaviors and other characteristics of operational strength in further fatigue tests. The AE method can be used to solve these tasks.

Three types of AE systems were used to detect the fatigue crack initiation and growth. There are:

- PAC-3000/3104 analyzer (frequency band – 20 kHz…2 MHz; USA);
- AF-15 analyzer (frequency band – 20 kHz…2 MHz; Moldavia);
- AE control system on PC base (includes of the P-DAQ and T-DAQ subsystems; frequency band – 10 kHz…3.5 MHz) giving the opportunity to synchronize AE signals (the P-DAQ subsystem) and acting loads (the strain gauge was connected to the T-DAQ subsystem) and carry out the initial analysis of information.

For all equipment there was used a piezoelectric sensor connected to the AE system components with preamplifiers. The sensor was installed to the piston rod.

AE results during fatigue crack initiation and development are represented in Fig.1 (the total AE N_{AE} versus loading cycle number N; PAC analyzer) and Fig.1a,b,c (load $\boldsymbol{P}$ change and AE intensity N'; P-DAQ and T-DAQ subsystem).

The analysis of the graph shows alternation of zones with slow (1, 3, and 5) and fast (2, 4, and 6) accumulation of total AE. The 1, 3, and 5 zones are characterized by sporadic appearance of AE signals. The 2, 4, and 6 zones are additionally designated by α_1, α_2, α_3 angles which show velocities of total AE N_{AE} accumulation [2, 3, 4]. They have two main features: firstly, AE signals are practically appeared in each cycle of loading; secondly, each zone has its own features of AE signal appearance (see Fig.1a,b,c).

The initial period of testing (from 0 to 850 cycles approximately; zone 1) is characterized by sporadic appearance of AE signals when probably energy accumulation occurs in different dislocation zones. The first slow accumulation of total AE is changed by fast growth about 850 cycles approximately – it is a zone of the fastest total AE accumulation (zone 2). In most cycles AE signal change does not differ from previous zone but in separate cycles AE intensity has powerful bursts at the moment of loading fall in the cycle (see, Fig. 1a). The level of these bursts is maximal in the whole testing. A subsequent fracture researches along the fatigue crack showed that the crack appeared in this zone of testing – it happened in the area of the left edge of the concentrator. After 1200 cycles AE intensity dropped, and probably from this moment up to about 2000 cycles there takes place the new stage of slow energy accumulation (zone 3) but it is mostly in the place of crack initiation in this loading stage (crack growth is practically stopped).

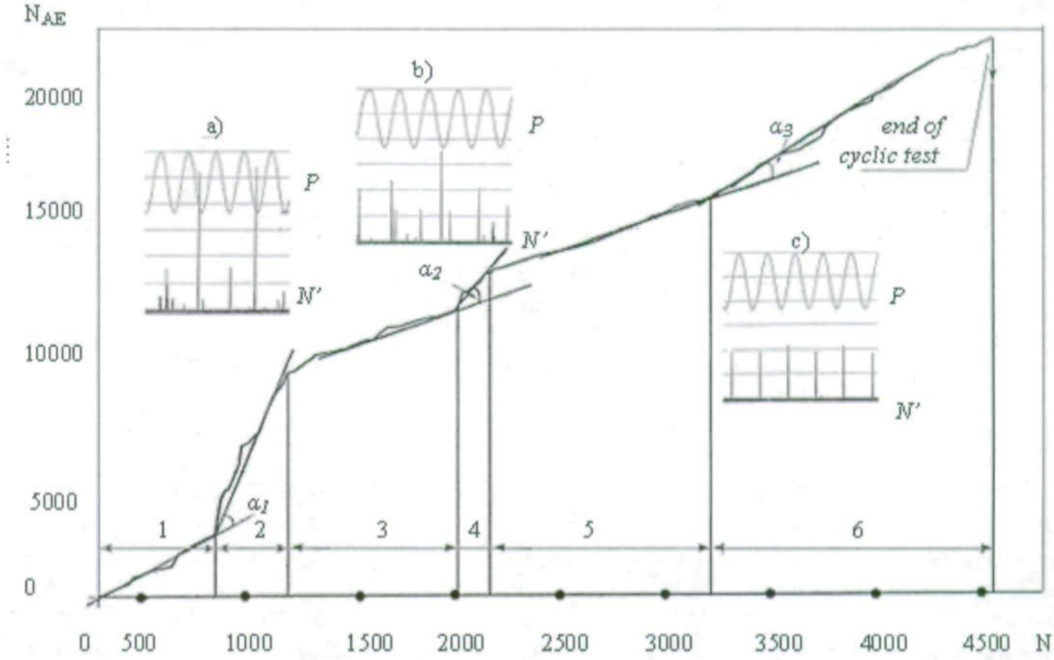

Fig.1. Total AE N_{AE} versus cycle number N and synchronous record of load P change and AE intensity N' in the 2 (a), 4 (b), and 6 (c) zones

From 2000 cycles the second growth of the crack occurs, which is confirmed by fast accumulation of total AE (see the α_2 in the zone 4; Fig. 1). In this zone the frequency of the AE signal appearance increases but the level of these signals is less than in stage 2 and they occur in different parts of the loading cycle. This process is finished about 2150 cycle and is changed by slow increase of total AE (zone 5), parameters that practically do not differ from characteristics of 1 and 3 zones.

New features of the process of fatigue crack development appear about 3200 cycles (zone 6). Although in this stage, α_3 angle differs a little from the similar angle in 5 zone and AE intensity is less than 1 and 3 zones, it is characterized by stable value of AE intensity – signals appeared in the beginning of the loading cycle (see Fig.1c). The basic feature of this zone is as follows: the crack increases in each loading cycle – it was confirmed by the subsequent fracture analysis.

Periodical ultrasonic testing of the concentrator zone was carried out after each 200 to 400 load cycles and it showed the first detection of fatigue crack initiation (0.6…1.7 mm) only in 3550 cycles. Since there was no full confidence in this, the testing was continued during 1000 cycles (up to 4550 cycles), when it was suspended (during this testing in each 200 cycles crack is cheked by ultrasonic method and its size was 0.2…1.8 mm).

The subsequent fracture analysis also confirmed the fatigue crack appearance and development in this zone of testing; the crack went through the material of the piston for a distance not exceeding 0.6 … 1.00 mm.

Thus, the AE data confirm certain discrete mechanism of crack growth [5]. External influence causes appearance and development of failures. There are several stages of failure development and each stage consists of energy accumulation process which then begins work of material destruction. In this step beginning of new crack growth is generated by accumulated energy and further crack development is provided by external loading.

As a result, it is possible to distinguish three stages of fatigue crack development which are characterized: the first – by the α_1 angle; the second – by the α_2, and the third – by the α_3 angle. It illustrates 3-stage (or 2-stage) development of fatigue crack [6, 7]: the first stage is microcrack initiation and its development; in the second stage this microcrack is transformed to mezocrack (of course, this stage may also analyzed as the stage of microcrack development); the third stage is characterized by appearance of the macrocrack which can be checked by ordinary NDT methods.

3. AE monitoring during static testing of residual strength

In the second stage of the fatigue testing the residual strength of construction was analyzed under the influence of the static load. Simultaneously the correlation between the AE signals and crack development was also studied.

In this case the landing gear was exposed to loading, maximal value which (100%) equals about 70% of the operational breaking load. The loading was increased step by step: in each step the load was increased by 10% from maximal value and maintained during 10 s.

The analysis of the total AE versus load (see Fig.2), received by means of AF-15 device, displays two sectors of AE abrupt change: at 40% (α_1) and 60% (α_2) of the maximum working load.

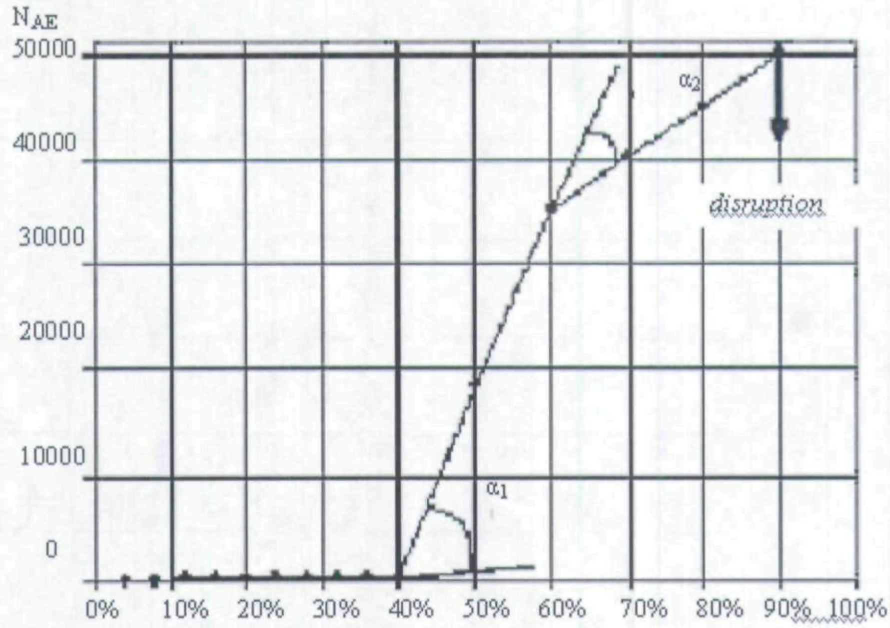

Fig.2. Total AE N_{AE} versus working load

The first break (α_1) corresponds to the moment of the crack start and acceleration of crack growth in region 40...60% of the maximum loading. The second break (α_2) characterizes some deceleration of the crack growth rate. In the step of 90% from the maximum working loads, in one or two seconds of time delay, there occurred the landing gear piston destruction accompanied by a loud clap.

The dependences of the total AE N_{AE} in the process of program static loading, obtained by the PC AE control system (P-DAQ/T-DAQ; see Fig.3) show the same results in general. But if the AF-15 analyzer gives average results, the PC AE control system shows more accurate data. The rapid increasing of the total AE N_{AE} began in the region of 50% from the maximum working loads and accompanied by sharp increase of the AE intensity at the moment of load change. It testifies about beginning of crack growth. The main features of this growth are the following (see Fig.4):

- the crack grows in the moment when the load is changed (increased);
- during load exposure the growth of crack practically stops;
- fast growth of the crack is observed in the initial stage of loading;
- crack development rate slows down gradually when the load level is increasing.

As a result, the total AE N_{AE} change versus working load has stepped character. The dependences of the total AE N_{AE} obtained by the PAC-3000/3104 analyzer have the same view. These results are confirmed by subsequent fracture analysis.

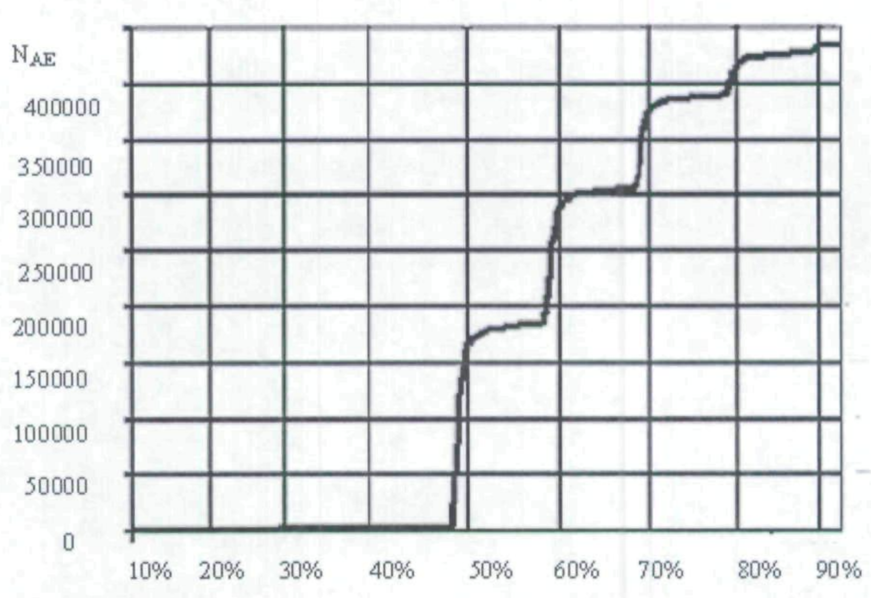

Fig.3. Total AE N_{AE} versus working load

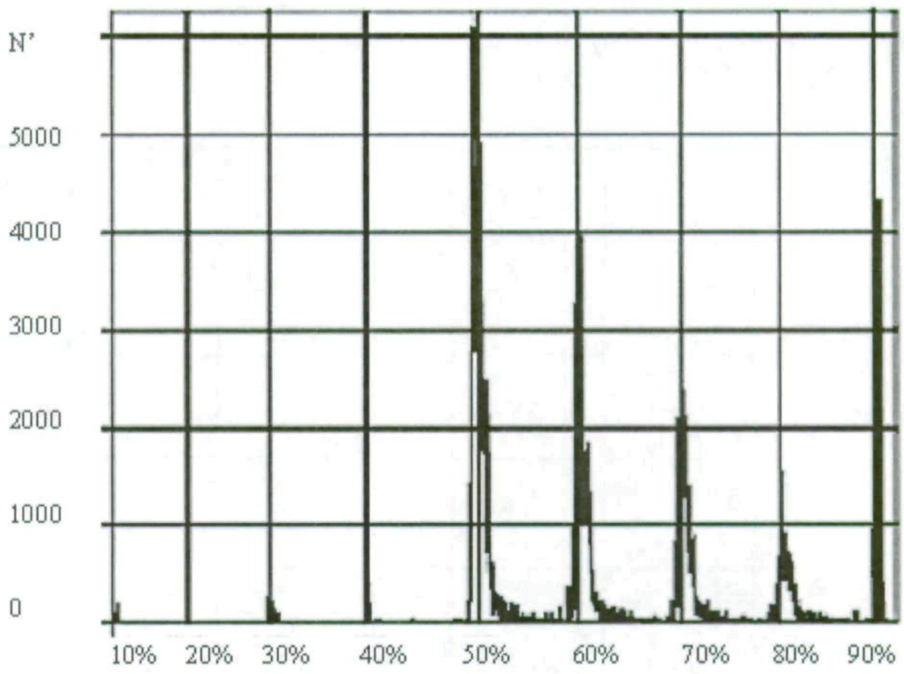

Fig.4. AE intensity N' versus working load

4. Conclusion

During fatigue testing the AE information may be used:

- to register the microcrack initiation (the microcrack is began in the region of 850 cycles);
- to monitor fatigue crack development;
- to analyze multi-stage development of fatigue crack;
- to fix transformation microcrack to the macrocrack (in the region of 3200 cycles).

During the static testing of residual strength the AE method can be used to monitor crack development:

- appearance and the steps of crack growth;
- crack development rate.

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