ISSN 1392-2114 ULTRAGARSAS, Nr.2(59). 2006.

Undercarriage fatigue test control by acoustic emission method

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Abstract

Acoustic emission (AE) monitoring during fatigue and residual strength tests of aircraft undercarriage is discussed. In several variants of loading the processes of crack development are analyzed. It is shown that AE control gives possibility to discover fatigue crack initiation, to fix different stages of crack propagation (including stop of crack growth and renew its development), to analyze velocity of crack growth, to discover initiation of several cracks, to localize crack position, to discover cracks in internal parts of test object (which cannot discover by ordinary methods of non-destructive inspection), to decrease expenses of experimental tests, to decrease test object disassembly and assembly (comparing with use of ordinary methods of test control), to prevent stand failures, etc.

Keywords: aircraft undercarriage, fatigue cracks, acoustic emission.

Stand fatigue tests of aircraft structure components (including an aircraft undercarriage) are very important stages of aircraft development and endurance tests. Similar tests are necessary to study process of fatigue failure accumulation, to discover criteria of fatigue failures, and to analyze fatigue strength of aircraft structures.

During fatigue tests of complex structures the main problem is discovery of fatigue cracks initiation and their propagation. In this case it is necessary to use effective methods of early checking of fatigue cracks and control during their development because similar cracks may appear in different places of aircraft component (including internal chambers of undercarriage where usage of ordinary non-destructive testing (NDT) is impossible). Method of acoustic emission (AE), which is also method of NDT, gives possibility to decide problems connecting with control and diagnostics of fatigue cracks.

AE method is passive method, which is based at the analysis of transient elastic waves generating by object of control during internal local dynamic reconstruction (rebuilding) of its material structure, when rapid release of energy from localized sources happens. The sources of AE signals in metallic structures are closely associated with the dislocation movement accompanying plastic deformation and the crack initiation and development [1]. As a result, AE method gives possibility to discover developing failures. If several AE transducers are used during tests it is possible to localize place of fatigue damages.

The object of control in this investigation is the main undercarriage leg of ageing aircraft. It is typical design, which consists of a shock absorber piston and a cylinder, which are joined by upper and lower spline-hinges. Necessity of continuation of similar aircraft usage urged to carry out full-scale fatigue tests. One main task during these tests is discovery of fatigue cracks. With this aim this leg was installed in special stand, which gives possibility to load it during fatigue test and, in particular, to imitate real static and dynamic loading acting to undercarriage during aircraft operation. Ordinary NDT (ultrasonic and magnetic particle inspections) were used for cracking analysis. But sometimes fatigue cracks appeared in the internal chambers of object of control. In this case AE method was additionally used.

The AE sensors were located at the head of shock absorber piston (N1), lower hinge (N2), and shock absorber cylinder (N3). The signals from all sensors were analyzed in range from 20 kHz to 2.0 MHz by system including a pre-amplifier, a frequency-meter, and AE analyzers. The two AE parameters were used: cumulative AE count and AE intensity (AE count relative number of loading blocks).

AE monitoring was used during two test variants. First from them was ordinary fatigue test when loading was realized by special program before fatigue crack appearance. The loading program consists of any repeating segments of loading, which imitate the real loading of aircraft undercarriage during its operation. The main task of AE monitoring during this test consists of discovery of fatigue crack initiation and its transformation from tiny crack into crack which may discover by ordinary NDT methods.

The second test variant was residual strength test. In this case special failure, notch, was inserted into piston rod of the shock absorber internal chamber in the place where fatigue cracks appeared during aircraft operation. It is necessary to take into account this defect may be discovered by ordinary NDT if fatigue crack goes only through rod wall (after leakage of shock absorber working fluid). Since strength of undercarriage component in this case is considerably changed, this damage may be very dangerous.

The test program in this case was realized corresponding to “typical flight” including of load imitation during pre-takeoff evolutions, undercarriage stowage/deployment, landing, and ground evolution after landing. Before “typical flight” testing main undercarriage is underwent to static loading in residual strength. Main task of monitoring in this case was studying of relation between different stages of fatigue crack propagation and AE parameter changes.

After test the destroying parts containing fatigue fractures were cut out from the undercarriage components. The fatigue fracture features were analyzed using a scanning electron microscope. Striation spacings and areas of fracture containing different fracture features were measured in the direction of crack propagation.

The AE results of two tests are below analyzed. The first from them was used during ordinary fatigue test for discovery of cracks in the lower hinge and shock absorber rod head. The cumulative AE count and AE intensity (at the base of 100 cycles) are measured versus cycle number (*fig.1*). Additionally continuous records of AE signal amplitude were. To analyze different stages of crack development the α-criteria was characterized [2], [3], [4]. This criteria connects with change of inclination of cumulative AE count.

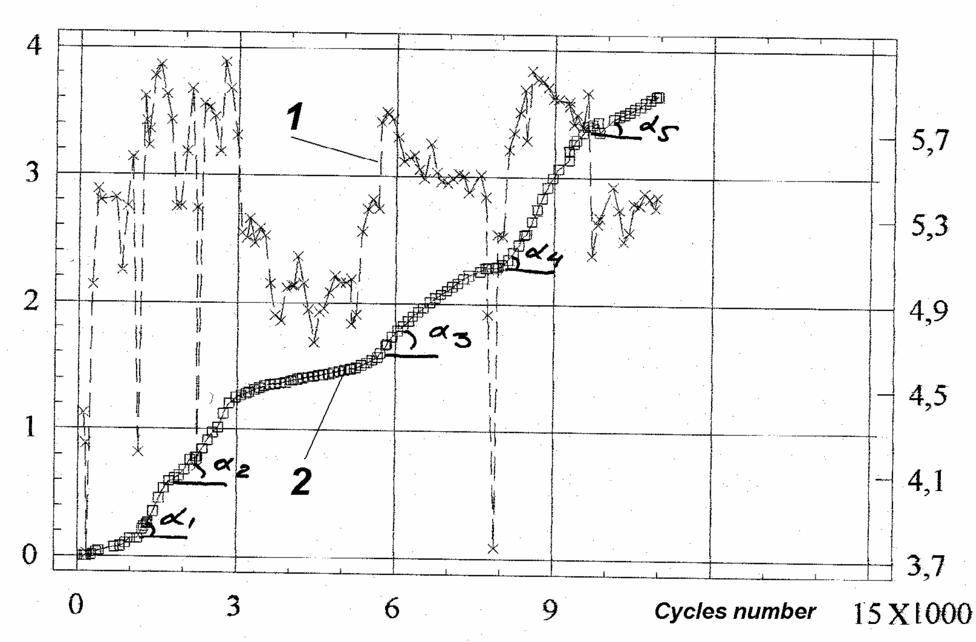

Fig.1. **AE parameters versus cycle number: 1 – AE intensity; 2 – cumulative AE count**.

Analysis of these graphics shows the following. The monotonous growth of cumulative AE count is changed about 1400 cycles fatigue crack initiation; it shows fatigue crack appearance. Then, intensity of crack growth is decreased near 1800 cycles; it says about crack brake. Similar processes are repeated near 2800 and 3000 cycles. It shows change of growth mechanism of fatigue crack. Later, the fracture analysis had shown: the first turning-point corresponds to first crack and the second turning-point – second fatigue crack (both cracks are located in one zone).

New sharp change AE dependence was near 5700 cycles; it was connected with joint bolt failure. After bolt replacement test was continued. New AE signal changes happen near 7900 and 10000 cycles. These changes were also connected with crack failures.

The next results are connected with residual strength test. The change of cumulative AE count and AE intensity versus loading block are shown in *fig.2*. Additionally function of failure intensity, which is calculated as parameter of operation to failure, is also shown. Analysis of these characteristics testifies about sufficient effectiveness of AE method for test monitoring.

Firstly, damages, which appear as in the object of testing as in the test equipment during fatigue test, are accompanied by AE intensity increasing. The level of AE signals can exceed their ordinary level during accumulation of fatigue failures in several times. As it was in previous variant, appearance of majority of damages (breakdown of studs and bolts, cracks) may be discovered by analysis of change of inclination of cumulative AE count characteristics, that is, by α- criteria. Effectiveness of α-criteria usage is confirmed by Table 1.

Fatigue crack initiation and propagation is confirmed by fracture analysis. Obviously, that crack initiation and AE signal, which corresponds to the first crack appearance, is at low stress levels. Crack development is accompanied by accumulation of AE count. Then crack is closed and AE signal is around zero. New crack opening and closure is accompanied by similar change of AE signals. However, similar changes of AE signals are results of dislocation movements from one side and cyclic hardening or softening from another side. As a result, α- criteria may be informative parameter for investigation of fatigue crack development.

Secondly, comparison of functions of failure intensity and AE intensity give possibility to conclude that preliminary sharp growth of AE signal level is before peak of the number of stand failures. Consequently, it is possible to predict general state of stand and undercarriage elements by monitoring of changes in AE parameters. If AE signal level is sharply increased it is desirable to decrease period of visual checking of stand and details of test object. Besides it is necessary to use different ordinary instrumental NDT for fatigue crack discovery. It is very important for aircraft endurance tests since additional damages in test equipment components may change results of fatigue tests. In opposite variant, when character of AE signals is stationary, testing procedures may fulfill without any stops – it may decrease time of tests and increase their accuracy.

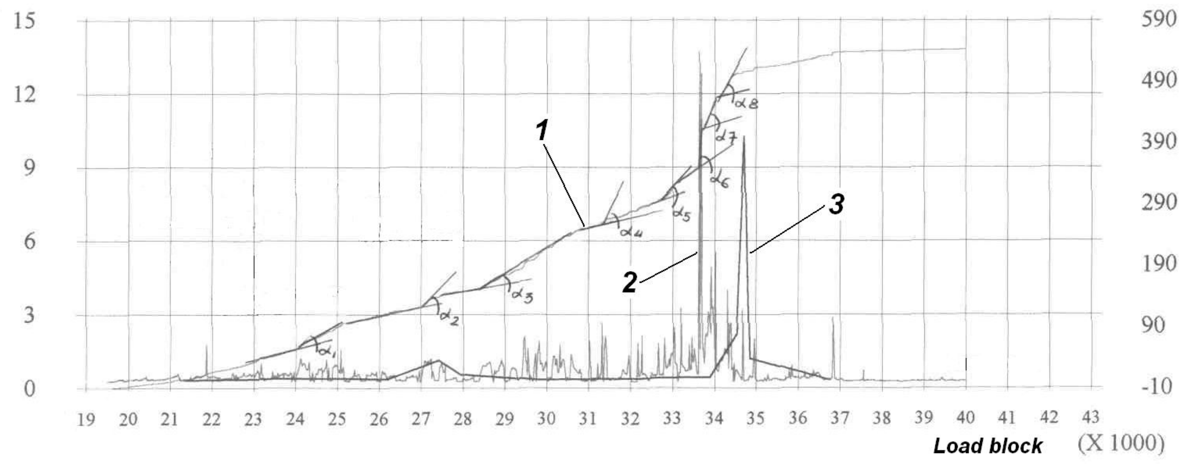

Fig.2**. Parameters of residual strength test versus load blocks: 1 – cumulative AE count;** ***2 – AE intensity; 3 – failure intensity.***

Table 1.

N	Number of loading blocks	Type of failure
1	18710 – 25150	Breakdown of studs (brake drum, cylinder bracket, and stand support); damage of bolt head lobe.
2	27290 – 28400	Breakdown of bolts of the bracket yoke-lifter/wing joint and brake drum stud.
3	31330	Breakdown of bolt of the bracket yoke-lifter/wing joint.
4	33210	Crack in the base of bolt head lobe (yoke-lifter/yoke eye).
5	34560	Damage of bolt head lobe.
6	34690	Breakdown of bolt of the bracket yoke-lifter/wing joint.
7	34710	Breakdown of bolt of the bracket yoke-lifter/wing joint.
8	34980	Breakdown of bolt of the yoke-lifter/yoke eye joint.

To increase AE method effectiveness it is desirable to use spectrum (frequency) analysis and analysis of shape of AE signals. It allows, for example, to distinguish appearance of several cracks and to watch different crack development.

As a result, usage of AE control during fatigue tests gives possibility:

- to discover fatigue crack initiation;
- to fix stages of crack propagation (including stop of crack growth and renew its development);
- to analyze velocity of crack growth;
- to discover initiation of several cracks;
- to localize crack position;
- to discover cracks in internal parts of test object (which cannot discover by other methods of non-destructive control);
- to decrease expenses of experimental tests;
- to decreasing of test object disassembly and assembly for usage ordinary methods of test control;
- to prevent stand failures.

Thus, AE could be used to monitor conditions of structural components during fatigue tests.

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Received 04 04 2006