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Acoustic emission characteristics of fatigue crack development in a pitch control arm of helicopter lifting propeller blades

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Abstract

It is observed change of acoustic emission (AE) parameters during stand fatigue tests of pitch control arm of helicopter lifting propeller. The total AE and AE intensity in a loading cycle were analyzed during these researches. It was confirmed the stepped change of the total AE which is typical for strong structures of aircraft and reflects irregular development of fatigue crack. It is shown that micro-cracks formation is securely fixed by AE method long before visible crack appearance. It is recognized that AE signal emergence in a loading cycle and crack development are as during load growth as during load decreasing in the loading cycle.
KEY WORDS: *acoustic emission, fatigue crack, helicopter.*

1. Introduction

The methods of non-destructive checking are used for detection of different failures in the process of fatigue test of aircraft structures. Traditional methods between them are visual-optical, ultrasonic, eddy current, magnet particle methods, and method of dye (fluorescent and color) penetrant inspection. However, their possibilities for fatigue crack detection limited. Like that, visual-optical and dye penetrant methods are effective in causes when crack goes out to the object surface in the visible places. Ultrasonic, eddy current, and magnet particle methods give possibility to inspect sub-surface cracks. Ultrasonic inspection allows detecting cracks in the material depth. But all these methods possess by some limitations because cracks appear in the different detail joints and their examination in the majority either impeded or impossible without disassembling.

The necessity to use periodic disassembling for determination of technical state, firstly, leads to increase labor intensity of test. In the second, any joint disassembling/assembling slightly changes its technical state and can lead to change of fatigue characteristics of structure. In the third, time of fatigue tests is increased.

As a result, it is desirable to study possibilities of other, non-traditional methods of non-destructive inspections. One from them may be method of acoustical emission (AE). Its application during fatigue tests of aircraft undercarriage ([1,2]) confirmed its high effectiveness. The further use of this method connects with necessity of detail analysis of AE parameters during fatigue crack initiation and development.

2. Features of fatigue tests and AE measurements

In this article it is analyzed the change of AE parameters when a fatigue crack is developed in process of cyclic stand tests. The object of investigation is a pitch control arm of helicopter lifting propeller blades. In the process of stand tests, it was imitated operating loads, which act to the control arm. As a result, the control arm underwent to the multi-component periodical loading by the forces acting to it from helicopter lifting propeller blades (the centrifugal force and bending forces in two normal planes) and from pitch control system of lifting propeller connecting with blade turning.

The loading carried out according to special program by stand hydro-mechanical system. As a result, the all forces were changed corresponding to symmetrical trapezium law with the given amplitude, that is, the loading cycle consisted of 4 stages: initial state, loading, load action, and unloading. The frequency of loading was 0.25 Hz.

The AE transducer was located in the control arm. AE parameters are synchronously fixed with load change (signals about load change was generated by tensile gage of one from loading hydro-cylinders). There were to measure the total AE and AE intensity in the each cycle of loading.

The stand tests are continued before visual crack detection. The fatigue crack 15 mm long was observed in 136137 cycle of loading whereupon test was stopped.

3. Analysis of total AE change

The total AE change versus the number of loading cycles is shown in fig.1. As in the previous stand fatigue tests of aircraft components [3], it is observed stepped change of total AE. In the first approximation, AE characteristics may be divided into 6 stages where slow growth of the total AE is consecutively changed by its quick increasing. Like that, stages 1, 3, and 5 are different from other stages by relatively slow growth of total AE; the total AE in 2, 4, and 6 stages is quickly increased. As it was early showed, this change of the AE parameter reflects irregular growth of fatigue crack: it is connected with energy accumulation in atomic bonding and its further extrication during crack development. Features of stepped growth of fatigue crack were early confirmed by fractal analysis [4].

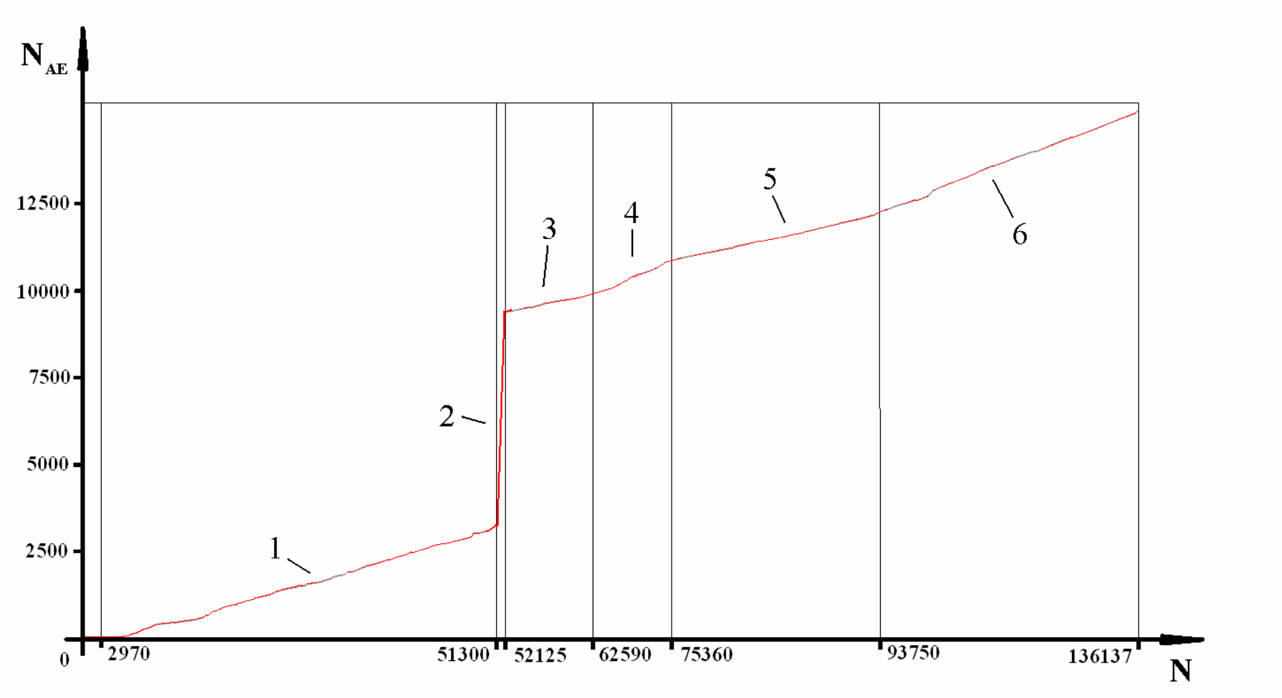

Fig.1. Total AE N_{AE} versus the number of loading cycles N: 1…6 – stages of crack development

Thus, AE characteristics for undercarriage tests and for given investigation are similar in general. However, there are some differences between them. Firstly, the growth of total AE in the second stage was significantly quicker than similar AE increasing during undercarriage tests. Secondly, velocity of total AE change in the 1st stage is similar to its growth in the 4th and 6th stages – it reflects crack development during the all these stages. Thirdly, direction of action of one from loads was changed during loading and unloading. In all probability AE signal appearance during these stages is also connected with this feature. That is, fatigue crack growth during these stages is practically stopped – it is confirmed by analysis of AE signal changes in a loading cycle.

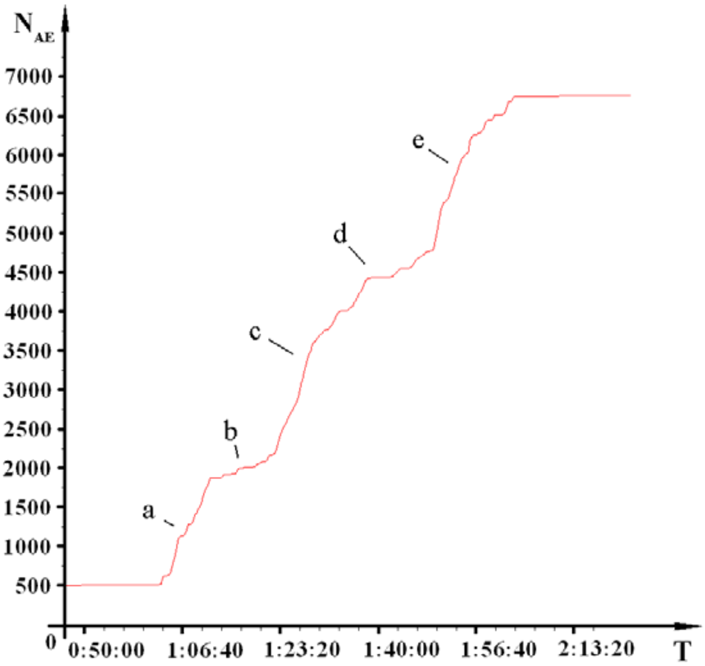

Fig.2. Total AE N_{AE} versus loading time T (hour;min;sec) in the 2^{nd} stage: 2a…2e – plots of crack development

The stage 2 is allotted from other stages by maximum velocity of total AE growth. In the previous researches the similar stage usually reflects formation of numerous micro-cracks. Essentially, this moment may scrutinize as the moment of fatigue crack initiation.

As it was early shown [5], α-criterion may be used to analyze changes of total AE versus loading. The α-criterion is angle, which is possible to find as difference of average angles of inclination of total AE lines in the neighboring stages. The α-criterion reaches maximum value in the second stage – it is attested about energy level which is necessary to form the break in a solid material. It is necessary to note, that α-criterion values of the following stages of fatigue crack development are considerably less. Therefore, expenditure of energy for crack advance in each cycle of loading is significantly less than energy, which is necessary for its initiation.

In detail analysis of the second stage it may be divided into several plots (fig.2). In this case the second stage puts sequence of plots where slow growth of total AE is changed by its quick increasing. Since the second stage is usually characterized as stage of micro-crack generation, the plots with very quick growth of total AE reflect initiation and development either separate micro-cracks or their groups (if the loading is more intensive). Therefore, in this case the second stage is possible to divide to 5 plots: from 2a to 2e. That is, it is possible to say either about consecutive initiation of three main micro-cracks or about initiation and development of three micro-crack groups.

The high level of AE signals during the second stage permits also to do the following supposition: in continuation of micro-crack initiation and development, the amalgamation of micro-cracks also is in this stage. As a result, it is probably transformation of some micro-cracks into unite macro-crack and beginning of its development.

4. Analysis of AE changes in a loading cycle

The typical changes of AE signals in a loading cycle for different stages of crack development represent in fig.3. Analysis of these data shows that AE signals are in all cycles for this level of loading. During the first stage it connects with gradual accumulation of failures, which leads to micro-crack initiation during the second stage. The fatigue crack arising in the end of the second stage later on grows in all loading cycles.

AE signals appear in the process of load growth as well as its decreasing. Accordingly the crack development is during loading as well as unloading of testing object. AE signal intensity (and consequently, velocity of fatigue crack growth) is different during the different stages of crack development: during the 4th and 6th stages it is more than during the 3th, and 5th stages). Other parameters of AE signals (position in the loading cycle, ratio of levels, etc.) are insignificantly changed from one stage to other.

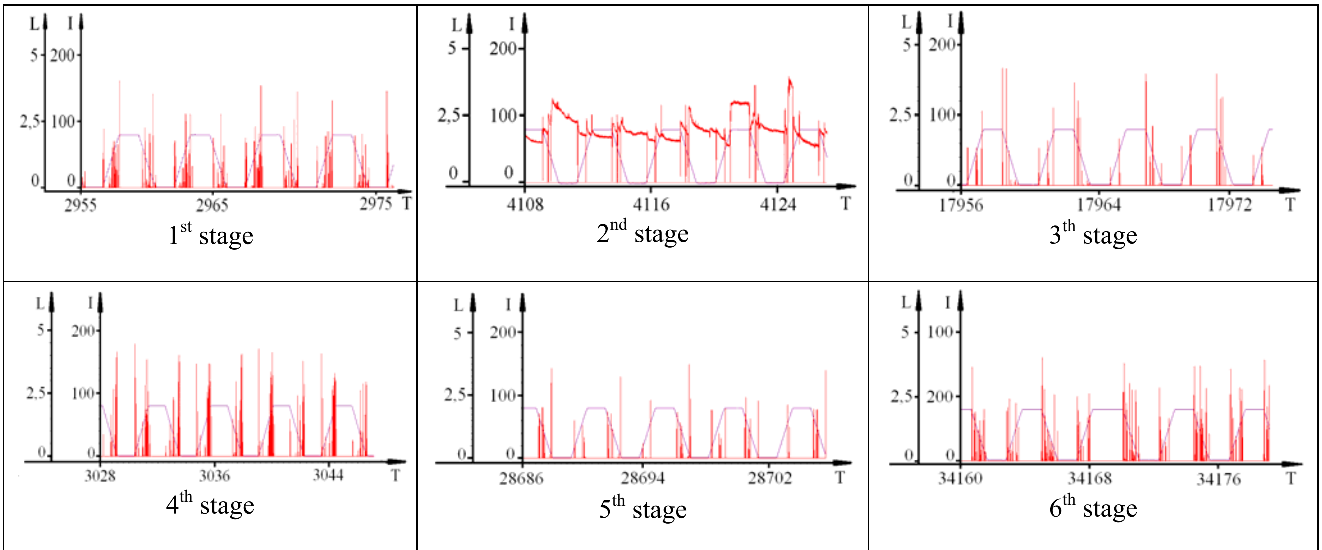

Fig.3. AE intensity I change in a loading cycles (L – load (V)) during different stages of crack development (T – loading time (sec))

The greatest values of AE intensity are observed during the second stage – it is stage of micro-crack initiation and development. Here, discrete AE, which is typical for the all stages (besides the second stage), are changed by practically uninterrupted (continuous) AE.

As it is mentioned above, in more detail analysis initiation and development of three micro-cracks are probably during the second stage. Accordingly the uninterrupted AE is observed during intensive development of micro-cracks, which in the next stage is changed by AE regularity, which is typical for 4 and 6 stages (fig.4). The maximum values of AE are mostly reached in the stage of object unloading. If to suppose that intensity of AE signals reflects level of disruption of object material during all stages, it is mean that micro-crack growth in this time may be more intensive than during load increasing.

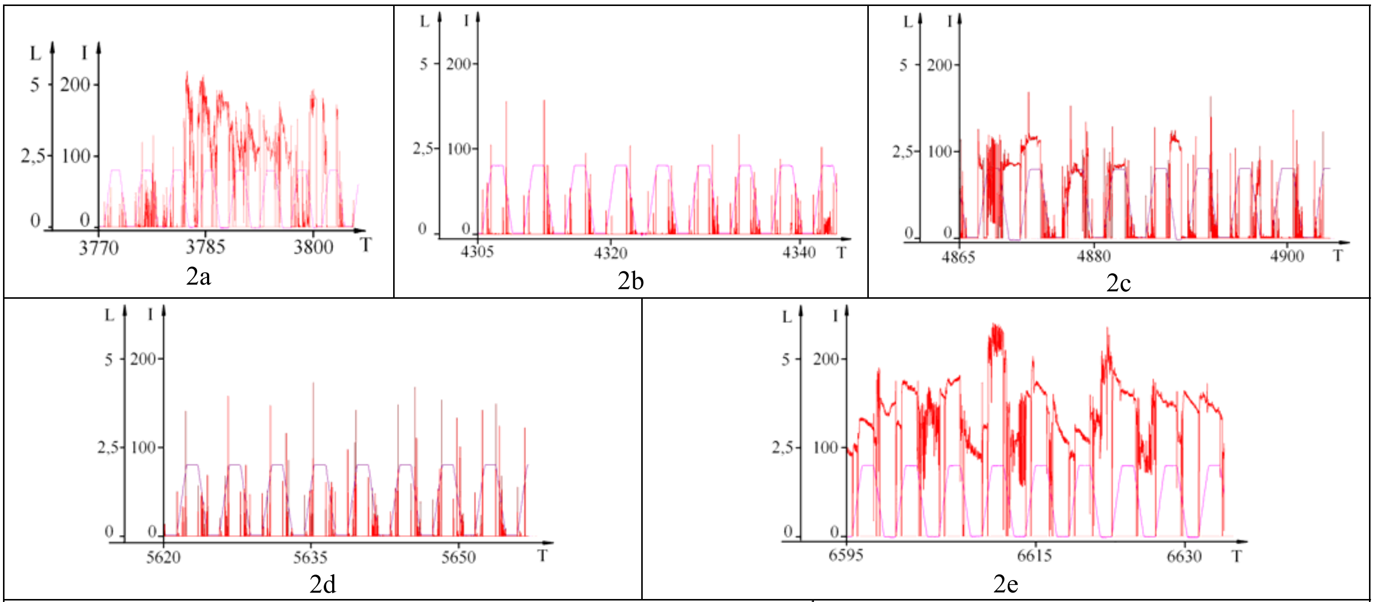

Fig.4. AE intensity I change in a loading cycles (L – load (V)) during 2nd stage (2a…2e – plots of crack development; T – loading time (sec))

5. Conclusions

The main results which are received in this research may be formulated by the following:

1. It is confirmed stepped change of the total AE which is typical for strong structures of aircraft and reflected irregular development of a fatigue crack.
2. It is shown, that AE method detects moment of fatigue crack initiation enough securely.
3. It is recognized that the total AE reflects appearance of some separate micro-cracks (or micro-crack groups) at the stage of fatigue crack initiation.
4. It is discovered that AE signal appearance in a loading cycle (and consequently fatigue crack growth) is as in the moment of object loading, as in the time of object unloading.

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